Use of ultrasound to describe descent and rotation of the fetal head in spontaneous nulliparous labors

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Ágrip

Bakgrunnur: Þær hefðbundnu klínísku skoðanir á kvið og um leggöng sem beitt er til að fylgjast með framgangi fæðingar eru í eðli sínu ónákvæmar. Þar til nýlega höfðu nákvæmari aðferðir ekki verið aðgengilegar. Undanfarin 20 ár hafa ómunaraðferðir, þar sem bæði er skoðað um kvið en einnig frá spangarsvæði, verið þróaðar til að hægt sé meta útvíkkun leghálsins, legu fósturhöfuðsins og hve djúpt það er gengið niður í grindina. Stungið hefur verið upp á ómskoðunum sem aðferð til að fylgjast á hlutlægan og nákvæman hátt með framgangi fæðingar en þetta hefur ekki verið rannsakað með framskyggnum langsniðsaðferðum. Þekking lá ekki fyrir um hvort hægt væri að lýsa því með ómskoðunum hvernig fósturhöfuðið gengur niður fæðingarveginn og hvort slíkt mætti nýta í klínískum tilgangi.

Markmið rannsóknanna sem ritgerðin byggir á var að kanna möguleika ómskoðana til að fylgjast með framgangi fósturhöfuðsins í fæðingu og bera saman við hefðbundnar þreifingar um leggöng. Markmið rannsóknar I var að lýsa breytingum á stöðu (station) fósturhöfuðsins í grindinni með mælingum á höfuð-spangarfjarlægð og framgangshorni og tengslum þeirra við legu (position) fósturhöfuðsins, fæðingarmáta, tímalengd að fæðingu og klínískt mat á útvíkkun legháls. Markmiðið með rannsókn II var að skoða breytingar á legu (position) fósturhöfuðsins í grindinni með ómun og tengsl þeirra við stig fæðingar og í hvaða stöðu fósturhöfuðið fæddist. Einnig að bera ómskoðanir saman við klínískt mat á legu höfuðsins. Í rannsókn III var markmiðið að prófa gildi þess að meta með ómun, við innlögn í virkum fasa fæðingar, stöðu og legu höfuðs og útvíkkun og hvort þessir þættir gætu spáð fyrir um lengd fæðingarstiga og líkur á sjálfkrafa fæðingu. Aðalmarkmið rannsóknar IV var að prófa áreiðanleika höfuð-spangarmælinga en einnig hve ásættanleg aðferðin væri fyrir konur.

Aðferðir: Allar rannsóknirnar voru framskyggnar. Í rannsóknum I-III var rannsóknarhópurinn frumbyrjur í sjálfkrafa sótt eftir fulla meðgöngu (>37 vikur) með einbura í höfuðstöðu. Frá því að virkur fasi fæðingar greindist og þar til konurnar fæddu var ómskoðun bætt við allar klínískar skoðanir. Rannsóknirnar voru gerðar á Landspítala. Ómskoðun um spangarsvæði var notuð til að mæla höfuð-spangarfjarlægð (head-perineum distance) og framgangshorn (angle of progression). Lega höfuðsins í grindinni var skoðuð með ómun um kvið og á spangarsvæði. Margliða aðhvarfsgreining var notuð til að teikna línur til að

sýna breytingar á stöðu höfuðs og útvíkkun leghals. Í rannsókn IV mynduðu konur í fæðingu rannsóknarhópinn. Höfuð-spangarmælingar gerðar af læknum og ljósmæðrum með mismunandi reynslu og með tveim mismunandi tækjum voru bornar saman. Konurnar voru beðnar að meta sársauka/óþægindi sem fylgdi skoðuninni. Rannsóknin var gerð á Háskólasjúkrahúsinu í Lundi, Svíðþjóð og á Landspítala.

Niðurstöður: Höfuðspangarmælingar og framgangshorn mynduðu mismunandi ferla eftir því hver fæðingarmáti varð. Þegar konur fæddu eðlilega byrjaði fósturhöfuðið að ganga hratt niður í lok virks fyrsta stigs fæðingar. Hjá þeim konum sem þurftu aðstoð sogklukku eða tanga til að fæða varð þessi breyting hægari og engin breyting varð á stöðu höfuðs þegar fæðing endaði með keisaraskurði. Klínískt mat á stöðu höfuðs var ónákvæmt borið saman við mælingar með ómun. Legu og snúningi fósturhöfuðsins í fæðingarveginum var lýst með ómskoðun. Framhöfuðstaða var algengust á fyrsta stigi fæðingar og í flestum tilvikum átti snúningur sér stað eftir að fullri útvíkkun var náð, neðan við miðja grind. Klínískt mat á legu fósturhöfuðsins var oft ekki mögulegt og reyndist ónákvæmt. Ekki var munur á fæðingarmáta þegar framhöfuðstaða greindist við innlögn í virkum fasa fæðingar miðað við aðra legu höfuðs. Tengsl voru milli ómskoðana til að mæla bæði stöðu höfuðs í grind og útvíkkun leghals og áætlaðrar fæðingarlengdar. Mælingar á stöðu höfuðs í grind voru einu þættirnir sem sýndu tengsl við líkur á sjálfkrafa fæðingu. Höfuð-spangarmælingar reyndust áreiðanlegar með litlum breytileika við endurtekningu hjá bæði óvönum og reyndum skoðurum. Mismunandi tæki og skoðarar tengdust litlum en marktækum áhrifum á mælingarnar. Það var marktæk fylgni milli klínískra skoðana og höfuð-spangarmælinga. Sársauki eða óþægindi við ómskoðun var marktækt minni en við þreifingu um leggöng.

Ályktanir: Sýnt var fram á að framgangur fósturhöfuðsins í fæðingu fylgdi ákveðnu ferli sem auðvelt var að meta með ómun. Ómskoðanir um spangarsvæði voru áreiðanlegar, nákvæmari en klínískar skoðanir og ollu konunum minni óþægindum. Ómun við innlögn í fæðingu gat að nokkru leyti spáð fyrir um fæðingarmáta og lengd fæðingar.

Lykilorð:

Ómskoðun, fæðing, staða fósturhöfuðs, höfuð-spangarmæling, framgangshorn

Abstract

Background: The progress of labor is traditionally assessed clinically with subjective abdominal and vaginal examinations. Until recently no adequate objective tools have been available for this purpose. During the last 20 years transabdominal and transperineal ultrasound methods have been developed to assess fetal head station, position and cervical dilatation. Ultrasound methods have been suggested as an objective way to follow labor progress but this has not been tested in prospective longitudinal studies. It was not known whether the pattern of fetal head rotation and descent could be described by ultrasound methods and be used in a clinical way in laboring women.

Aims: The overall aim of this thesis was to investigate the patterns of fetal head descent and rotation during labor, using ultrasound methods and comparing the methods to vaginal digital examinations to assess labor progression. The aim of study I was to describe the descent of the fetal head through the pelvic cavity, longitudinally, using ultrasound measurements. Head-perineum distance (HPD) and angle of progression (AoP) were related to fetal head position, delivery mode, time remaining in labor and clinical assessments of cervical dilatation. The aim of study II was to investigate longitudinally fetal head rotation patterns with ultrasound and relate these to clinical assessments of position, labor phases and fetal head positions at delivery. The aim of study III was to test the value of ultrasound as an admission test for women in active labor and whether HPD, AoP, fetal head position and cervical dilatation assessed with ultrasound could predict duration of labor phases and spontaneous delivery. The main aim of study IV was to test the reproducibility of HPD measurements, but also to evaluate the acceptability of the method for laboring women.

Methods: All the studies were prospective. In studies I-III primigravid women in spontaneous labor, with a single cephalic fetus at term (>37 weeks) were studied from when the active stage could be diagnosed until delivery. The studies were done at Landspitali University Hospital, Iceland. Transperineal ultrasound was used to measure HPD and AoP. Fetal head position was assessed with transabdominal and transperineal ultrasound. Descent and dilatation patterns were described. In study IV, HPD measurements were done by novel and experienced examiners with two different types of equipment. The study group was women in active labor at the labor units in Landspitali and

Lund University Hospital in Sweden.

Results: The ultrasound methods, HPD and AoP, demonstrated distinctive patterns of fetal head descent which differed according to the mode of delivery. In women delivering spontaneously there was continuous rapid descent beginning at the end of the active first stage, in women delivering with vaginal instrumental assistance there was more gradual descent and no descent was seen in women who delivered with cesarean section. Clinical assessments of station were inaccurate when compared to ultrasound measurements. Fetal head position could be determined at every examination and rotation was described using ultrasound methods. Most commonly fetal head was in the occiput posterior position during the first stage of labor and rotation occurred in the majority of women at full dilatation, below the spinal plane. Clinical assessments of position were frequently not possible and inaccurate. The delivery mode was not different when the fetal head was in the occiput posterior position at inclusion but there was an association between both ultrasound measurements of fetal head station and cervical dilatation and the estimated median duration of remaining time in labor. The assessments of fetal head station at inclusion were the only parameters associated with operative delivery. HPD measurements were shown to have very good repeatability for both novel and experienced examiners. Different devices and operators may influence reproducibility but it is likely to be less than the reproducibility of clinical methods. There was a significant correlation between the clinical assessments and the mean HPD. The pain score associated with ultrasound examinations was significantly lower compared to clinical vaginal examinations.

Conclusions: The patterns of fetal head descent and rotation were demonstrated and easily followed with ultrasound. Trans-perineal ultrasound methods were more accurate than clinical examinations and more acceptable to the women. Ultrasound on admission in active labor showed potential in predicting duration of labor and mode of delivery. HPD measurements showed good reproducibility.

Keywords:

Transperineal ultrasound, head-perineum distance, angle of progression, progress of labor, fetal head descent, fetal head rotation

Acknowledgements

It all began in 1981 when I became pregnant with my first child. I had begun to study linguistics and medicine was not on the horizon. However, my interest in the physiology of pregnancy and birth was awakened and I went to the university book store and bought textbooks in obstetrics and gynecology for medical students. Childbirth only heightened my interest and with my oldest child less than a year old, I decided to convert to the study of medicine and become an obstetrician. I have never regretted this decision and although I briefly considered other medical specialties I always returned to my initial goal of becoming an obstetrician. Although I do not come from a scientific family background, let alone medical, both my grandmothers revealed to me, after I had started my medical studies, that they had dreamed of becoming doctors. They, however, knew these dreams would never materialize as their opportunities to study were very limited, both being born around the turn of the 20th century. Studying was not something a girl from a poor farming community could expect as in the case of Hulda Guðnadóttir, my paternal grandmother, but she made the most of the schooling she received during her teens. Even for my maternal grandmother, Guðbjörg Bjarman, who was the daughter of a well educated clergyman and was home schooled by her father along with her 10 brothers and sisters, further education was a privilege she missed out on and sorely regretted. These two women, who played an important part in my upbringing, taught me about the value of education as did my parents, Hjörtur Pálsson and Steinunn Bjarman, for whom education was encouraged by their families, although at that time childbirth meant that studies were cut short for my mother. The changes brought by the fight for equal rights for women meant I never once doubted my right to be educated nor was I ever discouraged. My parents always had an unwavering faith in my abilities to achieve whatever I set my mind to and I am greatful for this freedom and their unconditional love.

Although I had considered PhD studies both during and after my specialty training I had not found the enthusiasm to start such a project until I met Torbjørn Moe Eggebø, my colleague and supervisor, who planted the seeds of this project and encouraged me to consider a path of research. We shared a common interest in labor and both felt the need for further study of this fascinating subject in the hope that further knowledge might mean that women could have better outcomes of their labors. Torbjørn was certain that ultrasound would provide important new knowledge and objectivity in the study

of labor and that the field was waiting for further research. After some thought I decided to take the jump and started preparations for the work described in this thesis. I would not have begun this research project without his encouragement and I would not have completed it without his support either. My sincere thanks go to him for his constant encouragement, mentorship, guidance and support. I also am indebted to the other members of my doctoral committee, Sigrún Helga Lund who supported me both with her amazing statistical knowledge and her words of support and friendship during difficult times. Reynir Tómas Geirsson, who with his enthusiasm and expericence spurred me on and helped me with the writing of the thesis and Þóra Steingrímsdóttir, my old friend and colleague, who helped to create the structure and space I needed for my project and was always within an arms reach with her support. I also owe thanks to Kjell Å. Salvesen and Sigurlaug Benediktsdóttir for involving me in their study and to Sigurlaug for helping with the initial setup for the main project, training me in the skills needed and helping with the examinations. Special thanks go to Helga Birna Gunnarsdóttir who helped to prepare and structure the database for the project. I also want to warmly thank all the midwives on the labor ward who helped to recruit the patients and who did all the clinical examinations, I would not have managed to complete this project without their positive attitude and dedication. I also want to thank all my colleagues at the Department of Obstetrics and Gynecology at Landspítali for their patience and for taking on extra workload during my absences from work. The financial support of The Icelandic Centre for Research, with a doctoral grant no. 185435-052 made everything easier, allowing me to take time off from my work and for this I am very greatful. I also want to thank Anna Haarde for her help with the final preparation of the tables and layout of the thesis and my sister, Þórunn Hjartardóttir, for corrections and proof reading. And last but not least I am greatful to all the women who allowed the intrusion into their labors in order for us to acquire this new knowledge.

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List of abbreviations

Abbreviation	Definition
2D	Two-dimensional
3D	Three-dimensional
ACOG	American College of Obstetricians and Gynecologists
ALARA	As low as reasonably achievable
AoP	Angle of progression
AUC	Area under the curve
BMI	Body mass index
BMUS	British Medical Ultrasound Society
CI	Confidence interval
cm	Centimeters
CME	Continuing Medical Education
CT	Computer tomography
EFSUMB	European Federation for Ultrasound in Medicine and Biology
HPD	Head-perineum distance
HR	Hazard ratio
ICC	Intraclass correlation coefficient
ITU	Intrapartum translabial ultrasound
ISLANDS	The International Study Group on Labor and Delivery Sonography
ISUOG	International Society of Ultrasound in Obstetrics and Gynecology
LOA	Left occiput anterior
LOP	Left occiput posterior
MI	Mechanical index
min	Minutes
mm	Millimeters
NICE	National Institute for Health and Care Excellence
OA	Occiput anterior
OECD	Organisation for Economic Co-operation and Development
OP	Occiput posterior

OR	Odds ratio
RCOG	Royal College of Obstetricians and Gynaecologists
ROA	Right occiput anterior
ROT	Right occiput transverse
ROC	Receiver operating characteristics
ROP	Right occiput posterior
TI	Thermal index
TPU	Transperineal ultrasound
VAS	Visual analog scale
WHO	World Health Organization

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List of original papers

This thesis is based on the following original publications, which are referred to in the text by their Roman numerals (I-IV)

I. Fetal descent in nulliparous women assessed by ultrasound: a longitudinal study. Hulda Hjartardóttir, Sigrún H. Lund, Sigurlaug Benediktsdóttir, Reynir T. Geirsson, Torbjørn M. Eggebø. American Journal of Obstetrics and Gynecology, Epub 2020 Oct 8, doi.org/10.1016/j.ajog.2020.10.004.

II. When does fetal head rotation occur in spontaneous labor at term: results of an ultrasound-based longitudinal study in nulliparous women. Hulda Hjartardóttir, Sigrún H. Lund, Sigurlaug Benediktsdóttir, Reynir T. Geirsson, Torbjørn M. Eggebø. American Journal of Obstetrics and Gynecology, Epub 2020 Nov 15, doi.org/10.1016/j.ajog.2020.10.054.

III. Can ultrasound on admission in active labor predict labor duration and a spontaneous delivery? Hulda Hjartardóttir, Sigrún H. Lund, Sigurlaug Benediktsdóttir, Reynir T. Geirsson, Torbjørn M. Eggebø. Accepted for publication in American Journal of Obstetrics and Gynecology MFM, Epub 2021 April 23, doi.org/10.1016/j.ajogmf.2021.100383.

IV. Reproducibility and acceptability of ultrasound measurements of head–perineum distance. Benediktsdottir, S, Salvesen, KÅ, Hjartardottir, H, Eggebø, TM. Acta Obstet Gynecol Scand 2018; 97: 97-103 doi.org/10.1111/aogs.13251

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Declaration of contribution

Studies I-III: Hulda Hjartardóttir (HH), the doctoral student and Torbjørn Moe Eggebø (TME) were responsible for the study conception and designed the research work with assistance from Sigurlaug Benediktsdóttir (SB) and Sigrún Helga Lund (SHL). HH included and examined the patients with the assistance of SB. HH and SHL set up the data base and HH collected and entered all the data into the database. HH and SHL performed the statistical analysis. HH, TME, SHL and Reynir Tómas Geirsson (RTG) interpreted the results. HH drafted the manuscripts under the supervision of TME and SHL, SB and RTG made critical revisions to the articles for important scientific content.

Study IV: SB was responsible for planning the study in Sweden under the supervision of TME and Kjell Å. Salvesen (KÅS). SB supervised the training of the examiners, including HH. SB conducted the study in Sweden. HH assisted SB with planning and conducting the study in Iceland. SB performed statistical analysis under the supervision of TME and KÅS. SB drafted the manuscript under the supervision of KÅS and TME and HH made critical revisions for important scientific content.

1 Introduction

> Before we can discuss intelligently the detection of aberrant patterns of labor and their management, we must be able to characterize normal labor clearly. Clinical labor varies widely and the practitioner´s skills are taxed to their utmost in this regard. Innumerable intricate nuances are involved. Many of our clinical concepts of labor and its abnormalities are rather poorly founded; hence much of the discipline of obstetrical pathology is based on personal experience only. It is imperative that objectivity be introduced so that all physicians, experienced and inexperienced, may be well equipped to diagnose disorders of labor early and definitively.
>
> Emanuel A. Friedman(1972)

Human parturition is a complicated process and although, in most cases, it results in the birth of a healthy child to a healthy mother, it entails dangers for the mother and the fetus. Through the centuries women and their families have waited for the birth of a child with fearful anticipation mixed with the hope that all will be well at the end. Only in the last century or so have advances in medicine and society in middle- and high-resource countries allowed the mother to expect to deliver a healthy baby and be alive herself at the end of the birth process. This is still not the case in large parts of the world where poverty, lack of education and poor access to medical care is wide-spread. In Sub-Saharan Africa the maternal mortality rate is still > 50-fold higher than in Europe(WHO 2020b) and the neonatal mortality rate is >40 times higher than the rate in Iceland which at the present is close to 1/1000 and is among the lowest national rates in the world.(WHO 2020a)

> Labor is the process that leads to childbirth. It begins with the onset of regular uterine contractions and ends with delivery of the newborn and expulsion of the placenta. Pregnancy and birth are physiological processes, and thus, labor and delivery should be considered normal for most women.(2018 Williams obstetrics, Ch. 22, p. 1)

Labor depends on effective contractions of the uterine smooth muscle and simultaneous dilatation and thinning of the largely collagenous cervix. In the human, the fetal head is usually the leading fetal part that has to negotiate the curved pelvic cavity as it descends and rotates, pushed on by the forces of the uterus and, towards the end, by considerable maternal efforts in order to be delivered.

The length of this labor process is very individual but prolonged labor is known to increase the risk of adverse outcomes for both the mother and the newborn and it is also often associated with a negative birth experience for the mother.(Allen et al., 2005; Cheng et al., 2010) Slow progress in labor occurs in 13-37% of nulliparous women dependent on the populations investigated, and prolonged labor (dystocia) is the most frequent indication for cesarean section during labor.(Gifford et al., 2000; Kjaergaard et al., 2009; Torkildsen et al., 2011) Although knowledge has slowly increased, in the last century, of the various adverse factors and influences that may affect the normal processes of labor, many questions remain unanswered. It is still not known why and how labor starts and there is incomplete understanding of why some labors last longer than others. Increased understanding of both normal and abnormal processes might lead to more correctly timed, effective interventions when they are indeed needed or supportive observation when this would be the safest option for the mother and the fetus.

Modern care for women in labor has been set up in systems that aim to safeguard the mother and the fetus. Electronic fetal heart rate monitoring has undoubtedly led to better outcomes for many newborns in the last half century, but at the same time it may have been harmful for the mothers in many uncomplicated normal labors due to the considerable potential for interpretational error of this method. As a result, cesarean section may be overused in order to avert fetal distress situations.(Spong et al., 2012)

Monitoring labors with simultaneous graphic plotting and analysis of cervical dilatation and fetal head descent against time has become widely accepted. Several such display methods are currently available and these "partographs" should alert the staff caring for the laboring woman as to when the progress of labor starts to become abnormal and when an intervention might be necessary.

A problem with both fetal heart rate monitoring use of the partograph for following labor progress and for guiding intervention is that neither method was tested in a sufficiently rigorous scientific way, or in other words prospectively and methodically evaluated, before they were adopted into widespread

practice. This was largely because they seemed to provide an obvious major step forward in clinical practice and were easy to apply through hospital settings. Both methods were, undoubtedly, beneficial in many ways, but also had drawbacks. Raised intervention rates in labor and delivery resulted, often without the expected benefits, especially in the longer term.(MacDonald et al., 1985) Although prospective, randomized and large-scale studies would not have been the obvious answer in all such situations, the lesson has been learnt that any new method being introduced into the field of obstetrics should be tested against what is at the time perceived as the best practice.

Expectations of a normal outcome for the fetus, - a healthy child, have led to the attitude in many societies, among the public as well as some professionals, that cesarean delivery may be the safest mode of delivery. This disregards the risks to the woman with immediate post-operative complications and later risks associated with a scarred uterus.(Declercq et al., 2007; Liu et al., 2007; Makoha et al., 2004; Miller et al., 2013; Silver et al., 2006; Tulandi et al., 2009) It also carries risks to the child, some immediate, but also other conditions which only become apparent in later life.(Hansen et al., 2008; Keag et al., 2018; Zanardo et al., 2004) A majority of women wish to be able to give birth normally, but many fear difficult complications that are sometimes linked to childbirth. All obstetricians want the best outcomes for their patients. Although they know of the immediate and long-term risks involved, caesarean sections have become a relatively safe procedure, with advances in anesthetic techniques and in pre- and postoperative care. All these considerations need to be balanced in the best possible way to achieve the best outcomes. However, and no doubt, the public attitude and risks of litigation play a part in the increasing rates of cesarean sections seen worldwide. In the OECD countries the highest rates are now reported from Korea, Chile, Mexico and Turkey, rates ranging from 45-53% of births.(OECD Health Statistics 2019) This rising trend has not been proven to improve the outcomes for the women or their children. The Nordic countries have seen a slightly increasing cesarean section rate but it has stabilized or even decreased and excellent outcomes are demonstrated with rates between 15 to 20% of births.(Pyykonen et al., 2017) In the USA over a third of births are now cesarean deliveries, which has been a matter for concern. A high rate of cesarean sections is usually related to a high primary cesarean section rate, resulting in a high frequency of repeat cesarean sections. In a summary from a workshop aimed at finding ways to prevent the first cesarean delivery it was noted that many methods and interventions can safely be applied in order to achieve this.(Spong et al., 2012) The most common indications for the first cesarean is failure to progress in the

first and second stage and better management of these complications might be the most effective way of avoiding unnecessary cesarean sections. Among the suggestions to ensure that vaginal delivery is given a fair trial is the use of clear definitions of how to define and treat failed progress of labor, encouraging the provision of training in appropriate assessments and acquisition of the skills to perform operative vaginal deliveries in a safe manner.

Ultrasound, although in use for over 50 years, has only in recent years been widely studied to improve safety before instrumental delivery. Guidelines have been produced that recommend its use in this setting.(Brooks et al., 2020; Ghi et al., 2018b; Kessler et al., 2020; Murphy et al., 2020) There has also been increasing interest in the potential of using ultrasound during labor as a means to visually and in real-time investigate anew how normal and abnormal labor proceeds, how fetal and maternal mechanistic, anatomical and physiologic factors interact in human birth. It has been suggested that ultrasound may be the tool needed to help with a more rational diagnosis of abnormal labor and that it would be of use to predict problems more accurately and earlier.(Hassan et al., 2014; Kwan et al., 2020; Usman & Lees, 2015; Wiafe et al., 2016) The hope is that the studies presented in this thesis will contribute to defining normal and abnormal progress during the first and second stage of labor. If this can be done, it will at the same time add knowledge on the abnormal and give insight into ways that might improve outcomes in difficult labors.

In this thesis, I will first give an overview of the labor process and then address particular problems in assessing the progress of labor. To do this, historical aspects on how knowledge has developed are essential, followed by an overview of the use of ultrasound in obstetrics, in particular leading in towards the present day use of ultrasound in labor.

1.1 Normal labor and the cardinal movements

> It follows that some process of adaptation or accommodation of suitable portions for the head to the various pelvic planes is necessary to insure the completion of childbirth. This is brought about by certain movement of the presenting part, which belong to what is termed the mechanism of labor.
>
> J. Whitridge Williams (1903)

As quoted above, labor involves the expulsion of the fetus and placenta from the uterus. The largest dimensions of the fetus passing through the birth canal are those of the head and the shoulders. The head has its largest diameters in

the anteroposterior plane and the shoulders at 90° angle to the head, transversely, through the shoulder tips. The pelvic inlet has the largest dimensions transversely and in the outlet at a 90° angle to it, antero-posteriorly. In addition to this the birth-canal is curved or J-shaped with the shorter curvature anteriorly and the longer one posteriorly. In order for the fetus to pass through the pelvis in the easiest way it needs, in addition to the forwards movement, to negotiate this passage with twists and turns. These movements needed for the child to be delivered are often termed the cardinal movements and are counted as four or seven according to existing custom. When the seven movements are described, they include **engagement, descent, flexion, internal rotation, extension, external rotation and expulsion,** but others leave out the movements describing the forwards motion, only counting the actual fetal movements of flexion, internal rotation, extension and external rotation. Before labor the fetal head is often freely floating, especially in multiparous women. The **engagement** of the fetal head occurs with the anteroposterior plane of the head in the transverse or oblique diameter of the pelvis, so the fetus is facing the mothers right or left side. Further **descent** of the head occurs with contractions of the uterus and simultaneously good neck **flexion** ensures that the smallest possible diameter of the head enters the maternal pelvic inlet. To exit the birth-canal the head needs **rotate internally**, so that the occiput comes to lie anteriorly in the pelvis with the fetus facing the mothers back (or more rarely, internal rotation brings the occiput posteriorly with the fetus facing anteriorly). The fetal back will then lie anteriorly in the mother's abdomen which allows the fetal shoulders to enter the inlet of the pelvis in the transverse plane. At that stage, the fetal head has passed the mid-pelvic plane, defined to be at the level of the ischial spines, and with neck **extension**, the fetal head is pushed further anteriorly from underneath the symphysis pubis, stretching the perineum and dilating the vulva until it is delivered. **External rotation** of the head marks the rotation of the shoulders into the antero-posterior plane of the pelvis and the head which has now been completely delivered will be facing the mother´s right or left thigh, also called restitution. The anterior shoulder will then be delivered, usually by gentle downward traction on the head by the accoucheur, and then again, an upward push underneath the head which will deliver the posterior shoulder and the whole fetus is **expulsed** (Figure 1).

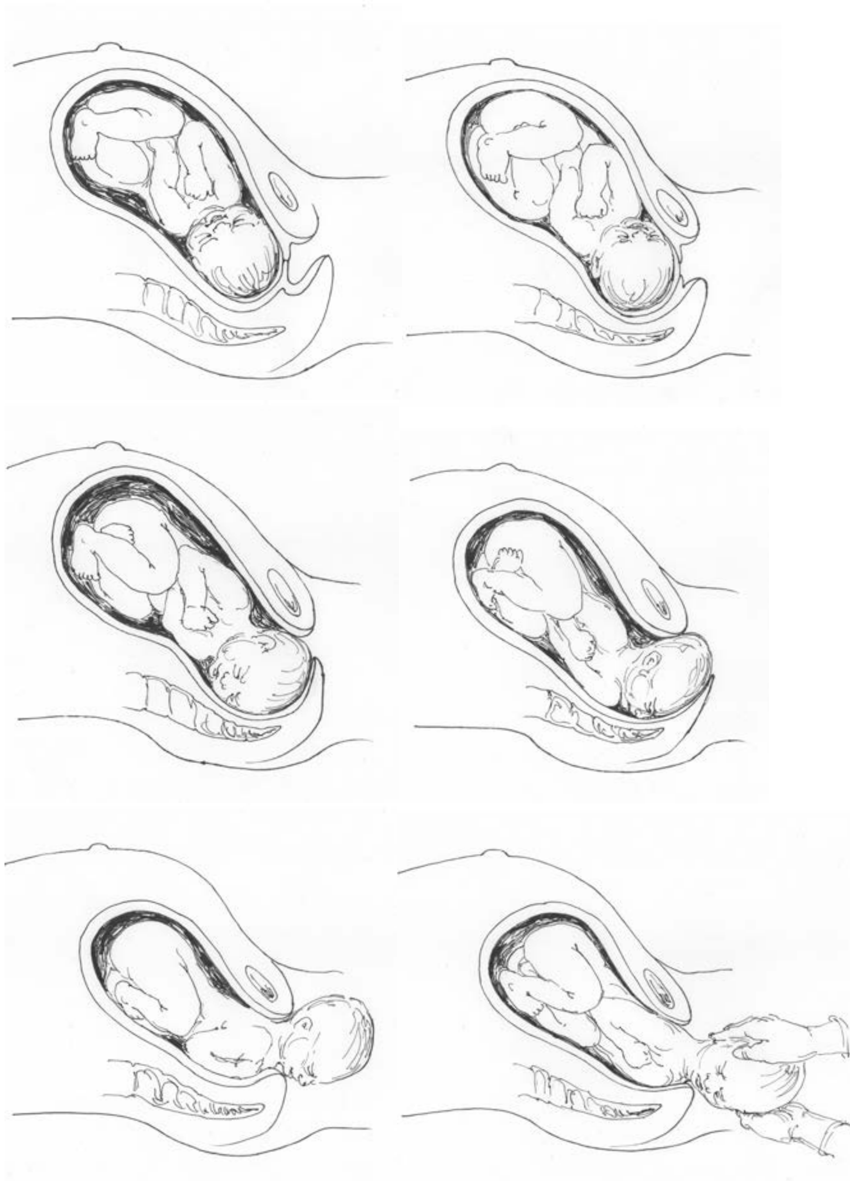

Figure 1. The mechanism of birth showing the cardinal movements (Images drawn by Eggert Pétursson)

The Austrian obstetrician Scanzoni, in his textbook from 1867, talks about 5 movements, the first one being engagement or descent.(1867) The other four are the actual fetal movements, flexion, internal rotation, extension and external rotation. He does not call them cardinal movements but "fünf Bewegungen" (five movements):

1. Heruntersteigen des Schädels
2. Drehung desselben um seine Querachse
3. Drehung des Kopfes um seine senkrechte Achse
4. zweite Drehung des Kopfes um seine Querachse
5. äusseren Drehung um seine senkrechte Achse

The German Spiegelberg in his 1878 textbook also calls them "Drehungen" (rotations) and numbers them as four movements.(1878) He talks about engagement before starting to explain the rotation.

1. Die erste Drehung: Beugung des Kopfes
2. Die Drehung um die lange Eiachse
3. Drehung um seine Querachse, eine Extension
4. Einer neuen Drehung um die lange Eiachse

In the textbook of Eden and Holland, published in 1957 in London(1957) the movements are not called cardinal movements but Descent and accompanying movements:

1. Flexion
2. Internal rotation
3. Extension
4. Restitution and External Rotation

In Williams Obstetrics from 1950(Eastman, 1950) the following description is found in the chapter on The Mechanism of labor in vertex presentations:

"…the mechanism of labor consists of a combination of movements, several of which may be going on at the same time as it is manifestly impossible for any one of them to occur unless the presenting part descends simultaneously. These movements are divided into two classes, depending upon whether they are essential to the completion of labor, or merely facilitate its progress. To the first group belong the so-called cardinal movements - descent, internal rotation and extension; to the second, the accessory movements- flexion and external rotation…." Then they start the sections on Engagement, Descent, Flexion, Internal rotation, Extension and External rotation. There is no mention of the seventh Expulsion.

In Williams Obstetrics from 1989(Cunningham et al., 1989) the subheading in the chapter on Mechanism of Normal Labor in Occiput Presentation is: Cardinal movements of a labor in occiput presentation and the movements are counted as seven:

1. Engagement

2. Descent
3. Flexion
4. Internal rotation
5. Extension
6. External rotation
7. Expulsion

It therefore seems as if the cardinal movements are counted as seven movements in the USA but in Europe they are counted as four movements.

1.2 Powers, Passage and Passenger

1.2.1 The Powers

To describe the mechanistic factors that are involved in the labor process the three P´s are often used: **p**ower, **p**assage and **p**assenger. The power driving the passenger (the fetus) through the passage (the pelvis and the birth canal) is provided by contractions of the upper segment uterine muscle and then at the end, in addition, maternal pushing efforts. The contractions of the uterus usually have a gradual onset, the frequency increasing gradually often from every 10-15 minutes during the latent phase up to every 2 minutes during the second stage. The contractions usually last around 60 seconds and with each contraction the myometrium in the upper segment of the uterus shortens but during each relaxation it doesn´t return to the same length but shortens a little increasing the tension on the uterine content, i.e. the fetus and amniotic fluid. At the same time the less muscular lower segment of the uterus stretches and the cervix begins to thin and open from the inside in a funnel-like manner. In the days or weeks leading up to labor the cervix has undergone a remodeling process, or "ripening", which involves a reduction in collagen structure and content which changes the consistency of the cervical tissue, allowing the cervix to change shape and open up. Insufficient remodeling of the cervical tissue leading to an increased resistance to the uterine muscular action has been linked to prolonged duration of cervical dilatation.(Ekman et al., 1986; Granström et al., 1989; Sundtoft et al., 2011; Uldbjerg et al., 1983; Uldbjerg & Ulmsten, 1990) Gradually the cervix is entirely stretched or taken up and can at full dilatation not be felt digitally at all, as it becomes flushed with the vaginal walls and lower uterine segment. The strong uterine contractions and stretching of the lower segment, cervix and vagina, make it possible for the fetus to be pushed down through the pelvic cavity. The mother completes the birth with voluntary pushing action against the resistance of the pelvic floor and stretching of the perineal tissues as described above.

1.2.2 The Passage - Pelvic anatomy

The fetus not only has to pass through the dilating cervix, it also needs to traverse through the maternal bony pelvis with its inside musculature and ligaments. The bony pelvis is composed of three bones joined together to form a circle. The sacrum is joined on each side through the sacroiliac joints to the two innominate bones, each consisting of three parts, the ilium, ischium and pubis bones. The symphysis binds the pubic bones firmly together with fibrocartilaginous tissue at the front (Figure 2). The pelvic floor forms a diaphragm-like closure to the lower portion of the birth canal. Its main component is the levator ani muscle which is like a sling encircling the vagina and rectum and fastened to the pubic bones anteriorly. It hypertrophies during pregnancy but undergoes changes before labor that allow it to stretch and thin when the fetal head begins to descend sufficiently during labor. It offers a considerable resistance to the fetal head which is thought to play a part in the internal rotation as there is evidence suggesting that excessive neuraxial analgesia increases the rate of rotational instrumental deliveries. (Anim-Somuah et al., 2011; Lieberman et al., 2005)

1.2.2.1 The pelvic inlet

The iliopectineal line at the sides, the sacral promontory at the back and the upper edge of the pubic rami and the pubic symphysis anteriorly, form the upper border of the true pelvis or the pelvic inlet. The diameters of the pelvic inlet are of importance for successful labor. The shortest distance of the inlet is usually the anteroposterior diameter, from the uppermost margin of the symphysis pubis to the sacral promontory, the true obstetric conjugate. It is usually the biparietal diameter of the fetal head, around 9.5 cm that passes through this diameter of the pelvis. For this reason, it is considered the most important clinical diameter and usually measures at least 10 cm. The transverse diameter is the distance between the linea terminalis on each side, and usually measures 13 cm or more. In addition, two oblique diameters have been defined, the right and the left according to which sacroiliac joint is being pointed at.

1.2.2.2 The midpelvis

This is the middle of the true pelvis and is often its narrowest part measured at the plane of the ischial spinal processes on each side. This distance, the interspinous diameter, is often around 10-11 cm.

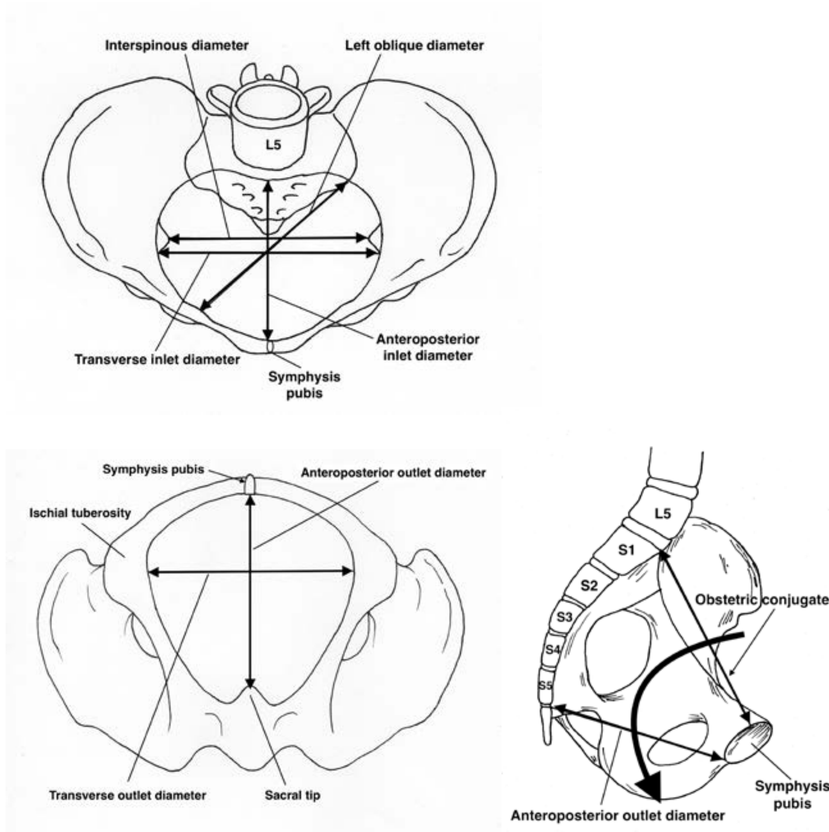

Figure 2. The anatomy of the pelvis showing the inlet from above, lateral view of pelvis and outlet from below. Pelvic axis is marked by thick arrow. (Images by Eggert Pétursson and Hulda Hjartardóttir)

1.2.2.3 The pelvic outlet

The boundaries of the outlet are shaped by the sacral tip and the sacrotuberous ligaments posteriorly, the ischial tuberosities laterally and the inferior pubic rami and the lower edge of the symphysis pubis anteriorly. The transverse sacrotuberous diameter usually measures approximately 11 cm and the anteroposterior diameter 9.5 to 11.5 cm, with a capacity to enlarge a little due to mobility of the coccyx.

1.2.3 The passenger - anatomy of the fetal head

The head is for the sake of delivery the largest part of the fetus and the presenting and leading part during normal labor. Its suboccipito-bregmatic (9.5 cm) and biparietal diameters (9.5 cm) determine the most favorable circumference (28 cm) for the fetal head to pass through the maternal pelvis

achieved when there is good flexion of the fetal neck. Lesser degrees of flexion of the fetal cervical spine lead to wider and more unfavorable diameters being pushed through the pelvis leading to difficulties during labor. When a less well flexed head in an occiput-posterior position is delivered it is the larger occipitofrontal diameter (33 cm) that needs to pass through the pelvis.

The anatomical landmarks used to assess the position and presentation of the fetal head on digital examination are the sutures and fontanelles where the nine bones of the fetal head are joined by membranes which allow the skull to mold and the bones to overlap during the process of labor. These landmarks can be felt during a clinical vaginal examination when the cervix begins to dilate (Figure 3).

Occipito-parietal molding, along the lambdoidal sutures is very common in occiput anterior positions and fronto-parietal along the coronal sutures more commonly seen in transverse and posterior positions. Parieto-parietal molding, also seen in occipito-posterior positions, has been considered abnormal and linked to adverse labor outcomes, especially when there is overlap along the sagittal suture. Molding has recently been studied anew with transperineal ultrasound by Iversen et al., reaffirming these findings.(2020)

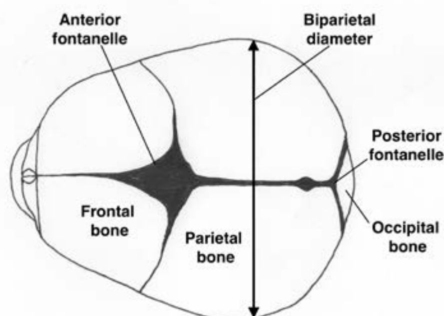

Figure 3. The anatomy of the fetal head showing fontanelles and sutures. (Image by Eggert Pétursson and Hulda Hjartardóttir)

1.3 Labor onset

There are many unanswered questions regarding the factors that lead to the start of human labor. Many hormonal pathways, both systemic and local, in the fetus and the mother have been studied and seem to be involved in this complicated process.

Defining the start of labor is problematic and a recent review demonstrates this.(Hanley et al., 2016) Timing is, however, crucial as the study and evaluation of labor progress is based on this point in time. The most usual definition in clinical practice, is the onset of regular, painful uterine contractions. Sometimes evidence of effacement and dilatation of the cervix are added to this definition but require that the woman is examined vaginally. This definition is not very helpful for the woman at home, who cannot check her cervix, but on questioning by skilled, experienced personnel, the onset of labor contractions can usually be established. Painful contractions may frequently occur during the last month of the pregnancy and this complicates the giving of advice on when women should contact a midwife or a delivery ward. As a guide, the woman is commonly asked to attend for examination when she feels that the contractions are regular, at least 5 minutes apart, lasting 45-60 seconds and are gaining strength and intensity. On assessing the contractions and by examining the cervix the attendant can then determine whether the woman is in labor.

The process of labor is usually considered to have three distinct stages, which are then further subdivided into phases.

1.3.1 The first stage

The first stage is the time from the onset of labor until the cervix is fully dilated. The first stage is further divided into a latent and an active first phase and the second stage into the passive and active second stages.

1.3.1.1 The latent phase

During this phase the cervix begins to efface and dilate and contractions may be irregular in intensity and frequency. This phase can last several hours and as described above the start is difficult to define and so is the length of this phase. Once the active phase of labor has been established, the length of the latent phase can be made retrospectively. It is now considered normal for this stage to last from 24-30 hours.(Tilden et al., 2019) Although the cervix has started to soften from its normal firm state already in the first few weeks of pregnancy it is during the last weeks leading up to labor that the cervix undergoes changes in consistency from being a relatively non-stretchable closed tube to being a soft, easily stretchable opening part of the uterus. These changes have sometimes caused shortening and opening up of the cervix before any signs of labor contraction appear, especially in multiparous women. In other women these changes occur within a matter of hours during the latent phase. The length of this phase does not seem to be linked to labor outcomes,

such as duration of the active phase or mode of delivery, but to the women experiencing pain during a long latent phase it can lead to exhaustion long before the active phase of labor begins.(ACOG 2019; Zhang et al., 2010b)

1.3.1.2 The active phase

During this phase there is more rapid cervical change. In recent years there have been changes in the definition of the transition from the latent phase to the active phase. (See section 1.5.3). The international WHO guidelines for intrapartum care have until recently considered this transition to be at 4 cm cervical dilatation(WHO 1994) but recently updated guidelines consider this transition to be at 5 cm and the length does not normally extend beyond 10 hours for parous women and 12 hours for nulliparous women(WHO 2018). This transition is based on the more rapid change of cervical dilatation followed be fetal head descent and ending at full dilatation of the cervix.

1.3.2 The second stage

This is the time from full dilatation of the cervix until birth of the child. During this stage there should be progressive fetal head descent and rotation. Often there is an immediate maternal urge to push, but sometimes pushing is delayed and then the first part of this stage is termed the passive phase of the second stage. The active phase of the second stage is from the time the mother starts expulsive efforts until the birth of the fetus. The normal length of this stage is considered three hours for nulliparous women and two hours for parous women(WHO 2018).

1.3.3 The third stage

This is the time from the birth of the child until the placenta has been delivered and is not relevant for the purpose of this thesis. The placenta is usually delivered within 30 minutes from the birth of the child.

1.4 The progress of labor and defining labor abnormalities

Following the progress of labor is a main component of intrapartum care and involves monitoring the regularity and strength of the contractions, cervical dilatation, fetal head descent and rotation and as a central issue, maternal and fetal well-being. Abnormalities in the progress of labor are considered a warning sign of increasing risk to the mother or fetus and an indication that intervention may be needed. Some of the factors monitored are fairly easy to judge, such as cervical dilatation, but others are either difficult to assess clinically, such as fetal head descent and rotation, or pose difficulties due to

problems with definition, as exemplified by labor duration.

Obstructed or prolonged labor is commonly called dystocia, originating from Greek; *dus* meaning difficult and *tokos* meaning childbirth. The meaning of the word does not give any clues to the causes for the difficulty and can as such be used for any part of the labor progress that is deemed abnormal. Dystocia can be caused by abnormalities in any of the three Ps described before, the power, the passage or the passenger, all of which have to harmonize for successful delivery of the fetus. Suboptimal labor progress is moreover often multifactorial, making classifications as to the cause difficult. It is most often diagnosed through a prolonged active phase of labor, when there is a lack or arrest of cervical dilatation and/or descent of the fetal head over a given time period.

1.4.1 Uterine dysfunction

Lack of coordinated contractions or weak contractions can be a cause of prolonged labor as can an unyielding cervix. The term uterine dysfunction or dysfunctional labor is often used and results in both abnormally slow or protracted labor and arrested labor. It is most often associated with primary dysfunctional labor, another term commonly used, when the whole of the active phase is prolonged. If the problem is due to lack of contractions in strength and/or regularity, the use of oxytocin will in the majority of cases correct the course of labor. Lack of maternal expulsive forces during the second stage can also result in an abnormally prolonged second stage or arrest of descent.

1.4.2 Fetopelvic disproportion

An abnormally shaped or small pelvis can cause absolute disproportion between the fetal parts and the pelvis so that the fetus has no way of negotiating through the obstruction. While stunted growth due to dietary deficiencies is now rarely seen in high- and middle-income countries this condition does still exist in low-income countries. More commonly seen is a relative disproportion due to a slightly narrowed pelvis combined with a large fetus or when an unfavorable diameter of the fetal body or head presents into the birth canal due to malpresentation or malposition. This fetopelvic disproportion can result in dysfunctional labor, or more commonly secondary arrest of dilatation during the last part of the active phase or slow progress or arrested descent during the second stage of labor. Fetopelvic disproportion can be aggravated by lack of strong, regular contractions and this can also be overcome, to some extent, by the use of oxytocin.

1.4.3 Abnormal progress - treatment

Although there is an ongoing debate regarding the definition of what constitutes abnormal progress, there is agreement as to the treatment. Most textbooks and guidelines now recommend conservative treatment of the latent phase. Support, analgesia and rest remain the best responses to painful contractions during this stage. When there is slow progress in the active first stage most guidelines recommend a trial of oxytocin infusion. This will correct labor abnormalities in a large number of cases and increase the number of spontaneous vaginal deliveries(Wei et al., 2009) and can be continued as long as there is continued progress, even if slow. If good contractions are achieved with oxytocin augmentation but there is still no progress after 4 hours, most hospital guidelines recommend delivery by cesarean section. During the second stage, when there is slow or arrested descent of the fetal head, oxytocin can be used, but usually management involves decisions regarding operative delivery. Assessment of station and position of the fetal head are the main factors in deciding whether vaginal delivery can be assisted instrumentally or if cesarean section is a safer option.

1.5 Historic overview

1.5.1 Pelvic shapes

After the invention of x-rays, it became possible to examine the bony pelvis in women due to give birth and much focus was placed on investigating pelvic shapes and sizes and relating them to obstetric outcomes. The research of Caldwell and Moloy on this subject is well known and widely quoted. They studied anatomical specimens and classified pelvic shapes into gynecoid, anthropoid, android, platypelloid and several overlap types(1933, 1938; 1934a; 1934b; 1939). They then tried to relate these findings to x-ray examinations taken during labor and the outcomes of labor. They described the various forms of the pelvic bony anatomy and related these to difficulties encountered during labor. Their suggestion was that knowledge of the pelvic type might help to predict difficulties during forceps deliveries and suggest the best methods to perform instrumental deliveries.

The pelvic dimensions had been well described before, based on anatomical skeletal specimens and different pelvic types, based on their inlet dimension, were recognized; a round type and predominantly transverse or predominantly anteroposterior types(Spiegelberg, 1878). In one of the articles by Caldwell and Moloy they discuss prior knowledge of the three or four different pelvic types. Weber in 1830 and von Stein in 1844 had recognized

the four inlet groups but not considered the borderline types while Turner in 1885 described three but failed to describe the fourth, the wedge shaped one and did not consider the borderline types(1938). Turner described the long narrow oval type appearing to resemble the pelvis of anthropoid apes. He considered this a primitive form, “more commonly found in primitive races". In the textbook by Scanzoni, “Lehrbuch der Geburtshilfe” from 1867 there is a detailed description of the four types(1867).

The methods Caldwell and Moloy used to select their study groups are not very apparent and numbers lack statistical comparisons. Confirmation that educating staff about the features of the pelvis and presumably utilizing x-rays has led to better outcomes of forceps deliveries for mother and child, is not obvious from their data. It is unlikely that their methods would have passed modern scrutiny and the significance of this work is now doubtful. The benefit of knowing the bony pelvic type has never been shown with certainty to be of clinical value. There is a large overlap between the types, and the classification has been questioned in recent publications based on MRI technology(Kuliukas et al., 2015). However, assessing the pelvic size by X-ray pelvimetry which was recommended by many obstetricians based on these results became commonplace during the remaining part of the 20th century. As benefits of x-ray pelvimetry in predicting the outcome of labor were never properly shown, they are now considered mostly obsolete.(Pattinson et al., 2017)

1.5.2 Duration of labor

The duration of labor has a high degree of individual variation, but is mainly affected by whether the woman is nulliparous or parous and whether the labor is spontaneous or induced. Other factors known or thought to play a role are pain and anxiety, state of nourishment and fluid intake, mobility and analgesia. Establishing what was considered an abnormally long labor before 1950 is not easy, since each obstetrician or country seemed to have their own opinion on the matter, based on their own experience or that of their masters.

In the textbook of Scanzoni, a prodromal phase at the beginning of labor is described but not its duration.(1867) The dilatation of the cervix is described as being slow until it reaches the size of a “Thaler” (40mm) but then a more active phase taking over where the cervix is changing more rapidly until full dilatation, estimated to take six to eight hours. According to Spiegelberg’s “Lehrbuch der Geburtshülfe” from 1878 the duration of labor in a primigravida was considered to be on average 20 hours, and 12 hours for a multipara (his own series of 500 cases resp. 17 and 10 3/4 hours) and the second stage for a primigravida 2 hours.(1878) In Eden and Holland´s “Manual of Obstetrics”

from 1957 the duration of the first stage is considered to be 16 hours for a nullipara and 8 for a multiparous woman, while the second stage lasted two hours in nulliparous women.(1957)

In "Williams Obstetrics" from 1950 the normal duration of the first stage of labor was considered to be 16 hours for a nullipara, 11 for a multipara and the second stage one to two hours for a nullipara.(Eastman, 1950) Labor was considered slow and abnormal if there was no change in cervical dilatation over 8 hours during the first stage of labor or no change in head descent or rotation over two hours during the second stage. At that time obstetricians were faced with the same problems as today, namely to determine the onset of labor. The recommendation was to be restrictive in diagnosing labor until 3 cm dilatation in a primigravida and 4 cm in a multigravida and consider them to be in "false labor" until this dilatation was reached.

1.5.3 Dilatation

The classic studies of Emanuel Friedman in the 1950s and his presentation of the results formed the basis of, and benchmark reference to, what constituted normal progress in labor.(1954, 1955) The results of his first study was based on 100 primigravidae, 96 of them laboring spontaneously, while four had their labor induced with oxytocin.(1954) There was one breech delivery and one twin delivery. Of the women, 68 had forceps deliveries and there was one caesarean section due to a prolonged second stage. Oxytocin was used to stimulate 15 labors due to labor inertia. Caudal anesthesia was used throughout the greater portion of 22 labors. Women were included early in their labors to permit adequate study. Examinations of the cervix were done rectally, unless results could not be obtained with this method, when they were vaginal. Hourly or bihourly examinations were performed. The curve for each laboring woman was drawn on a square-ruled graph paper with time on the x-axis and cervical dilatation in cm on the y-axis and it was observed that the shape of the curves was very similar in that there was an initial long phase with slow dilatation of the cervix, then a phase consistent with a rapidly dilating cervix and lastly a slowing down of the dilatation process, just before full dilatation was reached. The mean durations of the phases were calculated (assuming labor started when the woman reported that regular uterine contractions had been established) and the latent phase (from closed cervix to 2-2,5 cm dilatation) was found to be on average 7.3 hours (range 1.7-15). Friedman called the remaining period, until full dilatation, the active phase and divided it into three sub-phases, slow acceleration, maximum acceleration and deceleration, with a mean total length of 4.4. hours (range 1.8-9.5). The great

variation in duration of the latent phase did not seem to be reflected in a similar duration of the active phase or its sub-phases. The three subphases seemed, however, to be interrelated in duration. Based on these findings he recommended that the onset of labor was measured from the onset of the active phase.

In his discussion, Friedman mentions descent, finding that the major portion of descent takes place in the fourth phase of the first stage (the deceleration phase) and during the second stage of labor. He says that "descent accompanies full dilatation and retraction of the cervix, whether cause or effect is conjectural". In his final discussion he addresses the second stage stating that it cannot be studied with these methods as full dilatation has been reached, its length merely being noted. He found no statistical relationship between the total or any part of the first stage and the length of the second stage and said: "Its management is left as a clinical art."

Friedman was not the first to describe labor in these terms, as can be seen in the textbooks by Scanzoni and Spiegelberg(1867; 1878); the slow dilatation of the latent phase and then a more rapidly dilating cervix in the latter part of the labor and often a slowing down towards the end, but he was the first to define labor so that its elements could be quantified and standardized in a very descriptive way.

In his next publication, Friedman had collected labor details from 500 primigravidas, and using the same methods, drawn an average labor curve (Figure 4).(1955)

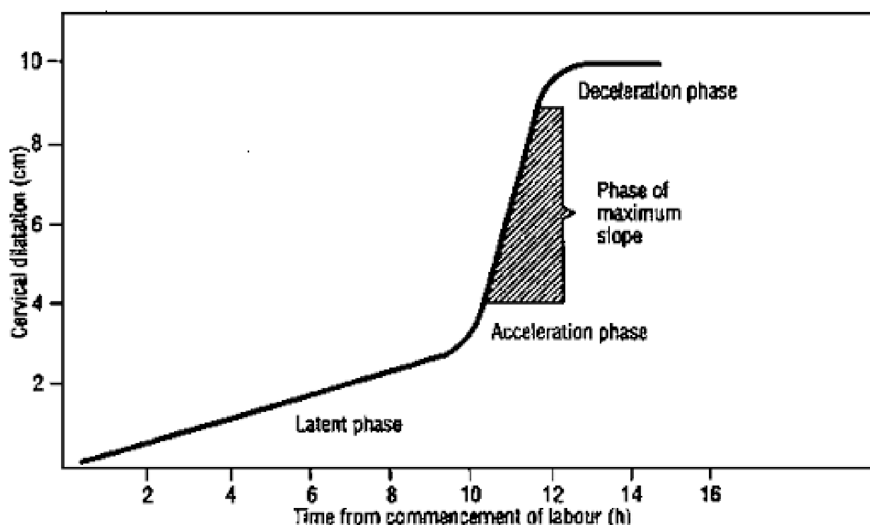

Figure 4. Friedman´s curve of cervical dilatation.(1955)

The findings were that the average length for the latent phase was 8.6 hours and the active phase was 4.9 hours. The definition of the start of the active phase was that it was the time when acceleration started and that this did not happen at a given dilatation of the cervix but varied from one woman to the next. The average curve, called "the Friedman curve", a partograph or partogram became widespread throughout the world. With it came also the recognition that prolongation of the different phases might have different causes.(Friedman, 1972) Prolongation of the latent phase was considered being mostly due to an unripe cervix, prolongation of the whole duration of the active phase, or primary arrest, being most often due to uterine inertia and prolongation of the acceleration phase, or secondary arrest, being due to cephalo-pelvic disproportion.

Hendricks et al.(Hendricks et al., 1970) and Philpott and Castle(Philpott & Castle, 1972a), studied labors in a similar way and found progress in cervical dilatation to be slower during the maximum acceleration phase than Friedman and co-workers, and they did not find a discernible deceleration phase. Their findings were that the labor pattern was sufficiently clear to alert the attendant staff when abnormalities or slowing down in cervical dilatation arose. Philpott and Castle developed the partograph further by plotting on it an alert and action line, to assist with the interpretation of the progress of labor.(1972; 1972a, 1972b) The alert line is a straight line shifted two hours to the right of the average progress line and an action line four hours further to the right, marking roughly the 5th centile for normal progress. In Philpott´s original description the alert line was started at 3 cm dilatation which he considered to be similar to Friedman´s definition of the start of the active phase of labor. Studd and Philpott developed this idea further, and the partograph with the alert and action lines was introduced to labor units in the UK in the 1970'ies.(1973; 1972) Similar curves have been adopted for use in labor and as a part of birth records very widely (Figure 5). The WHO recommended the use of this type of partogram in 1994, starting at 4 cm dilatation.(1994) One of the main aims was to allow for timely transfer of laboring women, especially in rural areas, (when the alert line is especially helpful) when abnormalities of the labor progress become apparent. In the most recent intrapartum guidelines of the WHO from 2018 they no longer recommend using the alert and action lines which they say have not been proven to improve the management of labor or labor outcomes, but instead recommend using a guide of the upper 95th percentile of duration for cervical change.(2018)

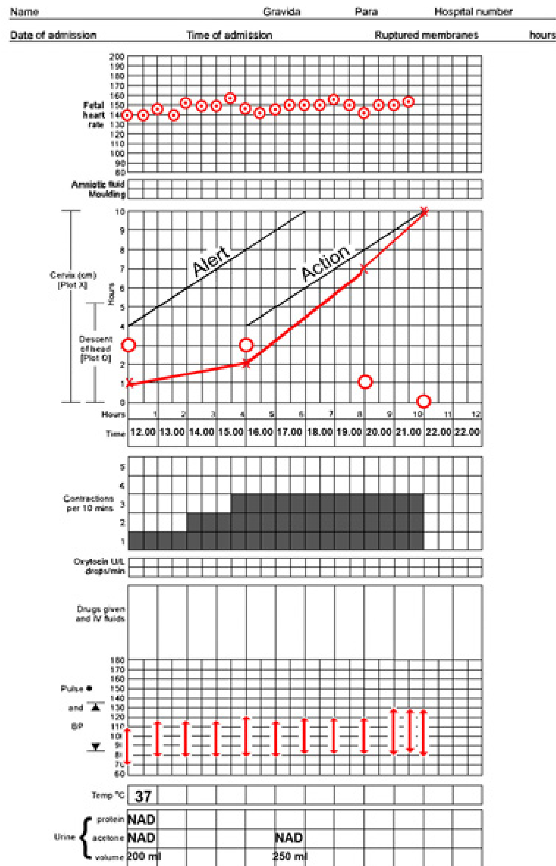

Figure 5. Partograph with alert and action lines.

The studies of Zhang and his co-workers challenged the applicability of Friedman´s labor curve in contemporary obstetric populations(Kominiarek et al., 2011; Laughon et al., 2012; Zhang et al., 2010a; Zhang et al., 2010b; Zhang et al., 2002). In their study from 2002 they found labor to be much slower than indicated in Friedman´s original findings. In particular, a more prolonged early active phase was found and no discernible deceleration phase towards the end of the active phase could be verified(Zhang et al., 2002). They also found that the second stage of labor took considerably longer. Zhang et al. then published a much larger study looking at the labor progression of over 60 thousand women, and constructed new average labor curves by parity with information on the 95th percentile for progression (Figure 6).(Zhang et al., 2010a)

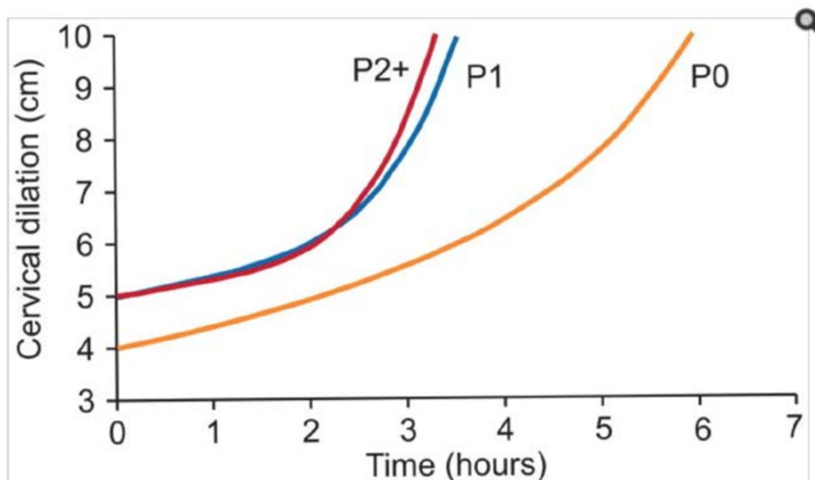

Figure 6. Zhang´s labor curves.(Zhang et al., 2010a)

All labors were spontaneous, at term, with a cephalic presentation and ended with a vaginal birth of a healthy neonate. This study confirmed the findings of the first study and showed that in this contemporary population with good outcomes the time taken to progress from 4 to 5 cm in cervical dilation could be over 6 hours and from 5 to 6 cm over 3 hours. From 6 cm the progress accelerated in both nulli- and multiparas. The active stage in nulliparas had a median length of 5.3 hours (95th percentile 16.4) when taken from 4 cm dilation. The second stage was found to have a median length of 1.1 hours with, and 0.6 hours without epidural, respectively (95th percentile of 3.6 and 2.8 hours, respectively). Adjustments for maternal and pregnancy characteristics suggested that the difference in labor duration may be due to changes in obstetric practice rather than due to population changes.(Laughon et al., 2012) The findings of Suzuki et al. studying dilatation patterns of Japanese nulliparous women and of Shi et al. studying Chinese nulliparous women, were similar to those of Zhang et al.(Shi et al., 2016; Suzuki et al., 2010)

New guidelines for management of labor, based on the results of Zhang et al. were developed and issued jointly by the American College of Obstetricians and Gynecology and the Society for Maternal-Fetal Medicine in an attempt to try to reduce the rising rate of caesarean section in the United States.(Caughey et al., 2014) These guidelines recommend that the active phase is diagnosed as starting at a dilatation of 6 cm. A similar adjustment to the previously accepted standards in diagnosing the active phase of labor and normal labor progress have been promoted in a recent publication by the WHO, now

recommending that the active phase is diagnosed when the cervix is 5 cm dilated.(WHO 2018) Cohen and Friedman have contested the adoption of these new guidelines and argued that the differences in the shape of the curve may be due to selection biases and confounders. They also argue that the adoption of the guidelines has shown conflicting results in terms of lowering the rate of caesarean section and a possible increase in poor maternal and neonatal outcomes. Their criticism also concerns the lack of considering other factors necessary to monitor the progress of labor than cervical dilatation and time, such as fetal head station and descent, position and molding.(2015a, 2015b, 2019, 2020) A recent systematic review of available studies describing the progress of normal labor by Oladapo et al. has offered further support in favor of a more relaxed approach to the time limits set for labor.(2018) Change in cervical dilatation was found to increase step by step, producing hyperbolic curve shapes. Many women were found to progress to normal spontaneous delivery without ever dilating above the 1cm/hour threshold. The controversy regarding the normal progress of cervical dilatation has placed the focus on the first stage, but is not helpful in determining progress in the second stage, where fetal head descent and rotation become the important issues.

1.5.4 Descent

Our knowledge of the pattern of fetal head descent during labor comes mainly from the classic series of articles by Friedman and Sachtleben published in 1965, describing the pattern of fetal head descent in mostly spontaneously laboring women.(1965a, 1965b, 1965c) These results were based on clinical digital estimation of the fetal head station in the pelvic cavity, using the ischial spines and the leading fetal bony part as reference points, using the -5 to +5 cm grading system. Use of these landmarks had previously been described by DeLee in 1924 and they were studied using x-ray techniques in the 1930's.(Caldwell et al., 1934a; Javert & Steele, 1942) There are, however, no studies that attempted to standardize this scale by comparing digital estimation of fetal head station during labor, directly with anatomical findings using radiological techniques.

In their first article, Friedman and Sachtleben used results from 1000 labors (500 nulli- and 500 multiparas) studied for dilatation patterns.(1965a) They created descent curves for nulliparas based on 421 laboring women who presented early enough in labor and did not have a cesarean delivery at or shortly after the onset of labor (Figure 7). They found a distinct pattern of descent reflected in an exponential curve. In nulliparas the mean fetal head station was -0.5 cm at the onset of the latent phase and +0.4 cm at the onset

of the active phase. They found that rapid descent coincided with the phase of maximum slope of dilatation (see section 1.5.3) and this pattern appeared during the last four hours of birth. This rapid descent continued into the second stage, at the onset of which the mean fetal head station was +3.4 cm.

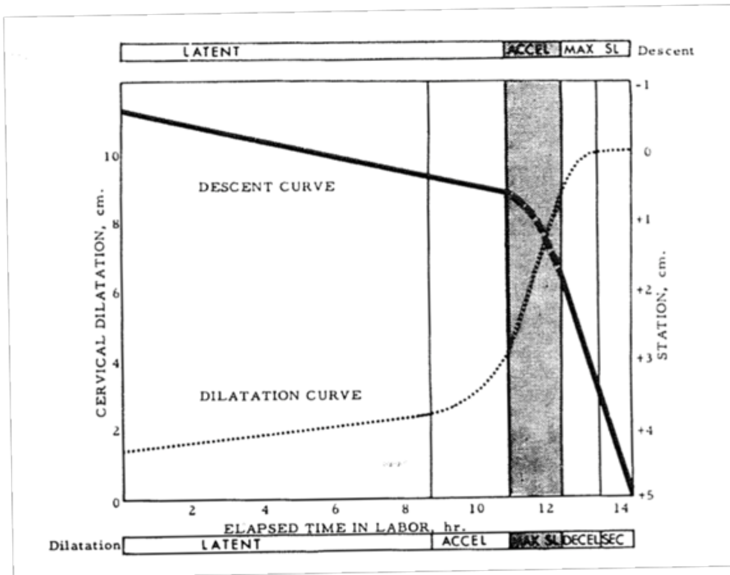

Figure 7. Friedman´s descent and dilatation curves.(Friedman & Sachtleben, 1965a)

In their second article studying the same group of laboring women, they examined the relation between fetal head station at the onset of the various labor stages and the occurrence of dysfunctional labor.(1965c) They found that a high head at the start of the latent phase seemed to be associated with fetopelvic disproportion, the higher the head, the higher the frequency. The same relation existed between a prolonged latent phase and both primary and secondary dysfunctional labor.

In their third article they looked at the inter-relationship between cervical dilatation, station and duration of the labor phases and showed that greater dilatation and lower station carried the best prognosis and vice versa. If either factor, dilatation or station, was unfavorable then the other factor could reduce the prognostic effect, when favorable (direct quote: "dilatation and station appeared to be mutually compensatory (when one was salutary and the other unfavorable) or augmentative (both choice or both disadvantageous) with regard to their influence on progression in labor").(1965b)

In the fourth article they attempted to calculate the mean rate of descent in the second stage and found it to be around 3.3 cm/hour in nulliparas and the

upper 95th percentile for progression (slowest progress) to be around 1 cm/hour.(1970)

The renewed focus on the progress of labor in recent years, with re-examination of the classic Friedman curve, has mainly applied to the study of the rate and pattern of cervical dilatation.(Chen & Chu, 1986; Oladapo et al., 2018; Shi et al., 2016; Suzuki et al., 2010; Zhang et al., 2010a) Relying on dilatation patterns has been challenged as there is some evidence that its predictive value is poor.(Ferrazzi et al., 2015; Ferrazzi & Paganelli, 2016) It must be said, however, that in Friedman´s original work and his and Cohen´s criticism of the new partograms, it has been emphasized that the reliance on dilatation patterns was never meant to be the only means of following the progress of labor and that following the descent patterns was an inherent part of the method.(Cohen & Friedman, 2019, 2020).

Fetal head descent has recently been studied in a contemporary obstetric population. Zhang et al.(2002) and Graseck et al.(2014) both examined cervical dilatation and head descent, Zhang et al. only in nulliparous women in spontaneous labor, but Graseck et al. reported on nulliparous women in spontaneous and induced labors (Figure 8). They both found a more gradually sloping descent curve than that described by Friedman and Sachtleben and that the fetal head did not descend below the ischial spines until at 8 to 9 cm of dilatation. The subjective nature of assessing fetal head station clinically has been acknowledged by investigators.(Friedman & Sachtleben, 1965a; Zhang et al., 2002)

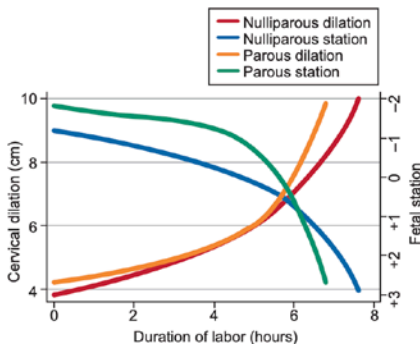

Fig. 1. Cervical dilation and descent curves by parity.
Graseck. Fetal Descent in Labor. Obstet Gynecol 2014.

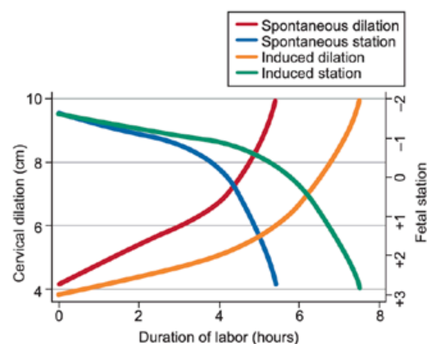

Fig. 2. Cervical dilation and descent curves by labor type.
Graseck. Fetal Descent in Labor. Obstet Gynecol 2014.

Figure 8. Clinical descent and dilatation curves.(Graseck et al., 2014)

1.5.5 Position

In their paper from 1942, Javert and Steele gave a detailed historic overview,

up until that time, of the controversy regarding how the fetal head engaged.(1942) They recounted that from the time of Hippocrates, and for a long time thereafter, it was believed that the fetus was sitting in the mother's abdomen and turned to present with the head only just before labor (Figure 9).

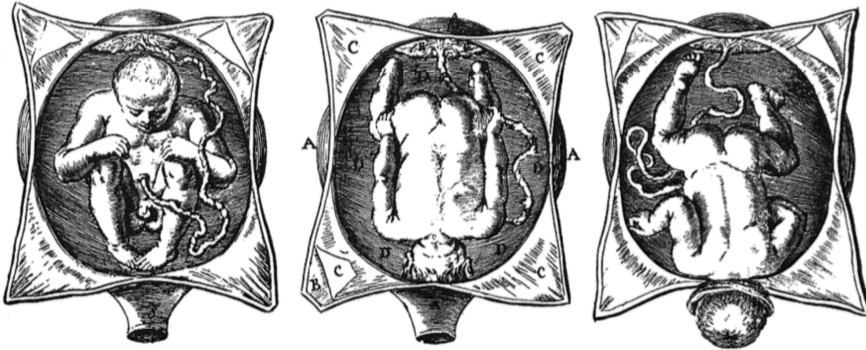

Figure 9. The somersault of the fetus and engagement and descent of the head. From Mauriceau, 1668.

From the 17th century onwards there was a great deal of controversy over how the fetal head entered the maternal pelvis. At first it was believed that the head entered in the true conjugate, probably due to its presentation at the birth itself. Later Sir Fielding Ould (1742) contradicted this conception and thought the fetus always turned to one side or the other when engaging. In the atlas of Smellie (1752) the illustrations of the fetus in the uterus (Figure 10) show how it engages in the transverse diameter.

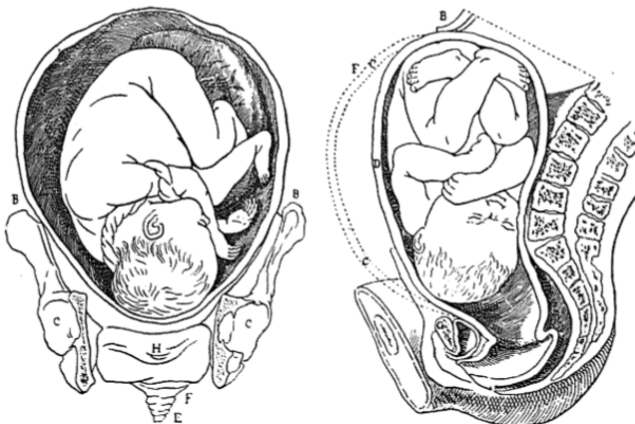

Figure 10. Transverse position of the fetal head. From the Atlas of Smellie, 1752.

Roederer (1762) took a compromise between these two opposing views and suggested that the fetal head engaged in the oblique diameters. Saxthorp (1764) agreed and offered the explanation that this was probably due to the encroachment of the sacral promontory. Solayres de Renhac (1771) was the first to use a systematic description of the various ways the skull was positioned, presenting it as six positions.

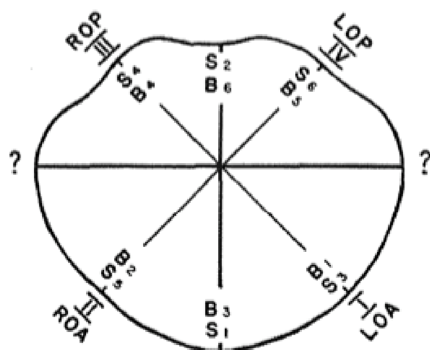

Figure 11. The positions of the vertex according to Solayres de Renhac S1-S6 (1771), Baudelocque, B1-B6 (1781), Busch, I-IV, (1829) and Washington conference, LOA, ROA, etc. (1887).(Javert & Steele, 1942)

Baudelocque (1791) who followed de Renhac´s teachings adjusted the classification slightly, stating that the occipitopubic and occipitosacral positions (B3 and B6) were unusual (Figure 11). Beaudelocque´s views were very influential and prevailed through the 19th century.

In old German textbooks from the nineteenth century the view was that the head most commonly engaged in the oblique positions and the least common were the transverse occiput positions. The most common positions were in the right oblique diameter, the LOA and ROP, and less common were the positions in left oblique diameter, the LOP and ROA. According to Spiegelberg 70% engaged on the left side and 30% on the right, and he considered the oblique diameters to provide the greatest space in the midpelvis. He found the most common position in the left anterior quadrant and the second most common in the right posterior quadrant.(1878) Scanzoni agreed with him in that the fetal head most commonly engaged with the occiput in the left anterior part of the pelvis, and quoted an agreement with Naegele that the ROP was the second most common. Scanzoni said that Naegele maintained that the ROA was least common but Scanzoni was of the opinion that this was not correct - it should be the third most common and the left posterior the least common. Scanzoni then went on to state that the least common finding was that the fetal head

engaged in the direct transverse plane, on the right side, even more uncommon than the left.(1867)

At the beginning of last century, it was still a matter of dispute whether the fetal head engaged in the pelvis in the oblique or transverse position.(Caldwell et al., 1934a; Javert & Steele, 1942) Most obstetricians agreed that the direct anteroposterior positions were unusual and this led to the adoption of the classification system including only four positions, occiput left anterior (OLA), occiput left posterior (OLP), occiput right posterior (ORP) and occiput right anterior (ORA), agreed upon in the Ninth International Medical Congress in Washington in 1887 (Figure 11). This was still the presiding view one hundred years ago. In Williams Obstetrics, 3rd edition from 1912 the four positions mentioned (and abbreviated) are LOA, LOP, ROA and ROP.(Javert & Steele, 1942) A year later, in 1913, DeLee in the first edition of his textbook of obstetrics supported the transverse position of the head.(Javert & Steele, 1942)

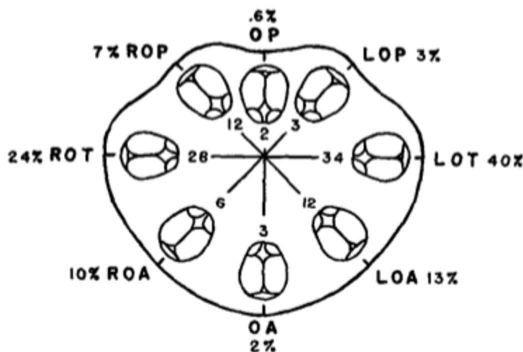

Figure 12. The incidences of positions at the brim from roentgenograms of 1040 cases.(Javert & Steele, 1942)

In the 1930ies these controversies were more or less acquiesced by the articles published by Caldwell, Moloy and D'Esopo(Caldwell et al., 1934a) and Steele and Javert.(Steele & Javert, 1942) In the study of Caldwell et al. data were presented on 200 consecutive, white primipara who were examined as early in labor as possible with X-ray stereoscopic techniques looking at head engagement. They maintained that the direct transverse and also direct OA or OP were easy to recognize with these methods. They then went on to state that a small number of cases were slightly anterior or posterior to the precise transverse diameter of the inlet and called these "anterior" or "posterior tendencies". Using this classification their results were that 60% of heads engaged in the transverse position, 18.5% in the ROP or LOP position, 16% in

ROA and LOA and 5.5% in the direct OA position. On the left side were 59% and 36% on the right side. It is not possible to know, from reading the article, exactly what is meant by the difference between "anterior" and LOA/ROA on the one hand or "posterior tendency" and LOP/ROP on the other hand. It is also clear that it may be more difficult to judge the exact degree of rotation from the X-ray images. Steele and Javert studied over 1000 women. They studied women with non-engaged heads and engaged heads before labor, and women during early labor and at the beginning of the second stage. They found little difference in the positions whether the head was engaged or not. The incidence of the various positions can be seen in Figure 12 where the combined transverse positions add up to 64%. This classification was adopted and used internationally.

Very few studies on internal rotation have been performed, so accurate descriptions of when in relation to dilatation or descent this occurs are difficult to find. In Williams Obstetrics from 1950 and up to the present day publication, Calkins is quoted when describing when rotation occurs.(Calkins, 1939b; Eastman, 1950) In his clinical study from 1939 he described that internal rotation was a late occurrence in labor and that in nulliparas it occurs in 24% at or before full dilatation of the cervix, in 35% during descent to the pelvic floor and in another 35% after being on the pelvic floor for some time, and that in 4% the head does not rotate.

1.5.5.1 Right or left side?

Does the progress of labor to some extent depend on which side of the pelvis the fetal occiput enters? This is maintained in older textbooks and articles but has received little attention during the last decades. Calkins, in a second article from 1939 reporting on his clinical study, found that the occiput most commonly occupied the occiput left anterior position (43%), and least common was the occiput right anterior position (8%) with the right and left posterior, in order of frequency, being in between these two extremes.(1939a) He quotes Bird and Williams in saying that the occiput is usually found in the right oblique diameter of the maternal pelvis, meaning that the fetal head will more commonly be found in the LOA or ROP positions. Their explanation for this was that the left oblique is posteriorly occupied by the pelvic colon, making this oblique shorter and diminishing the available space. In the study of Steele and Javert they discuss the more frequent need of operative deliveries when the occiput is on the right side.(1942) In their study the ROA position was also found to be less common than the LOA at the pelvic brim, and even less common in the mid-pelvis where the ROT position became more common. The reason for this was

speculated to be due to dextrorotation of the uterus, at the same time favoring the LOT to LOA rotation. In Williams´s textbook from 1950 the occiput was stated to present on the left side in 64% of cases and in 36% on the right. Naegele was quoted as being the first to point out that the occiput was most commonly found anteriorly on the left and posteriorly on the right, probably owing to the fact that the colon occupies the left oblique diameter.(Eastman, 1950) In Eden & Holland´s Manual of Obstetrics the frequency of positions is LOA 53.1%, ROA 21.4%, ROP 14.0% and LOP 11.5%, or in the right oblique 67.1%, and in the left oblique 32.9%. This was based on a clinical assessment of 10.000 consecutive cases in early labor at Queen Charlotte´s Hospital in London.(1957) The explanation for the right oblique being more frequent was that the pelvic colon and rectum encroach upon the left oblique.

In later years these findings have received little attention and are not to be found in modern textbooks.

1.6 New aspects in studies of descent and rotation

The knowledge from these old clinical and radiological studies has been the basis of our understanding of the descent and rotational aspect of the physiology of labor. After the publications of Caldwell et al. and Steele and Javert, on the way that the fetal head engages and rotates it is only now, when ultrasound can be utilized on the labor ward, that this has received renewed interest. The existing partograms were based on digital vaginal examinations to assess cervical dilatation and descent. Clinical vaginal examinations are prone to considerable subjectivity by the individual examiner as the landmarks used can be hard to identify. Although regarded as sufficiently accurate by most accoucheurs, they are by no means easy to learn or to do.(Buchmann & Libhaber, 2008; Y. T. Chan et al., 2016; Dupuis et al., 2005b)

There are several problems with the existing clinical methods for assessing station. First of all, the spinal plane is not an actual plane. It is a line between two points which are not central but posterior to the middle of the central axis of the pelvis.(Simon et al., 2013) Because the birth canal is like a bent tube it also means that the distance that the fetal head travels is longer posteriorly than anteriorly. It therefore will make a difference whether the distance in relation to the spine is gauged anteriorly or posteriorly.

Then there is the problem of two different grading systems. Although both systems use the spinal plane as a reference point or point zero, one system then uses -3 to +3 to define station higher and lower than the spinal plane, and the other system -5 to +5. The first system refers to the markings as in thirds

above or below the spines and the second system refers to the markings in cm above and below. According to the article by Carollo et al. from 2004, the American College of Obstetricians and Gynecologists used the thirds system in a manual of standards in 1965 but in 1988 this changed to a system of cm.(2004) In Friedman´s studies from the 1950ies he uses the -/+ 5 cm scale, so there seems to have been differences of opinion within the USA for a long time. In the UK the system of +/- 5 cm is used and referred to in the RCOG online training and CME module. These different gradation systems are reflected in the scientific literature.

The leading bony reference point on the fetal head should be easier to determine, but the presence of caput succedaneum can make the examiner erroneously consider the head to have descended to a lower level.

Adding to this confusion there is inconsistency amongst both doctors and midwives regarding whether it is the leading bony part or the biparietal diameter which is meant when the station of the head is measured against the ischial spines. This confusion exists on both sides of the Atlantic as shown in two fairly recent studies from Denver in the USA and Liverpool in the UK, and staff did not seem to be aware of this difference in their assessments of station.(Awan et al., 2009; Carollo et al., 2004)

The known patterns of descent have been obtained with the above inaccuracies of clinical assessment being inherent. Therefore, other methods have been suggested.(Dupuis et al., 2005c; Ghi et al., 2009; Takeda et al., 2014; Yeo & Romero, 2009) The WHO has taken the stance not to recommend internal examinations to assess fetal head descent in their recommendations for management of labor, but instead only use the method of abdominal palpation of the head.(2018) Furthermore, studies have shown how subjective the clinical assessments are and how ultrasound methods, due to their objectiveness and reproducibility, seem to be a major advantage in comparison.(Dietz & Lanzarone, 2005; Dückelmann et al., 2010; Dupuis et al., 2005b; Ghi et al., 2009; Sherer & Abulafia, 2003; Tutschek et al., 2013)

The study of rotation and that of descent during labor can now be studied using objective methods described in the following chapters and demand that we use them to re-assess the process of labor, both normal and abnormal. This will be added to the knowledge provided by the recent clinical studies of cervical dilatation and descent(Ferrazzi et al., 2015; Ferrazzi & Paganelli, 2016; Graseck et al., 2014; Laughon et al., 2012; Suzuki et al., 2010; Zhang et al., 2010a; Zhang et al., 2002) and we can start building reliable benchmarks for the 21st century.

1.7 Ultrasound in medicine

1.7.1 Ian Donald

In 1958, Ian Donald and his team published their first article, describing the use of ultrasound in clinical medicine.(1958) This seminal publication, describing how ultrasound might be used in obstetrics and gynecology, paved the way for all subsequent developments in the use of this technique, not only in obstetrics and gynecology but in clinical medicine in general. The history of ultrasound in obstetrics and gynecology, and how its use has multiplied, almost exponentially, and is now almost used as an extension to the hand and eyes, is covered in detail in an article by Stuart Campbell, another pioneer in the field.(2013)

In the beginning the ultrasound equipment was large, almost filling an entire room and not easily transportable (Figure 13). As with many other equipment, technical advances have made the equipment steadily smaller and more mobile, the newest advances even using a smartphone into which a transducer is plugged (Figure 14). This has enabled clinicians to use ultrasound in more acute settings, bedside, both in the accident and emergency departments and on labor wards.

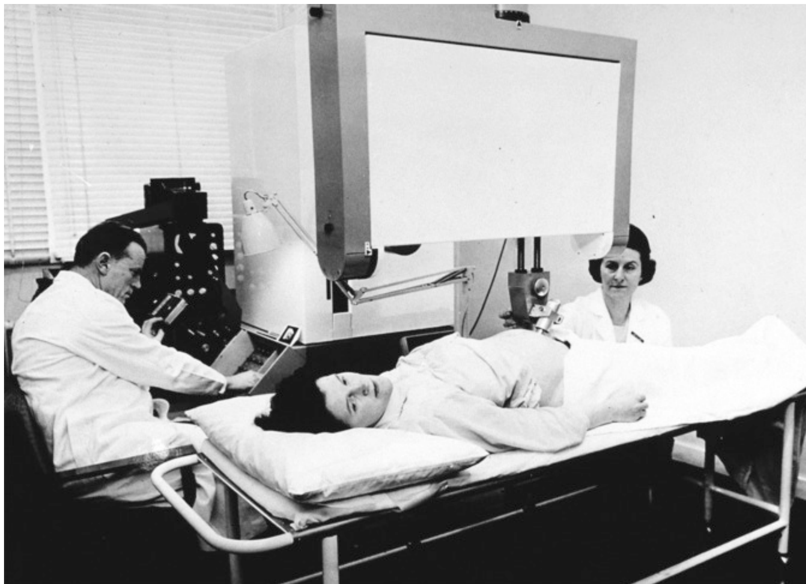

Figure 13. Ian Donald in action with the Mark 3 Diasonograph in 1960.(Campbell, 2013)

Figure 14. General Electric VenueGo and Philips VISIQ

1.7.2 Ultrasound in Iceland

The story of ultrasound in Iceland spans almost 50 years. The first ultrasound equipment, a Nuclear Enterprises model, designed by Donald and coworkers, was acquired by the Department of Obstetrics and Gynecology in Landspitali University Hospital in 1975.(Geirsson, 2001) The pioneers in the field, who helped develop the use of ultrasound and introduce advances in fetal diagnosis, were the obstetricians Jón Hannesson, Reynir T. Geirsson and Thora Fischer and the midwife María Hreinsdóttir. Real time ultrasound was available from 1983 and Doppler ultrasound from 1992. A routine ultrasound examination for pregnancy dating, ascertainment of placental position, detection of multiple pregnancies and fetal anomalies was eventually offered to all women in the country in the period between 1984 and 1986. In 1998 first trimester screening for fetal and chromosomal anomalies was introduced, and has been offered to all women from 2003. Obstetric ultrasound examination is available in eight hospitals or health centers outside Reykjavík. In Landspitali University Hospital there is a Fetal Medicine Unit with 4 specialists and 8 midwives.

1.7.3 Uses of ultrasound in obstetrics and gynecology

Ultrasound has become an indispensable part of obstetrics and gynecology as it has proved to be extremely useful for imaging both the female internal organs and also the fetus and placenta. It is now routinely applied during most gynecological examinations, mainly with a vaginal probe.

In obstetrics ultrasound has been developed as a tool to visualize the fetus, confirm viability, to detect multiple fetuses, fetal abnormalities and discrepancies in fetal growth. In addition to this it has proved an essential tool, with the addition of the Doppler technique, in surveillance of growth-restricted fetuses and fetuses with serious abnormalities or illnesses. It has also been developed to assist with invasive procedures and in fetal therapy. It is used to assess risk and to diagnose preterm labor and to screen for pre-eclampsia.

1.8 Ultrasound in labor - the early years

Lewin et al.(1977) were the first to describe the use of ultrasound to measure objectively the fetal head station. They applied a transabdominal transducer to the skin overlying the sacral tip, and using A-mode changed the signal being reflected from the sacrum and the fetal head to a mm measurement. They were able to relate these measurements to the clinical palpation of station according to the ischial spines and found that the head was engaged at 45 mm or less from the sacral tip. Their speculation was that use of this method might increase the predictive value of the Bishop score, and also increase the accuracy of fetal head station assessment to allow for safer application of forceps. The methods described do not seem to have received much attention and were neither further tested nor introduced into clinical practice. At the time ultrasound machines were very large and quite immobile, and this may have precluded their practical use during labor.

Jeanty et al.(1986) described perineal scanning in their attempt to improve accuracy of diagnosis of placenta praevia and in an attempt to improve diagnosis of an incompetent cervix. They found the technique useful and managed to diagnose dilatation of the cervix. They attempted using this technique to follow the progression of cervical dilatation in labor and found it useful until the cervix had reached 5 cm. In their comments they suggest that perineal scanning may be used to follow the progress of labor in addition to being a good way to assess early pregnancy. This was not investigated further, possibly due to the development of the transvaginal probe which was a major advance in gynecological and obstetric ultrasound during the following years. It became the chosen method to investigate the cervix, placental position and early pregnancies.

Richey et al.(1995) compared transperineal ultrasound to clinical assessment of cervical dilation, and effacement and fetal head station in women who were admitted with contractions. They used the sagittal plane and a simple measurement in cm from the transducer to the fetal head to measure

station, comparing it directly to the +5/-5 cm scale. They showed a significant correlation between digital examination and sonographic assessment of cervical length, dilatation and fetal head station. This study does not appear to have received much notice and the methods not replicated by others studying women in labor.

Voskrensensky(1996) used ultrasound transperineally to examine the passage of the fetal head through the pelvis. Although clearly indicated by the accompanying images it is difficult to establish what his findings are due to the language barrier. Only a short abstract accompanies the article which is in Russian. The language barrier may have prevented his methods from receiving attention in the English-speaking scientific community.

Rayburn et al.(1989) used transabdominal (TA) ultrasound to assess fetal head position when labor dystocia was diagnosed. They found that adding ultrasound was helpful, compared with digital vaginal examination alone, in arriving at a more precise diagnosis of fetal head position. The next publication was almost 10 years later, in 1998, when Gardberg et al. published their study on fetal head position during labor.(1998) They used TA ultrasound to study >400 nulliparous and multiparous women at the onset of labor (57%) or just before induction (43%) and their conclusions were that occiput posterior positions at delivery were due to a malrotation from an initial occiput anterior position. Their definitions of occiput posterior were that the orbital region had to be facing the symphysis and the spine seen posteriorly.

Akmal et al.(2003; 2004a; 2004b; 2002; 2004c) and Sherer et al.(2002a, 2002b) along with a few other groups(Dupuis et al., 2005a; Souka et al., 2003) published a series of studies comparing transabdominal ultrasound to vaginal digital examinations, in the diagnosis of fetal head position, and it was described how using the transperineal approach might be of added value to help to define position in addition to the transabdominal approach.(Chou et al., 2004; Kreiser et al., 2001) Sherer et al. also described how transabdominal ultrasound might be used to examine fetal engagement.(2003)

Dietz and Lanzarone described how translabial or transperineal ultrasound (at first developed by gynecologists to study the pelvic floor) might be used to assess fetal head engagement, using a midline sagittal view suggesting two measurement techniques using the infero-posterior part of the symphysis as a reference line and measuring the distance from this line to the fetal head.(2004, 2005) In a further study in 2006 they used the method, the head progression distance, to predict operative delivery before the onset of labor (Figure 15).(2006).

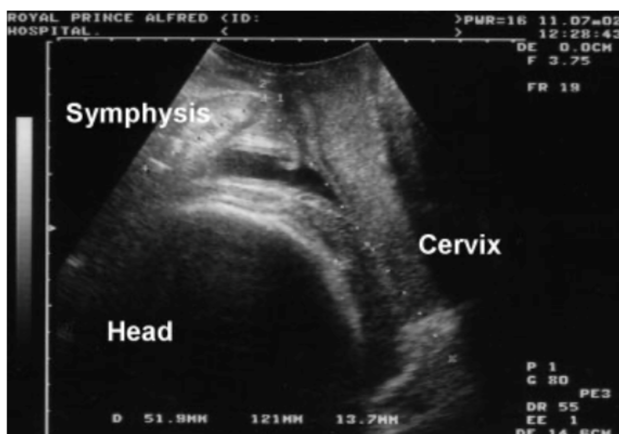

Figure 15. Head progression distance.(Dietz et al., 2006)

1.8.1 The last 15 years

Henrich et al. were the first to use transperineal ultrasound to study women in active labor systematically.(2006) They first used images from MRI examinations to describe the infrapubic plane, which is a plane at a 90° angle to the long axis of the symphysis in a sagittal view. This plane was described as 3 cm cranial to the plane of the ischial spinal processes (Figure 16).

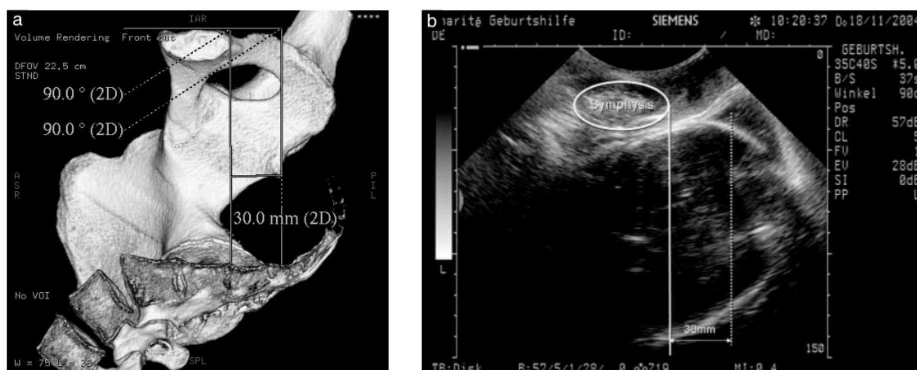

Figure 16. Correlation of intrapartum translabial ultrasound with computed tomographic (CT) reconstruction. (Henrich et al., 2006)

They then used transperineal ultrasound in women in active labor to obtain similar sagittal views, and document both whether the largest part of the fetal head had passed the infrapubic line and also the direction of fetal head descent, downwards, horizontal or upwards (Figure 17). They also considered

whether these findings correlated with the success of instrumental deliveries.(2006)

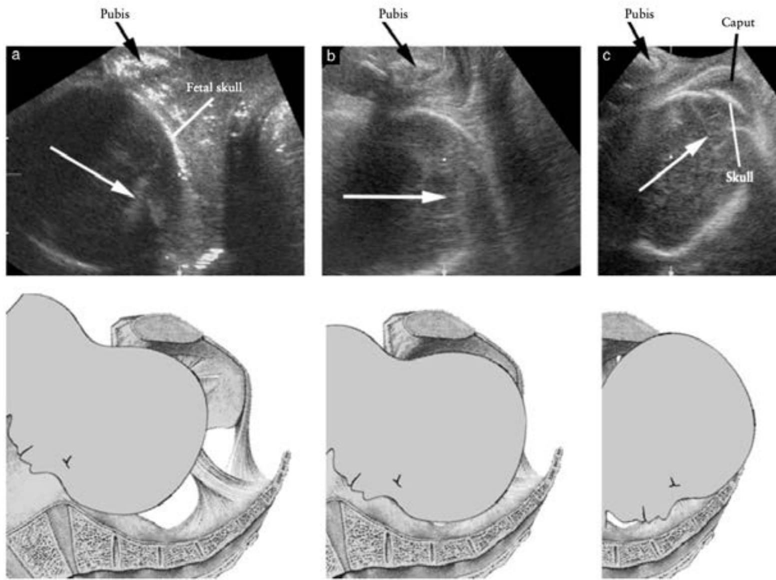

Figure 17. Categorization of fetal head direction (indicated by white arrows) in longitudinal translabial sonograms compared with schematic representations: (a) downward direction; (b) horizontal direction; (c) upward direction.(Ghi et al., 2009)

The same year, Eggebø et al., studying women with ruptured membranes at term, described the method of measuring head-perineum distance where a transverse view was used to measure the shortest distance from the skin of the perineum to the fetal skull (Figure 18).(2006)

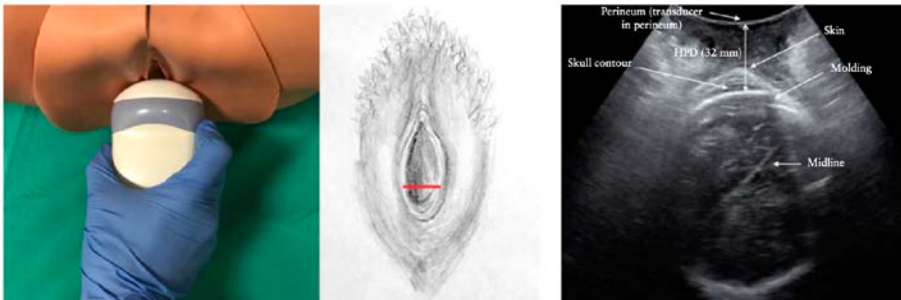

Figure 18. Measurement of head-perineum distance, showing placement of transducer and how distance is measured.(Ghi et al., 2018b)

Barbera et al. described a further method of mid-sagittal ultrasound where an angular measurement was made between a line passing through the long axis of the symphysis and a line from the inferior edge of the symphysis tangentially to the lowest edge of the fetal skull.(2009) They called this measurement angle of head descent, but it is now universally named angle of progression (Figure 19).

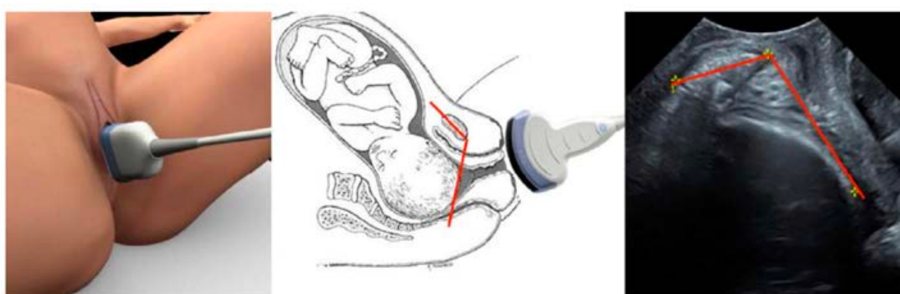

Figure 19. Measurement of angle of progression, showing placement of transducer and how angle is measured.(Ghi et al., 2018b)

Ghi et al. described how fetal head position could be assessed by using transperineal ultrasound in the coronal view, which allows visualization of the fetal head midline and it´s angle deviation from the antero-posterior axis of the pelvis (Figure 23).(2009)

Interest and research activity in the field of ultrasound in labor has multiplied, resulting in a growing body of published studies and further methods and definitions have been established. The International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) published practice guidelines on intrapartum ultrasound in 2018, describing all the most commonly used methods, quoting the most relevant studies.(Ghi et al., 2018b)

1.8.2 Transperineal/translabial ultrasound

The terms transperineal and translabial are used interchangeably when ultrasound imaging, using this approach, is discussed. The transperineal term was used when the male pelvic organs were examined so some researchers decided to use translabial to describe the same for females. The transperineal term was recommended by Salvesen (2006) and has since been the preferred one, used in the ISUOG guidelines for intrapartum ultrasound.(Ghi et al., 2018b) This term is therefore used in this thesis.

1.8.3 Smaller portable equipment

As ultrasound equipment has become more compact and mobile, this has allowed it being used more readily in the labor setting. Excellent equipment than can easily be moved to the laboring woman is now available. Some new models allow the operator to attach an ultrasound probe to a mobile phone. These changes in size and portability of the equipment have undoubtedly increased the interest in using ultrasound technology in the labor room.

1.8.4 Methods to assess fetal head position

Clinical digital examinations are predominantly used during labor to assess fetal head position. Some obstetricians and midwives become quite skilled at this but the learning curve is long and some people never acquire it fully.(Bergsjø & Koss, 1982; Iversen et al., 2019)

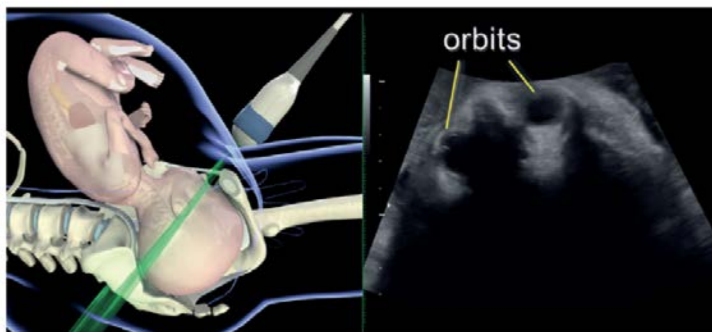

Figure 2 Transverse view on suprapubic ultrasound in a fetus with occiput posterior position, demonstrating fetal orbits.

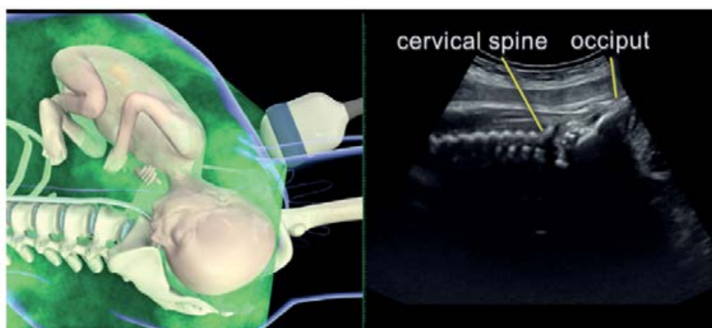

Figure 3 Sagittal view on suprapubic ultrasound in a fetus with occiput anterior position, demonstrating cervical spine and fetal occiput.

Figure 20. Transabdominal ultrasound to determine fetal head position.(Youssef et al., 2013)

Both the transabdominal and transperineal approach have been used to assess fetal head position. To determine position abdominally the fetus is examined longitudinally to detect the lie and localize the spine. Then the

transverse approach is used and the structures of the fetal skull, such as orbits and occiput are noted (Figure 20). Intracranial anatomy, including the interhemispheric midline, the thalami, the choroid plexuses and cerebellum are also used to define the position (Figure 21) (Youssef et al., 2013) which is then marked on a circular graph.(Akmal et al., 2004b)

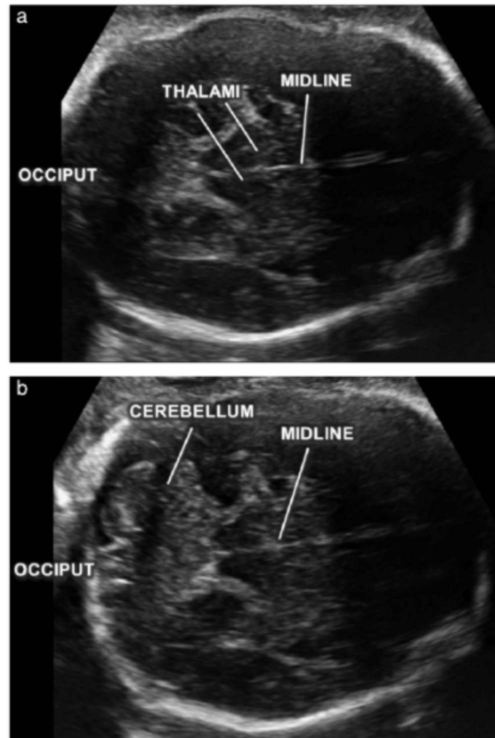

Figure 21. Transabdominal axial views of fetal head demonstrating midline, thalami (a) and cerebellum (b) used to determine fetal occiput position.(Youssef et al., 2013)

The transperineal coronal approach also uses the interhemispheric line and intracranial landmarks to identify the position. The orbits cannot be seen (unless the face is presenting) so the converging thalami, and the choroid plexuses diverging towards the occiput can be used to determine the occiput position. The methods are complimentary as the transabdominal view is easier at higher positions and the transperineal approach is clearer at low fetal head positions. The ISUOG guidelines recommend using the definition described by Akmal et al. to define the position of the occiput.(2004b) The occiput is marked on a clock-face like graph with half hourly markings (Figure 22).

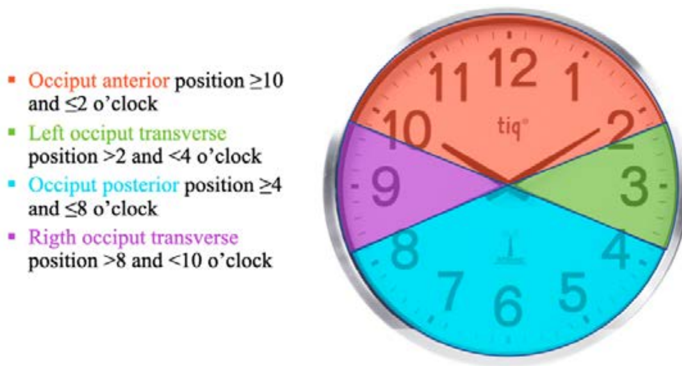

Figure 22. The definition of position of Akmal et al.(2004b)

The midline angle method, first described by Ghi et al. (Figure 23) (2009) is also commonly used in studies to describe fetal head position. The angle between the antero-posterior diameter of the maternal pelvis and the fetal interhemispheric line is measured as shown in the image.

In their study they found that a rotation of ≥45°corresponded to a fetal head station of ≤2cm in 98.6% of cases and a rotation of <45°to a station of ≥3cm in 83.7% of cases so the method can also be used to assess station.

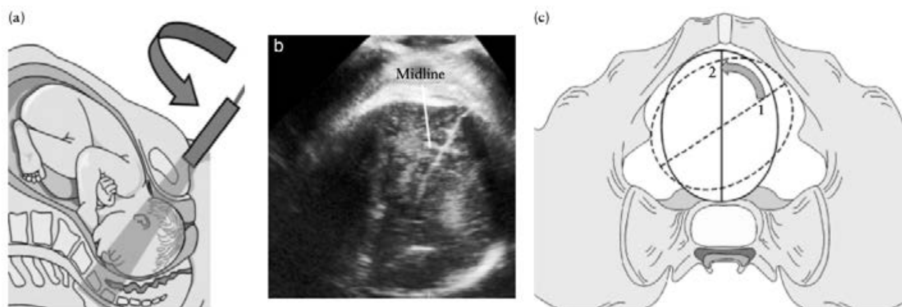

Figure 23. The midline angle. Transperineal ultrasound in the axial plane of the maternal pelvis.(Ghi et al., 2009)

Many studies have demonstrated the inaccuracy of the clinical estimation of position by comparing it with ultrasound examinations(Akmal et al., 2003; Akmal et al., 2002; Chou et al., 2004; Kreiser et al., 2001; Ramphul et al., 2014; Sherer et al., 2002a, 2002b; Yuce et al., 2015; Zahalka et al., 2005) and how sonography may help in this assessment.(Rozenberg et al., 2008) In 2001 Kreiser et al. used both transabdominal and transperineal ultrasound to study 44 women at full dilatation.(2001) They found that ultrasound examination had a lower error rate compared to digital examination in determining fetal head

position (6.8% vs. 29.6% p=0.01). Sherer et al. studied women in active labor and found that only 24% of digital vaginal examinations agreed with the ultrasound findings, but that this increased with clinical experience.(2002a) When they studied women who had reached the second stage of labor, only 35% of examinations were correct and they could not demonstrate that clinical experience improved the assessments.(2002b) Akmal et al. studied 496 women in labor and compared clinical examinations with TA ultrasound examinations.(2002) Position could always be defined by ultrasound, but only in two thirds of the clinical examinations and in less than half of these cases the findings were within 45° of the ultrasound findings. There was better agreement between clinical and ultrasound assessments with increasing cervical dilatation and also when examined by an obstetrician compared to a midwife. Chou et al. studied 88 women in the second stage of labor and compared clinical examination with combined transabdominal and transperineal ultrasound methods. They found that the clinical examination was correct in 71.6%, compared to the ultrasound examination in 92% cases (p=0.018) in predicting fetal occiput position at delivery.(2004) Dupuis et al. studied 110 women at full dilatation and compared clinical digital examination and transabdominal ultrasound and found a 70% agreement between the two methods but a higher clinical error rate with occiput posterior and transverse positions.(2005a) Souka et al. examined 148 women in active labor with TA ultrasound, and found that during the first stage occiput position could not be defined with clinical examination in 60.7% of cases and in 30.8% during the second stage.(2003) They found that the assessment was within 45°of the ultrasound assessment in 31.3% during the first stage and in 65.7% in the second stage, and was less likely to be correct when the position of the occiput was posterior. Akmal et al. found that one quarter of clinical examinations by obstetricians before instrumental delivery were incorrect to a greater extent than 45° and that this was more pronounced in occiput transverse or posterior positions, at higher stations and with lesser experience of the examiner.(2003)

1.8.5 Fetal spine position and attitude of the head

When the fetal head position is examined transabdominally, the position of the fetal spine is usually easily imaged. It can be visualized both in the transverse section and position noted as anterior, posterior, left or right or more specifically marked on a circular graph similar to the markings for fetal head position. On the longitudinal scan the flexion of the neck can be visualized when the spine is anterior or transverse. The assessment of the angle between the long axis of the cervical spine and the occipital bone was first described by Eggebø et al. in 2008, the presence of ≥90° flexion considered to be evidence

of a flexed neck.(2008) Ghi et al. have called it the "occiput-spine angle" and shown it to be on average 126° during active labor.(2016) Recently Ghi et al. have described the chin-chest angle that can be measured when the fetal spine is not accessible as in posterior positions of the spine (Presented at ISLANDS meeting 2021).

1.8.6 Methods to assess fetal head station

The methods used to assess fetal head station with ultrasound are mainly based on the transperineal view but transabdominal ultrasound has been used for this purpose. Sherer and Abulafia used transabdominal transverse views to assess engagement.(2003) The method involved marking the position between the L5/S1 vertebrae externally on the woman´s body because the promontorium could not be seen with ultrasound. The transducer then needed to be angled from the symphysis towards this point, and if the biparietal was seen below it, the head was considered engaged. The method is quite complicated and has not gained much attention. Only recently have Iversen and Eggebø suggested a transabdominal supra-pubic descent angle method measured in the sagittal plane, now under investigation.(2019)

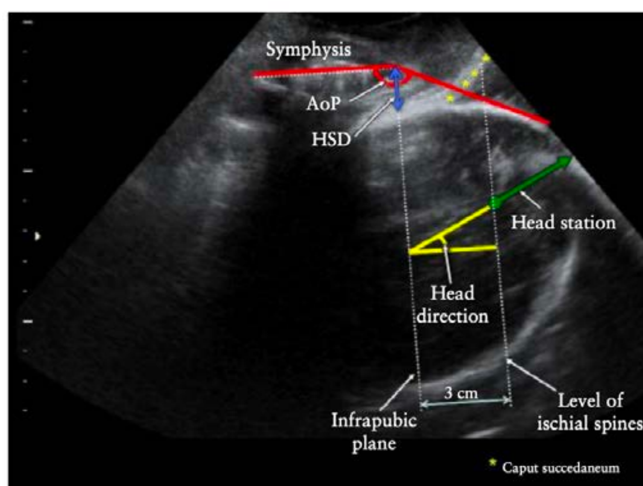

Figure 24. Transperineal ultrasound head station should be measured along line of head direction (adapted from Tutschek et al.2010).(Ghi et al., 2018b)

The most widely studied methods use the transperineal approach; the head-perineum distance, using the coronal view, and angle of progression and head direction, assessed in the sagittal view. The methods of measuring HPD and AoP are described in Paper I, see also Figure 18,Figure 19, Figure 26 and Figure 27.(Hjartardóttir et al., 2020) Three other methods have been described

to measure station, transperineal ultrasound or sonographic head station (TPU or ITU station), head symphysis distance (Figure 24) and head progression distance (Figure 15), also acquired from the sagittal view.

To measure sonographic head station (ITU) the distance from the infrapubic plane needs to be measured and also the angular measurement of fetal head direction to obtain the correct distance along the axis of the pelvis. The measurements obtained with this method correspond to the clinical scale of grading head station using the spinal processes +/- 5 cm.(Henrich et al., 2006; Tutschek et al., 2011) Tutschek et al. found a very good correlation between ITU and AoP measurements. They published a table converting AoP measurements to ITU. According to their measurements, a fetal head station of 0 corresponds to a measurement of 116° in AoP. As AoP is easier to measure, it is now the preferred method to use in the sagittal view.

Torkildsen et al. found a significant association between the measurements of AoP and HPD using both 2D and 3D methods.(2012) In his study with Tutschek and Eggebø, comparisons between clinical station, HPD, AoP, HSD and ITU head station were made and a conversion table constructed (Table 1).(2013)

Table 1. Conversion table for ultrasound methods to assess fetal head station.(Tutschek et al., 2013)

ITU head station (cm)	*Angle of progression (°)*	*HPD (mm)*	*HSD (mm)*
-3	84	54	*
-2	95	48	48
-1	106	42	41
0	116	36	34
1	127	31	27
2	138	*	*
3	148	*	*
4	159	*	*
5	170	*	*

They found that there was good correlation between all the ultrasound parameters examined but only moderate correlation with clinical assessments of head station. In their study HPD of 36 mm corresponded to AoP of 116° and 0 station. Other studies have shown station 0 to be at a level of HPD of 35(Kahrs et al., 2017) and 38(Maticot-Baptista et al., 2009) mm. Yuce et

al.(2015) also showed a very good correlation between HPD and AoP measurements but a wide variation in HPD and AoP measurements for each step of clinical station. They demonstrated well that the measurement error is far more likely to be due to inaccuracy in clinical assessment, rather than in the ultrasound measurements.

1.8.7 Standardization of measurements of station

Bamberg et al.(2011) compared the relation between the ultrasound measurements of AoP and the ischial spines examined with MRI in 31 women at full term but not in labor. They found a significant correlation between the distance from the presenting part to the ischial spinal plane and AoP ($y=-0.51x+60.8$, $r^2=0.38$, p=0.001). None of the fetal heads were engaged, but extrapolation of the x-intercept for the linear regression line showed that an AoP of 120° corresponded to the level of the ischial spines, or station 0. In a second study they compared the images obtained with MRI with ultrasound and found the mean difference between the two imaging methods to be 1.4°, and that the intraclass coefficient between the two methods was 0.89 (95%CI, 0.78-0.94) with limits of agreement of 14.9 to -12°.(2012) Arthuis et al. studied CT scans and sagittal angle measurements and found that the level of the ischial spines corresponded to 110° of AoP.(2016)

Molina et al. studied the repeatability of the measurements of head direction, angle of the middle line, progression distance and angle of progression in 50 women in the second stage of labor.(2010) They found that all methods were reproducible, but the angle of progression had the highest intraclass correlation coefficient for the same observer (0.94; 95% CI, 0.90-0.97, limits of agreement -9.2 to 11.1°) and for two different operators (0.84; 95% CI, 0.73-0.91, limits of agreement -15.4 to 18.3°). Torkildsen et al. compared 2D and 3D techniques for measuring AoP and found similar intraobserver variation for the two methods and the intermethod ICC was 0.93, limits of agreement -8.9 to 13.7.(2012) Dückelman et al. studied the interobserver agreement between operators with different ultrasound examination experience and found their ICC´s of 0.86 and limits of agreement between -8.8° to 6.6°. Ghi et al. studied AoP from 3D volumes of women in labor and found good intra and interobserver variation with ICC of 0.93 and 0.90 respectively and interobserver limits of agreement of -24.4 to 11.3°.(2010)

In the first study describing the HPD method Eggebø et al. reported the intraobserver and interobserver variations for HPD measurements as less than 3 mm, and the interobserver limits of agreement were -8.5 to 12.3 mm.(2006) Torkildsen et al. also studied HPD measurements with 2D and 3D techniques,

and similar to the results on AoP they found good intraobserver agreement with both methods (the ICC were 0.94 and 0.99 respectively) and the intermethod ICC was 0.93 with limits of agreement of -5.8 to 7.2 mm.

1.8.8 Predicting outcome of labor using ultrasound

Measuring head station has shown promise for predicting labor outcomes using ultrasound before labor start or induction(W. W. Y. Chan et al., 2019; Dietz et al., 2006; Eggebo et al., 2006; Eggebo et al., 2008; Eggebo et al., 2015; Levy et al., 2012; Torkildsen et al., 2011) and also when women are examined during the first stage of normal or prolonged labor.(Y. T. V. Chan et al., 2015; Eggebø et al., 2014; Eggebo et al., 2015; Torkildsen et al., 2011) The majority of clinical studies have focused on the use of ultrasound measurements of station and assessments of position during the second stage, to predict outcome in terms of spontaneous vs. operative delivery, or the level of difficulty of instrumental delivery.(Ciaciura-Jarno et al., 2016; Cuerva et al., 2014; Dall'Asta et al., 2019; Ghi et al., 2014; Gilboa et al., 2013; Kahrs et al., 2017; Kahrs et al., 2018, 2019; Kasbaoui et al., 2017; Maroni et al., 2014; Marsoosi et al., 2015; Masturzo et al., 2014; Pizzicaroli et al., 2018; Ramphul et al., 2014; Sainz et al., 2016; Sainz et al., 2015; Sainz et al., 2017; Sainz et al., 2018; Yonetani et al., 2017; Youssef et al., 2014) The results of these studies have shown that ultrasound is helpful in predicting how easy instrumental deliveries will be, and which deliveries are more likely to end as cesarean deliveries. Ultrasound has therefore been recommended, by professional or national guidelines, as a tool to objectively and accurately define position and station under these circumstances in addition to documentation of findings being possible.(Brooks et al., 2020; Ghi et al., 2018b; Kessler et al., 2020; Murphy et al., 2020; Yeo & Romero, 2009)

1.8.9 Randomized controlled trials

Four randomized trials have been done on the use of ultrasound in connection with delay in the second stage of labor. Ramhpul et al. performed a randomized study on 514 nulliparous women to see if adding TA ultrasound assessment of position to clinical examination before instrumental delivery, was superior to clinical examination alone.(2014) Ultrasound assessment was found to be incorrect in 1.6% of cases compared with 20.2% of the clinical examination alone (p<0.001). There was not a significant association with maternal or neonatal morbidity as a secondary outcome. Popowski et al. also evaluated the addition of transabdominal ultrasound determination to assess fetal head position on mode of delivery and found a statistically increased risk of both overall operative delivery and caesarean section in the group where ultrasound

was added to vaginal examination.(2015) Ghi et al. calculated that in order to study the risk of caesarean section due to failed instrumental delivery, 653 women needed to be randomized to each arm of a study comparing vaginal digital assessment alone versus with the addition of transabdominal ultrasound, to assess fetal head position before vacuum delivery. Such a study was attempted but was terminated prematurely, when only 222 women had been randomized, due to difficulties with recruitment. No difference was found in the primary outcome nor in any maternal or fetal outcomes, although a lower incidence of incorrect diagnosis of occiput position was found in the group randomized to the addition of ultrasound.(Ghi et al., 2018a) Barros et al. have recently published a study where 222 women were randomized to vaginal examination alone or with the addition of transabdominal and transperineal ultrasound.(2020) There was no difference in either composite maternal or neonatal morbidities. All the studies have underpowered to show a difference in rare adverse outcomes.

1.8.10 Longitudinal studies using intrapartum ultrasound to describe progress and predict outcome

The serial use of intra-partum ultrasound to describe the progress of labor has been reported in a few articles.(Adam et al., 2014; Chaemsaithong et al., 2019; Chor et al., 2019; Kwan et al., 2020; Lieberman et al., 2005; Souka et al., 2003; Tse et al., 2019) Chor et al. studied nulliparous women in spontaneous and induced labor.(2019) Only measurements at inclusion and after 1 and 2 hours were included, showing that a slower hourly fetal head descent was associated with an increased risk for caesarean section. Two articles report on a study of both nulli- and multigravid women in induced labors using HPD and parasagittal AoP. The first paper reported on the women who achieved vaginal delivery and showed that slower labor progress was associated with nulliparity, obesity, epidural use and the use of non-mechanical methods for labor induction.(Chaemsaithong et al., 2019) The second showed slower descent of the fetal head in women needing caesarean section compared with those who delivered vaginally.(Tse et al., 2019) A further article describing paired examinations from the start of labor until delivery also included reports of clinically estimated station, and cervical dilatation estimated both clinically and with ultrasound.(Kwan et al., 2020) This last study showed the feasibility of using ultrasound to follow labor longitudinally.

Three studies have described rotation during labor using ultrasound. Lieberman et al. described rotation in nulliparous women in spontaneous and induced labors, using transabdominal ultrasound to see if epidural use had an

effect on rotation.(2005) They studied over 1500 women longitudinally but there were many dropouts during labor, only half of the women were followed throughout labor and a portion of the scans were not interpretable. The main findings were that fetal position at delivery was not established until very close to delivery, and that epidural analgesia was strongly associated with occiput posterior position at delivery. They also found that 80% of occiput posterior fetuses late in labor were delivered in the anterior position. Souka et al. used transabdominal ultrasound at admission and at the start of the second stage in a mixed group in terms of parity, and both in spontaneous and induced labor.(2003) Adam et al. used transabdominal ultrasound longitudinally to describe position, but the description of the study group is lacking in terms of parity and onset of labor.(2014) Both the latter studies found that occiput anterior position at admission did not malrotate to an OP position.

Studies using both TA and TP ultrasound to describe rotation and descent longitudinally in primigravid women in spontaneous labor have not been found. The pattern of fetal head descent using ultrasound has not been described nor the pattern of fetal head rotation.

1.8.11 Cervical dilatation

The first description of using transperineal ultrasound to measure cervical dilatation was published by Zimerman et al.(2009) They used 3D volumes and found positive correlation with digital assessments. Hassan et al. described a 2D technique (Figure 25) used to examine 21 women and were able to obtain results in 19.(2013)

Benediktsdóttir et al. compared cervical dilatation assessed digitally with clinical vaginal assessment and measured with transperineal ultrasound in 86 women in labor.(2015) Ultrasound assessment was only possible in 71%, in most cases due to advanced dilatation (≥8 cm), similar to the study by Wiafe et al. who managed to examine the cervix in 175 out of 195 women (90%).(2018) They were unable to measure dilatation in women with dilatation of ≥8 cm, low head station and ruptured membranes. In the study by Cuerva et al. cervical dilatation could be assessed in 91% of women in early labor.(2019) In another recent, large study of Kwan et al., longitudinal paired ultrasound and clinical assessments of women undergoing induction of labor was done.(Kwan et al., 2020) Only 1.9% of ultrasound examinations were unsuccessful and all of them were in women found to be dilated ≥6 cm. They also found very good agreement between vaginally and ultrasound measured dilatation with a correlation coefficient of 0.96. Two other studies have shown dilatation to be 1 cm less when measured with ultrasound,(Benediktsdottir et

al., 2015; Yuce et al., 2015) but all studies have described high inter- and intra-observer agreement.

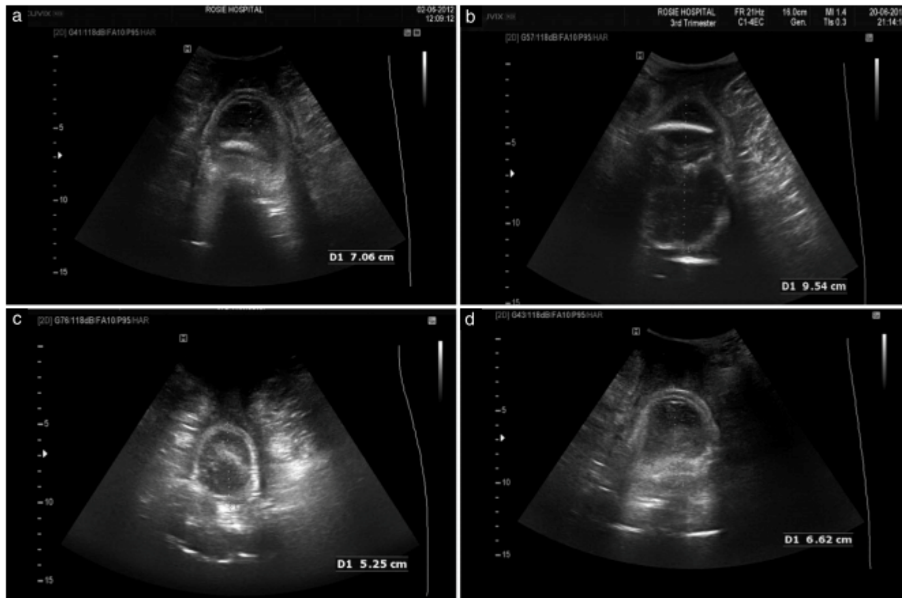

Figure 25. Two-dimensional ultrasound of cervical dilatation measurements: (a) 7.1. cm, (b) 9.5 cm, (c) 5.3 cm and (d) 6.6 cm.(Hassan et al., 2013)

1.8.12 Acceptability

All the studies that have investigated the acceptability of transperineal ultrasound have shown either no pain perception or reduced pain perception compared with conventional clinical vaginal examinations.(Alvarez-Colomo & Gobernado-Tejedor, 2016; Y. T. Chan et al., 2016; Iliescu et al., 2015; Rizzo et al., 2019; Seval et al., 2016; Usman et al., 2019; Wiafe et al., 2020) The non-invasive nature of the examination has the theoretical advantage of reducing the risk of infection which has been associated with repeated vaginal examinations.(Soper et al., 1989)

1.9 Safety of medical ultrasound

Ultrasound has been used for diagnostic purposes in medicine for decades and no deleterious effects have been demonstrated. Ultrasound produces heating, pressure changes and disturbances in tissue. Even diagnostic levels of ultrasound can produce temperature rises that could theoretically be hazardous to sensitive organs. Biological effects have been reported in animal models, especially with contrast agents containing microbubble gas. No

adverse effects have been reported when ultrasound is used for diagnostic purposes without such contrast agents. A thermal index, TI, is an on-screen guide that the user should observe as it warns of the potential for tissue heating. Another index, the Mechanical index, MI warns of the magnitude of non-thermal effects. Because of the possible risks all ultrasound examiners should adhere to the ALARA principle which involves keeping these indices as low as possible without compromising image quality. If values cannot be kept low the examination time should be kept as short as possible. During pregnancy the TI value should be kept under 0.7 and usually B- and M-mode imaging is achieved below these levels. Doppler ultrasound needs more consideration as it produces more thermal effects. It is generally not recommended for first trimester scanning or at least only for a very limited amount of time. Large professional bodies, such as ISUOG, BMUS and EFSUMB have produced safety statements for the use of ultrasound.(Abramowicz et al., 2000; 2009; Kollmann et al., 2020; Salvesen et al., 2011) Ultrasound examinations in labor last only a few minutes and no Doppler is used, only B-mode imaging.

2 Aims

2.1 Null hypothesis

Ultrasound methods do not give any added information compared to clinical assessments.

Fetal head rotation and descent is unpredictable and does not follow a pattern that can be used in a clinical way in laboring women.

2.2 Aims of the PhD thesis was:

To investigate fetal head rotation during the active phase of spontaneous labor in nulliparous women, with a cephalic singleton fetus at term (≥37 weeks)

To investigate if fetal descent during the active phase follows a linear or an exponential like progression.

Compare vaginal digital examination and ultrasound methods to assess labor progression.

2.3 Paper I

The aim of this study was to describe the descent of the fetal head through the pelvic cavity, longitudinally, using ultrasound measurements. Primigravid women in spontaneous labor, with a single cephalic fetus at term were studied from when the active stage could be diagnosed until delivery. The measurements used were HPD and AoP and these were related to fetal head position, delivery mode, time remaining in labor and clinical assessments of cervical dilatation.

2.4 Paper II

The aim of this study was to investigate longitudinally fetal head rotation patterns with ultrasound and relate these to labor phases and fetal head positions at delivery. The study group was the same as in Paper I.

2.5 Paper III

The aim of this study was to test the value of ultrasound as an admission test for women in active labor and whether HPD, AoP, fetal head position and cervical dilatation assessed with ultrasound, could predict duration of labor

phases and spontaneous delivery. The study group was the same one as in Paper I.

2.6 Paper IV

The main aim of this study was to test the reproducibility of the HPD measurements, both as intra-observer variability and interdevice variability, in women in labor. The second aim was to compare these measurements with clinical measurements of fetal head station, and lastly to evaluate the acceptability of the method for laboring women.

3 Methods and materials

3.1 Papers I-III

3.1.1 Study period

The study was performed at Landspitali University Hospital of Iceland during the period of January 2016 to April 2018.

3.1.2 Study group

The women were approached when they were admitted in labor. The eligibility criteria were: maternal age ≥ 18 years, primigravida, a single, cephalic fetus, ≥ 37 weeks' gestation and spontaneous onset of labor. Women were asked to participate on days when the examiners (HH and SB) were available to attend the whole of the labor. The women received oral and written information and if they agreed to take part, signed a consent form. When the midwife could confirm that the active phase had been reached, defined as ≥ 4 cm cervical dilatation of a fully effaced cervix, in the presence of regular contractions, at least 5 minutes apart, the study was started. Most women had reached the active phase on admission and hence were included at that time point. If women were admitted in the latent phase, and had given consent, the study only started when their labors had reached the active phase. Each woman was given a research number and all information was recorded and stored under this number without personal identifying details.

3.1.3 Methods

The equipment used was the Voluson *i* system described under section 3.2.4. Paired clinical and ultrasound examinations were done by two different examiners. A transabdominal and a transperineal scan were performed by one examiner (HH or SB) and a clinical examination by the midwife looking after the laboring woman. The results of the clinical examination were not revealed to the ultrasound examiners, only that the woman was in active labor. The results of the ultrasound examination were not revealed to the midwife and the ultrasound examiners were not involved with the clinical care or decision-making during labor.

The ultrasound examinations were timed just before or after a clinical examination was done by the midwife looking after the woman in labor. The women had an empty bladder and were examined between contractions.

3.1.3.1 Transabdominal ultrasound

The transabdominal scan was done with both a longitudinal and a transverse view of the fetus. The fetal lie was confirmed as cephalic as well as the presence of the fetal heartbeat. The fetal spine was located and noted as anterior, posterior, right or left sided. The presence of flexion of the neck was noted. The fetal head was examined and landmarks used to define the fetal head position were the orbits, the midline echo, the choroid plexuses diverging towards the occiput and the cerebral peduncle converging towards the occiput (Figure 20 and Figure 21). The position of the occiput was marked on a graph with a clock-face circle with markings for the hours and half hours between them (Figure 22). If the fetal head was too deeply engaged for the landmarks to be clearly seen, the transperineal view was used to define the position of the occiput.

3.1.3.2 Transperineal ultrasound

The transperineal ultrasound was performed with the women in a semi-recumbent position with flexion in their knees and hips, with the transducer covered in a glove. Both sagittal and axial scans were performed. The sagittal view was used to examine AoP. The axial view was used to examine cervical dilatation, HPD and fetal head position.

3.1.3.3 Angle of progression

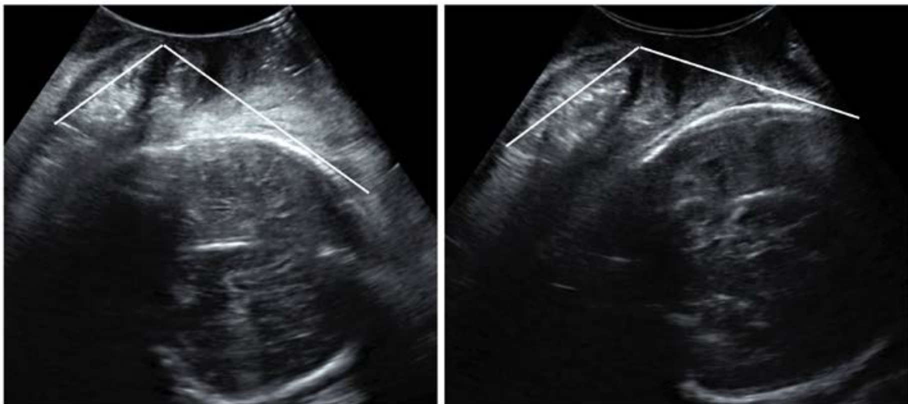

Figure 26. AoP measurements of 110° (left image) and 130° (right image)

The sagittal view was obtained by applying the transducer sagittally between the labia, on the perineal skin at the posterior fourchette and angling the transducer so that a clear view was obtained of the symphysis pubis and the fetal skull (see Figure 19 and Figure 26). The image was then frozen and a line

drawn through the long axis of the symphysis to its lowermost edge and another line perpendicular to the first from this point tangentially to the fetal skull edge. The equipment gives an automatic reading of the angle between the two lines. This measurement was done once, noted and the image stored.

3.1.3.4 Head-perineum distance

The transducer was placed transversely on the labia, just above the posterior fourchette. This gave an axial view of the pelvis and the fetal skull (see Figure 18 and Figure 27). Firm pressure, without causing pain, was applied and when as clear a view as possible of the lowermost edge of the skull was obtained, the image was frozen and the distance from the skin to the skull measured. This measurement was done once, noted and the image stored.

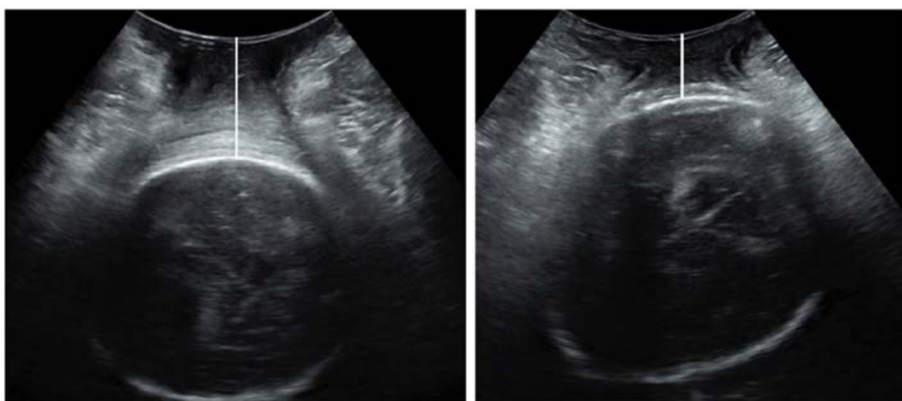

Figure 27. HPD measurements of 40 mm (left image) and 20 mm (right image).

3.1.3.5 Position

The position of the fetal head was defined by observing intracranial landmarks; the midline echo, cerebellum, choroid plexuses and the cerebral peduncles as described for the transabdominal scan. The frozen image showing the position was stored.

3.1.3.6 Cervical dilatation

The dilatation of the cervix was examined in the axial view, angling the transducer until the best view of the slightly more echo poor fetal head or sac of membranes, when the membranes had not ruptured, against the more echogenic circular cervix (See Figure 25). The cervical measurements were taken from one edge to the other, both transversely and longitudinally on the frozen image. An image of the cervix was stored.

3.1.3.7 *Clinical examinations*

The midwife examined the woman vaginally, noting cervical dilatation, fetal head station according to the WHO classification using the spinal plane as reference point and +/-5 cm(WHO 2017) and if possible fetal occiput position, marking the position on a similar clock-face chart as that used by the ultrasound examiners. The midwives were asked to try to obtain these results when at all possible. The results of the examinations were recorded on special charts designed for the study.

3.1.4 Outcomes and characteristics collected

After the delivery the midwife looking after the woman collected information on pre-pregnancy BMI, maternal age, gestational age, length of the labor stages, both the first stage, active and passive second stage, epidural and oxytocin use and when these were started, degree of perineal tear, blood loss, delivery mode, fetal weight, head circumference, fetal head position at birth and Apgar scores.

3.1.5 Process

When a clinical examination confirming the diagnosis of the active phase had been completed, the ultrasound examination was performed. This took place within 15 minutes. The paired examinations were repeated throughout labor using the hospital protocol, recommending an examination at least every four hours during the first stage and hourly during the second stage. If clinically indicated, such as if the woman felt an urge to push or there was evidence of fetal distress, an examination was done sooner. There was not a set order in which the examinations were done, sometimes the clinical examination was the first one and sometimes vice versa.

3.1.5.1 *Analysis of images*

The analysis of images was performed online in the examination room and the results recorded on a special chart designed for the study.

3.1.5.2 *Data management*

All data sheets, marked with study numbers only, were collected by the main investigator (HH) and the results entered and managed using REDCap electronic data capture tools, hosted at Landspitali University Hospital. A key with the study numbers and the patient´s IDs was kept in a locked cabinet in the main investigator´s office. Ultrasound images were stored with study numbers on the ultrasound equipment, and backup copies maintained and

kept in a locked cabinet in the investigator´s office. All analysis was performed with anonymized data only.

3.1.5.3 Operators

The ultrasound operators (HH and SB) are both trained fetal medicine experts. The staff performing the clinical examinations were the staff looking after the women in labor, almost always midwives, but a few examinations were done by obstetricians.

3.1.6 Epidural use and dosage

Women were able to request epidural analgesia on demand. This was cited by an anesthetist and after a test dose of 3 ml of Marcain® 2.5mg/ml an initial dose of Marcain® 2.5mg/ml 4ml + Sufenta® 5 microg/ml 2 ml + NaCl 0.9% 4 ml was given. After that intermittent doses, alternating between Marcain® 2.5 mg/ml 5 ml + NaCl 5 ml and Marcain® 2.5 mg/ml 5 ml+ Sufenta® 5 microg/ml 1ml + NaCl 4 ml.

3.1.7 Oxytocin use and dosage

A partograph adapted from the 1994 WHO partograph was used to monitor progress during labor.(WHO 1994) An action line was drawn at diagnosis of the active phase and if the cervical dilatation was slow, crossing the action line, an oxytocin infusion was started. Oxytocin could also be started during the second stage when there had been no progress in descent after one hour in the passive second stage, or after 30 minutes of active pushing. The infusion was made up with 10 i.u. of oxytocin in 500 ml 0.9% NaCl and the rate started at 12 ml/hour increasing the rate by 12 ml/hour every 30 min. until a maximum of 90 ml/hour. This corresponds to a starting dose of 2mU/min to a maximum of 30mU/min or a low-dose regimen.(Wei et al., 2010)

3.2 Paper IV

3.2.1 Study period

The study was performed at Landspitali University Hospital of Iceland in Reykjavík and in Lund University Hospital in Lund, Sweden, during the period of February 2015 to February 2017.

3.2.2 Study group

The group consisted of 44 women admitted to the labor wards with regular contractions in the first stage of labor. Both nulliparous and parous women with induced or spontaneous onset of labor were included. All were at term (≥37

weeks) with a single, cephalic fetus.

3.2.3 Operators

The ultrasound examinations were performed by two examiners with fetal medicine expertise, and three examiners (two midwives and one junior doctor) with either none or very little ultrasound experience prior to being trained to take part in the study. The two midwives were supervised for around 50 HPD measurements, but the junior doctor for 10, before they were considered to have sufficient skills and confidence to do the measurements independently for the purpose of the study.

3.2.4 Equipment

Two ultrasound devices were compared, the first was a Voluson *i* (GE Medical Systems, Zipf, Austria) with a 3.5- to 7.5-MHz 3D curved multifrequency transabdominal transducer, and the second a Philips VISIQ ultrasound system (Philips, Amsterdam, the Netherlands) with a C2-5 broadband curved array transducer - lightweight USB connector. The length of the Voluson *i* transducer was 70 mm and the width 45 mm. The Philips VISIQ device has a transducer directly plugged into a tablet. The length of this transducer was 62 mm and the width 17 mm. The longitudinal curvature of both transducers was similar. The same two devices were used for all examinations and the order of which was used first was decided in a non-formal random manner.

3.2.5 Head-perineum distance measurements

The HPD scan was performed in the same manner as described under section 3.1.3.4. The ultrasound examinations were timed just before or after a clinical examination was done by the midwife looking after the woman in labor. Each ultrasound measurement was repeated three times with one transducer, always removing it from the skin before each repetition. After the first examiner had left the room with the first equipment, another examiner entered the room and performed the same measurements using the other ultrasound system. A total of six measurements were therefore performed on each woman. None of the examiners were aware of the results of the other´s examinations.

3.2.6 Visual analogue scale

For assessment of acceptability the women were asked to fill in a visual analog scale (VAS) for the level of pain experienced during the examinations. Zero was used to mark no pain and 10 as the highest possible level of pain perception.

3.3 Ethical issues

The women received all the care that they normally would have been given during their labors. In addition, they agreed to be examined by one of the ultrasound operators at each vaginal examination. The midwife caring for each woman, obtained a verbal consent and offered written information, after which a written consent was obtained by the main investigator (HH). The extra member of staff and longer examination time, leaving the woman exposed, may be considered a negative factor which may interfere in the process of labor. Every effort was made to make the interruption caused by the study examination as quiet, gentle and short as possible. Before signing the consent, the women were made fully aware that they could decline at any point to continue in the study and did not have to give any reason for doing so. It would also not affect in any way the care they would be given, should they decide to refuse further continuation. Each examination only took a few minutes and from prior studies it was known that they were not painful and well tolerated. Ultrasound used for these imaging purposes is considered to be harmless to the fetus. Informing the women before labor started would have meant informing them in a less vulnerable state than doing so after labor onset. Practical issues, mainly the lack of constant availability of the ultrasound operators meant that a very large number would have been contacted unnecessarily. Therefore, this approach was used, to inform them at admission and ask for their consent at that time. As ultrasound is a well-known entity for pregnant women, experienced by all of them at least once during the pregnancy, it does not require much explanation. The novel issue in this study was the unusual approach. Although women were experiencing labor pains when introduced to the study in this way, it was felt that sufficient time could be given to provide the necessary information in-between contractions. No negative comments were received, apart from one woman who decided to withdraw from the study after inclusion. She felt the extra examination was too much of an intrusion in her privacy.

In the studies, no Doppler ultrasound was used and the examinations only lasted a few minutes each. This should not be a cause for concern as regards the safety of the procedure.

For the Studies I-III the approval of Landspitali Ethics Committee was received, reference number 26/2015. For Study IV the approval of the local ethics committees was provided, numbers 2014/180 in Sweden and VSN-15-216 in Iceland.

3.4 Statistical methods

3.4.1 Paper I

The time of delivery was used as a fixed reference point and time was calculated backwards, when analyzing labor patterns. The labor curves were constructed using fourth degree polynomial models with 95% CIs shaded. The measurement variables analyzed in this way were cervical dilatation assessed clinically, HPD and AoP for the whole group and also according to delivery mode; cesarean section, instrumental delivery and spontaneous delivery. Spontaneous deliveries were also analyzed separately, stratified by fetal head position at entry, degree of cervical dilatation at entry, epidural use and oxytocin augmentation. A mixed effects model was used to predict the HPD and AoP measurements at each cm of cervical dilatation, and to predict the time remaining to delivery for levels of HPD and AoP in women delivering vaginally. For HPD the level of 36 mm and for AoP 116° were used to define the midpelvic or spinal plane.(Arthuis et al., 2016; Ghi et al., 2018b)The Shapiro-Wilks test for normality was used for the AoP and HPD measurements. The AoP measurements were not normally distributed so the Kruskal-Wallis test was used to estimate differences in median cervical dilatation, AoP and HPD by mode of delivery. The correlation between the HPD and AoP measurements was estimated from a Spearman´s correlation coefficient, and this was also used to estimate the correlation between fetal head station and, respectively, HPD and AoP.

3.4.2 Paper II

The time of delivery was used as a fixed reference point and time calculated backwards, when describing the association between fetal head station and fetal head position against time. The Shapiro-Wilks test for normality was used for the AoP and HPD measurements. The AoP measurements were not normally distributed so the Kruskal-Wallis test was used to estimate differences in median cervical dilatation, AoP and HPD by occiput position at inclusion. The Fisher exact test was used to compare proportions. Other results were presented descriptively.

3.4.3 Paper III

The associations between spontaneous vaginal delivery vs. all operative deliveries related to ultrasound assessed HPD, AoP and cervical dilatation as continuous variables were evaluated, using receiver-operating characteristic (ROC) curves. To find the best cut-off levels of HPD and AoP for predicting

spontaneous delivery, Youden´s J statistic was employed.

Survival analysis was used to evaluate the differences in time interval from inclusion to vaginal delivery according to fetal head station, fetal head position and ultrasound measured cervical dilatation. Kaplan-Meier curves were generated for fetal head station categories based on the best cut-off levels, of OP vs. non-OP positions, and for cervical dilatation <4-5 cm vs. ≥6 cm. The curves were compared with a log rank test. Cox regression analyses were used to calculate hazard ratios (HR) as an estimate of the likelihood ("risk") of spontaneous delivery. In the Cox analysis the same categories of HPD, AoP, cervical dilatation and occiput were compared. Cesarean sections and operative vaginal deliveries were censored. The HR were adjusted for maternal age and pre-pregnancy BMI.

3.4.4 Paper IV

To assess intra-observer repeatability, the difference between the highest and lowest measurement value was calculated. Pooled calculations were based on both ultrasound systems and the measurements of all examiners. The intra-observer repeatability was expressed as the intraclass correlation coefficient (ICC). The range for the repeatability coefficient was the range within which two measurements for the same observer will fall for 95% of those examined. To determine if there was a systematic difference between the magnitude of the measurements by their order (first, second and last), analysis of variance for repeated measurements was used.

To determine inter-device agreement, the mean of the three measurements from each device were used. To assess if there was a systematic bias between the two systems and the magnitude and relation of this potential difference, the differences of the measurements against the means of the measurements were plotted in a Bland-Altman plot. To determine whether there was a difference the 95% CI for the mean difference was used. No bias was considered if 0 was within the CI. The limits of agreement with 95% CI were calculated as described by Bland and Altman.(2003) The inter-device agreement was also assessed with the ICC. Linear regression was used to correlate the ultrasound measurements and clinical assessments. The VAS scores were compared using a paired *t*-test.

3.4.5 Statistical software

For papers I-III the statistical software package R version 3.4.4 was used. (R

Foundation for Statistical Computing, Vienna, Austria; URL: https://www.R-project.org).

For data analysis in paper IV the statistical software package IBM SPSS statistics version 24.0 (IBM Corp., Armonk, NY, USA) was used.

4 Results

4.1 Papers I-III

4.1.1 Study group and characteristics

One hundred women were recruited but one declined participation after inclusion, so the results are based on 99 women in active labor. When the women were included 26 had a cervical dilatation of 4 cm, 30 women were 5 cm dilated, and 43 had a cervical dilatation ≥ 6 cm. The baseline and some of the outcome characteristics of the study group are presented in Table 2.

Table 2. Characteristics of the study group.

Characteristics	Median (range) or n (%)
Age	27.0 (18-40)
Body mass index (kg/m^2)	23.3 (16.7-36.3)
Oxytocin augmentation	41 (41.4)
Epidural analgesia	61 (61.6)
Spontaneous delivery	75 (75.8)
Ventouse delivery	15 (15.2)
Forceps delivery	1 (1.0)
Cesarean section	8 (8.1)
Blood loss (ml)	400 (100-2000)
Episiotomy	13 (13.3)
Degrees of perineal tear	
None	19 (19.2)
1°	22 (22.2)
2°	53 (53.5)
3°	5 (5.1)
Birthweight (g)	3540 (2480-5000)
Apgar score at 1 min	9 (2-10)
Apgar score at 5 min	10 (5-10)
Gestational age (days)	280 (259-293)

A total of 345 paired examinations were done. The number of examinations for each woman depended on the duration of labor, the average was 3.6. Two women were only examined once, 97 women were examined at least twice, 66

women three times, 49 women four times, 24 had five examinations, 15 had six examinations and three women were examined eight times. The mean duration of labor from inclusion was 8.4 hours (95% CI, 7.3-9.4 hours) for women delivering spontaneously, 10.5 hours (95% CI, 8.3-12.7) for women needing instrumental delivery and 14.3 (95% CI, 9.7-18.8) in the cases ending with a cesarean section. Of the eight cesarean sections, six were performed due to arrest of cervical dilatation during the first stage and two were performed during the second stage, one for failure of descent and one for fetal distress after a prolonged first stage. All the instrumental deliveries, except one ventouse done for fetal distress, were done due to failure to descend after a prolonged second stage.

4.1.2 Head-perineum distance compared to angle of progression

Angle of progression decreases linearly with head-perineum distance with a high correlation ($r = -0.80$; $p < 0.001$) and gave similar mirror image patterns.

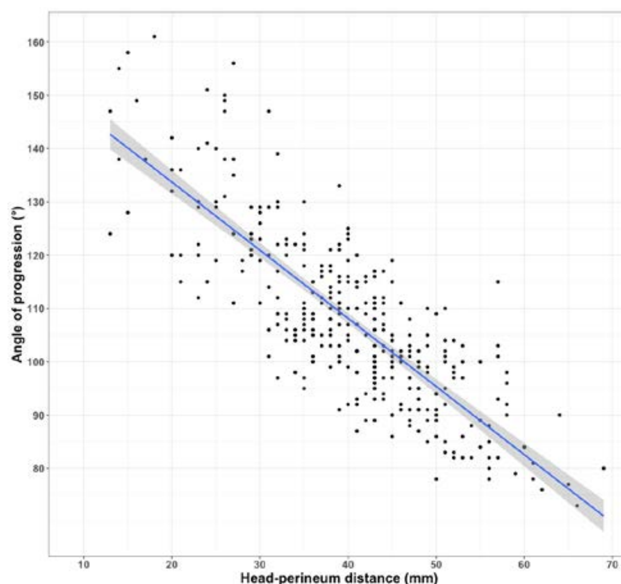

Figure 28. Linear regression of AoP vs. HPD measurements.

4.1.3 Clinical and ultrasound assessments of station compared

The correlation between clinically assessed fetal station and HPD was $r = -0.75$; $p<0.001$ and for AoP $r=0.75$; $p<0.001$. The association between clinically assessed station and ultrasound measurements is shown in Figure 29. At stations estimated clinically as +1 and +2 the HPD hardly changed compared

with at station 0 and both the median HPD and AoP measurements indicate a higher station at +2 than at +1.

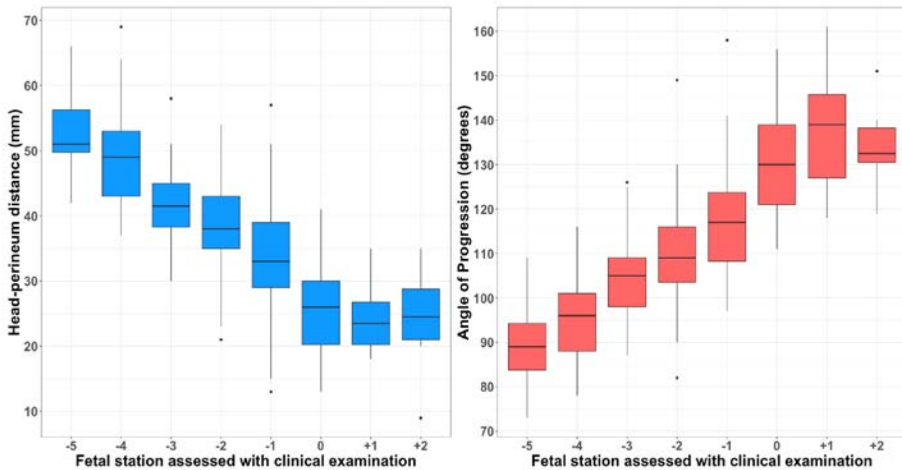

Figure 29. Comparisons of HPD (left) and AoP (right) with clinical methods for assessing fetal head station.(Hjartardóttir et al., 2020)

4.2 Results of Paper I

4.2.1 Descent and dilatation patterns

On the following images polynomial regression was used to draw lines, to show the association between ultrasound measurements of fetal head station and time. The same methods were used to describe the association between clinically assessed cervical dilatation and time. Figures 30 and 31 show all the measurement points as scatter graphs with the fitted regression lines, but Figures 32-37 only the fitted regression lines, stratified according to mode of delivery, occiput position at inclusion, oxytocin augmentation, epidural use and cervical dilatation at inclusion. In all the graphs the 95% confidence intervals for the regression are shaded.

In Figure 30 showing the overall pattern for all the measurements, descent was observed in decreasing HPD measurements in mm (Figure 30, left) and increasing AoP in degrees (Figure 30, right). Defining the mid-pelvic plane as 36 mm for HPD and 116° for AoP the graphs illustrate that the fetal head was on average stationed above this level during the early stages of the active phase and that descent began just before full cervical dilatation was reached. (Figure 31)

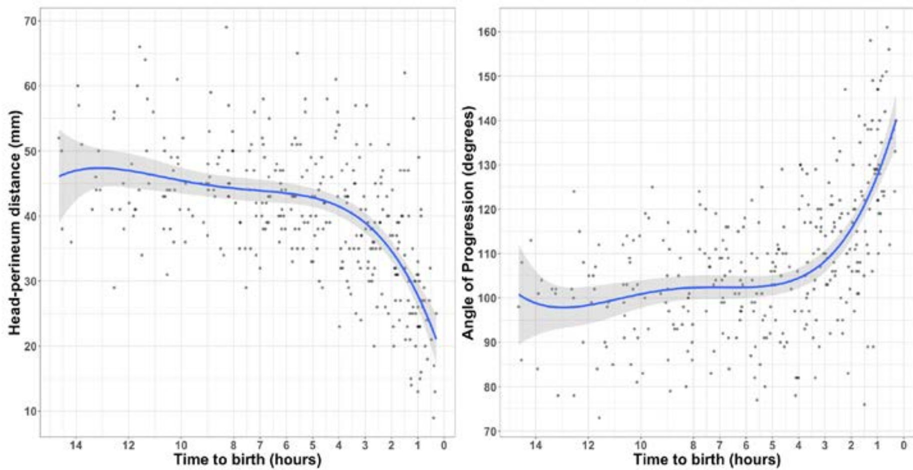

Figure 30. Patterns of fetal head descent using ultrasound to measure HPD (left) and AoP (right).(Hjartardóttir et al., 2020)

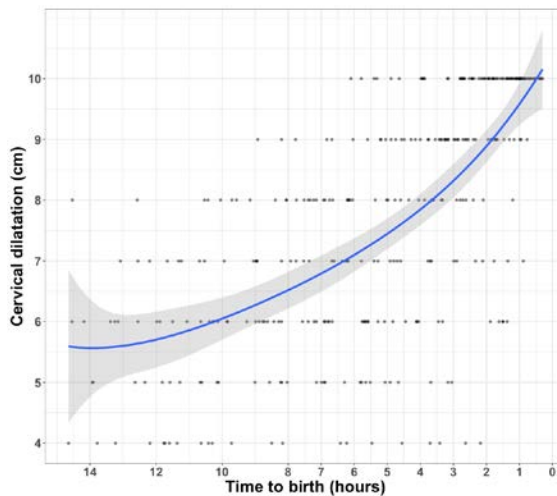

Figure 31. Pattern of clinically assessed cervical dilatation.(Hjartardóttir et al., 2020)

Figures 32 and 33 demonstrate the patterns stratified by delivery mode, i.e. spontaneous vaginal, instrumental vaginal and cesarean section. A steep and continuous descent can be seen on Figure 32 when the women delivered spontaneously. Around six hours before birth, at on average 7 cm dilatation, beginning descent was noted, becoming more accelerated at around 8 cm dilatation, four hours on average before birth. In the labor curves for women having instrumental vaginal deliveries the descent was more gradual and, in the cases, ending with cesarean delivery, descent was lacking.

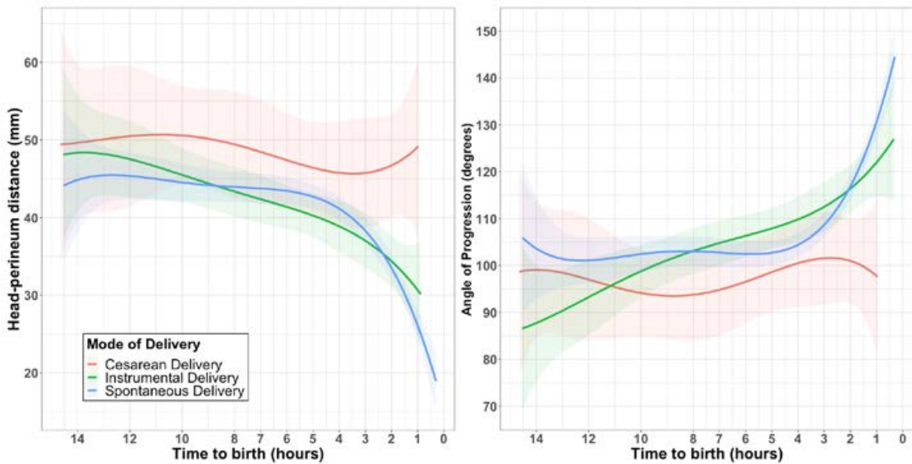

Figure 32. Patterns of fetal head descent using ultrasound to measure HPD (left) and AoP (right), by mode of delivery.(Hjartardóttir et al., 2020)

The patterns for clinically assessed cervical dilatation are demonstrated in Figure 33. The slope was steepest in labors ending with spontaneous deliveries and slightly less steep in those ending with instrumental vaginal deliveries. In the labors ending with cesarean section the slope was initially similar, but then tapered off and stopped demonstrating an arrest of dilatation at a mean of 8 cm, around 4 hours before delivery.

Figure 33. Pattern of clinically assessed cervical dilatation by mode of delivery.(Hjartardóttir et al., 2020)

The following images show the descent patterns for women who delivered spontaneously. HPD and AoP descent curves, stratified by ultrasound assessed fetal positions at the first measurement, are shown in Figure 34. The fetal head station was observed to be highest for fetuses in an OP position but the pattern of rapid descent was similar for all initial positions.

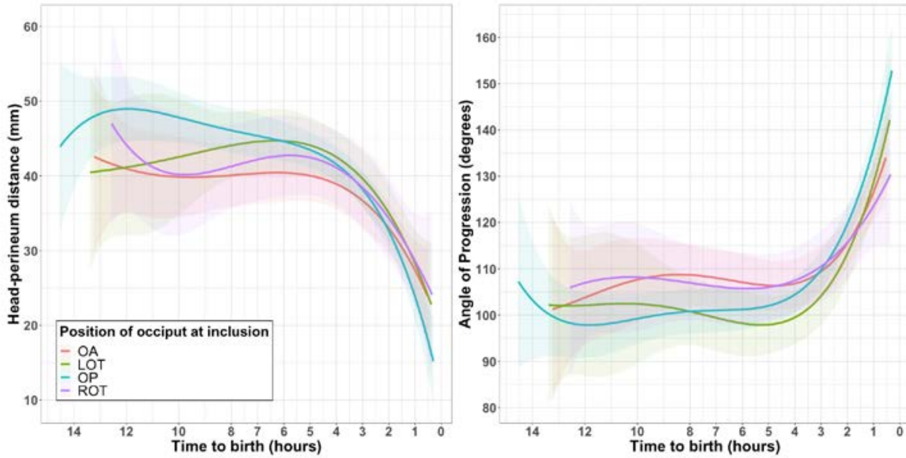

Figure 34. Patterns of fetal head descent using ultrasound to measure HPD (left) and AoP (right), stratified by occiput position at inclusion.(Hjartardóttir et al., 2020)

In women who delivered spontaneously, there was a need for oxytocin augmentation in 29% of cases. The HPD and AoP descent curves were stratified according to oxytocin augmentation, see Figure 35. Slower descent was noted for women needing augmentation.

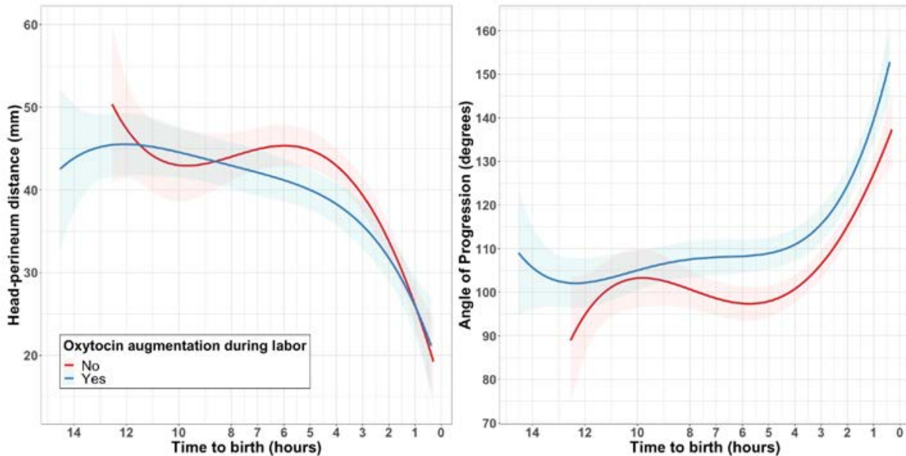

Figure 35. Patterns of fetal head descent using ultrasound to measure HPD (left) and AoP (right), stratified by use of oxytocin.(Hjartardóttir et al., 2020)

Epidural analgesia was used for 57% of women who delivered spontaneously. Figure 36 shows the HPD and AoP descent patterns, stratified by use of epidural analgesia. Descent was only slightly slower in the women having epidural analgesia.

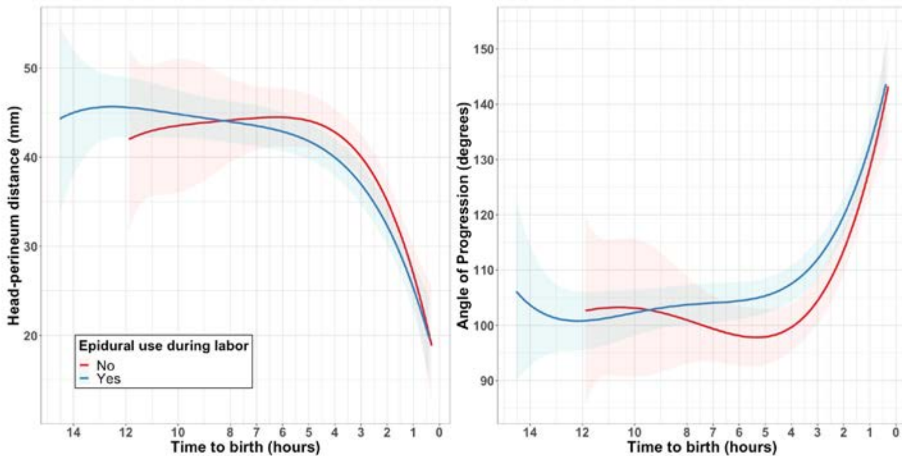

Figure 36. Patterns of fetal head descent using ultrasound to measure HPD (left) and AoP (right), stratified by epidural use.(Hjartardóttir et al., 2020)

Figure 37 shows the HPD and AoP descent patterns for women who delivered spontaneously, stratified by degree of cervical dilatation at inclusion. No difference in the descent patterns could be seen in those who had 4-5 cm dilatation, compared with those included with ≥ 6 cm dilatation.

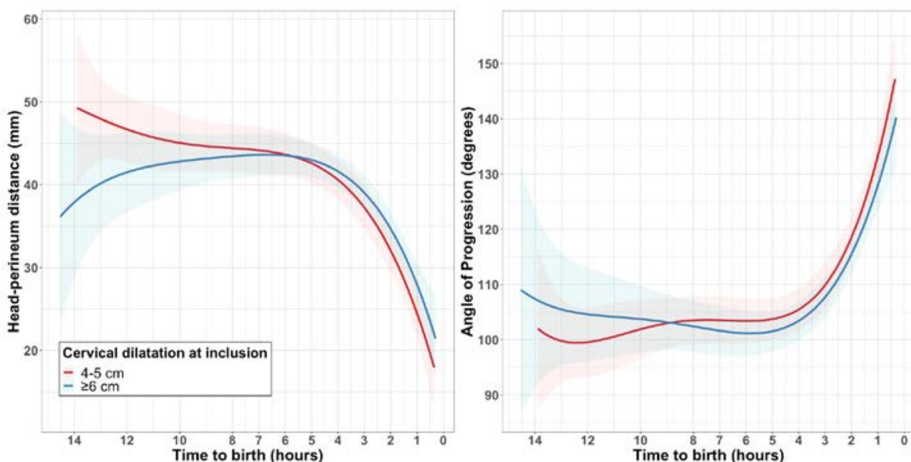

Figure 37. Patterns of fetal head descent using ultrasound to measure HPD (left) and AoP (right), stratified by cervical dilatation at inclusion.(Hjartardóttir et al., 2020)

4.2.2 Fetal head station at entry and last examination

Table 3. Cervical dilatation and ultrasound measurements of fetal head station at the first and last examination(Hjartardóttir et al., 2020)

	Cesarean Delivery **(n=8)**	***Instrumental Delivery*** **(n=16)**	***Spontaneous Vaginal Delivery*** **(n=75)**	***p value***
At first examination				
Cervical Dilation (cm)	5 (4-7)	5 (4-8)	5 (4-10)	*0.479*
Angle of Progression (degrees)	88 (73-105)	95 (78-112)	102 (81-128)	*0.011*
Head-perineum distance (mm)	56 (34-66)	47 (35-57)	43 (24-64)	*0.016*
At last examination				
Cervical Dilation (cm)	8 (6-10)	10 (5-10)	10 (5-10)	*0.006*
Angle of Progression (degrees)	104 (76-123)	114 (99-155)	123 (82-161)	*0.012*
Head-perineum distance (mm)	47 (33-62)	36 (14-51)	30 (9-57)	*0.001*

Values are median (range)

Table 3 shows that at both the first and last measurement in women ending with an operative delivery, a higher fetal head station was demonstrated by the HPD and AoP measurements and this was more pronounced in women needing cesarean section.

4.2.3 Prediction of station according to dilatation

Comparisons between the fetal head station measurements, HPD and AoP, and cervical dilatation analyzed with mixed effects models in women who delivered vaginally, showed that the relation was not linear and that a 2nd degree model had a better fit (*p* value for comparisons of 1st and 2nd degree models <0.001).

Table 4 shows the predicted fetal head station for each cm of cervical dilatation.

Table 4. Predicted fetal head station for each cm of cervical dilatation(Hjartardóttir et al., 2020)

Cervical dilatation (cm)	*Predicted head-perineum distance (mm)*	*95% CI (mm)*	*Predicted angle of progression (°)*	*95% CI (°)*
4	44	42-47	102	98-105
5	46	44-47	99	96-101
6	45	44-47	98	96-100
7	44	42-45	101	98-103
8	40	39-42	106	104-108
9	36	34-37	115	113-117
10	29	28-31	126	124-129

The prediction for an HPD measurement at 8 cm dilatation was 40 mm (95% CI 39-42) and for AoP it was 106° (95% CI 104-108°). At full dilatation this model predicted the HPD to be 29 mm (95% CI 28-31mm) and the AoP to be 126° (95% CI 124-129°).

4.2.4 Prediction of time to delivery based on fetal head station

The results of mixed effect models analyzing the relation between the fetal head station measurements of HPD and AoP and time remaining to delivery for women delivering vaginally, are shown in Table 5.

Table 5. Predicted time to delivery at level of head-perineum distance and angle of progression in women delivering vaginally(Hjartardóttir et al., 2020)

Head-perineum distance (mm)	**Predicted time to delivery (hours)**	**95% CI**
60	10.5	9.4-11.6
50	8.0	7.3-8.8
40	5.5	5.1-6.1
30	3.0	2.5-3.8
20	0.6	0.0-1.6
Angle of Progression (°)		
80	9.5	8.7-10.4
95	7.4	6.7-8.0
110	5.2	4.7-5.7
125	3.0	2.4-3.7
140	0.8	0.0-1.8

This predicted that at an HPD measurement of 40 mm delivery was expected in 5.5. hours (95% CI 5.1-6.1 hours) and for AoP of 110° the corresponding values were 5.2 hours (95% CI 4.7-5.7 hours). HPD of 30 mm and AoP of 125° both predicted delivery in 3.0 hours (95% CI for HPD 2.5-3.8, for AoP 2.4-3.7 hours).

4.3 Results of Paper II

4.3.1 Fetal head position longitudinally through the active phase of labor

Fetal head position at each examination is presented in Table 6.

Table 6. Position of occiput at each examination(Hjartardottir et al., 2020)

	1st (n=99)	2nd (n=97)	3rd (n=66)	4th (n=49)	5th (n=24)	6th (n=15)	7th (n=3)	8th (n=3)	last n=99
Occiput position									
OA	19 (19)	28 (29)	19 (29)	24 (49)	6 (25)	8 (53)	0 (0)	2 (67)	61 (62)
LOT	15 (15)	13 (13)	6 (9)	2 (4)	1 (4)	0 (0)	0 (0)	0 (0)	9 (9)
OP	52 (53)	42 (43)	28 (42)	19 (39)	10 (42)	6 (40)	1 (33)	1 (33)	25 (25)
ROT	13 (13)	10 (10)	7 (11)	2 (4)	3 (13)	1 (7)	2 (67)	0 (0)	4 (4)

Values are n (%)

The frequency and detailed distribution of the position of the fetal head at the first ultrasound examination, is shown in Figure 38. At the first examination the OP position was the most common position (52/99). The other positions were 19 OA, 15 LOT and 13 ROT.

Studying the individual rotation patterns, it could be seen that in most cases the occiput was either on the maternal left or right side throughout labor, but in six cases the occiput rotated over the 6 o'clock position.

The detailed distribution and frequency of positions of the fetal head at the last ultrasound examination before birth, is shown in Figure 39. At this examination the OA position was most frequent (61/99), nine were in the LOT position, 25 in OP and four in the ROT position.

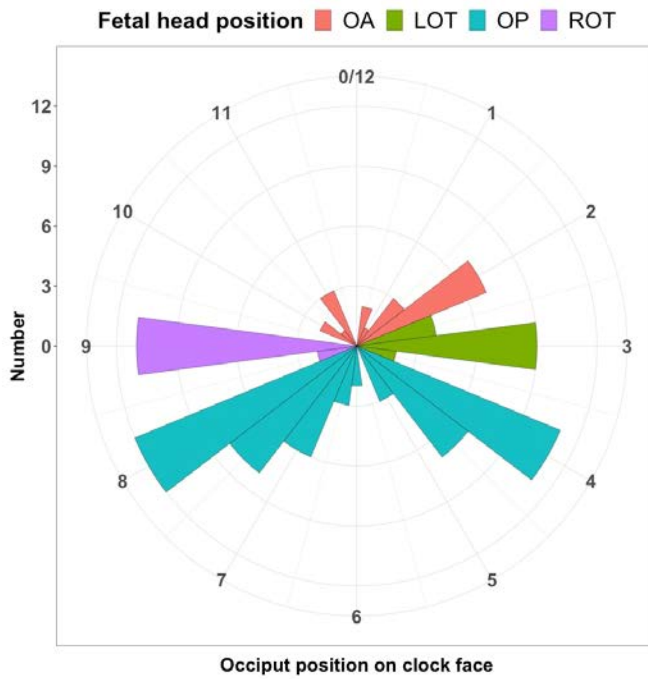

Figure 38. Fetal head position at the first examination.(Hjartardottir et al., 2020)

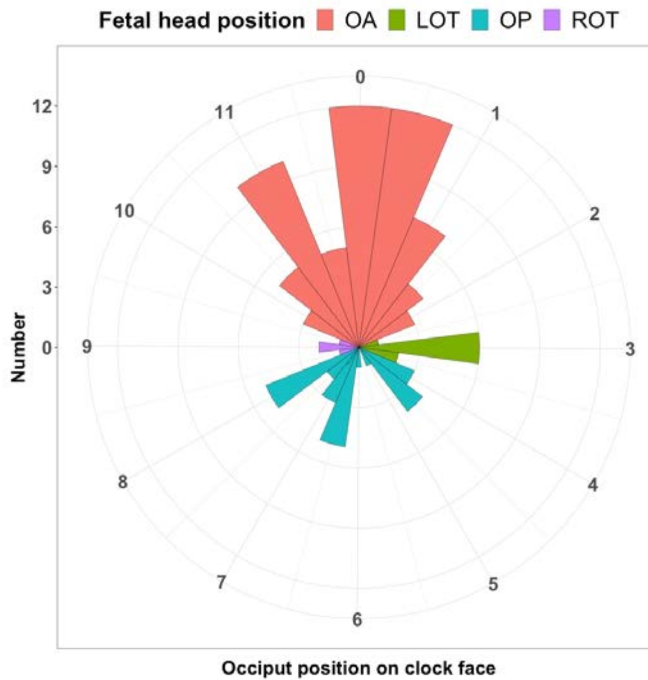

Figure 39. Fetal head position at the last examination.(Hjartardottir et al., 2020)

4.3.2 Occiput position at birth

At birth all the fetuses who were in an OA position at the first examination delivered OA, 26 of the 28 OT positions (93%; 95% CI: 75-99%) rotated to OA, the remaining two who were ROT positions were OP at delivery. Of the initial 52 OP positions 40 delivered OA (77%; 95% CI: 63-87%). All the 61 OA fetuses and all 13 fetuses in the LOT position at the last examination were delivered OA. Two of the four ROT positions and 12 of the 25 OP positions, at the last examination, were delivered OA.

All the six cases seen to rotate over the 6 o'clock position ended as spontaneous OA deliveries (rotating through >180°). Two rotated from the left side to the right (initially at 3.5 and 4.0 o´clock) and four from right to left (initially at 6.5, 7.0, 8.0 and 9.0 o´clock positions).

4.3.3 Occiput position and caesarean section

Of the eight fetuses delivered with cesarean section, six were in the OP position at the first examination, one was OA and one ROT. At the last examination before the operation the six starting as OP were still in that position, the one starting as ROT had rotated to OP, and the one starting OA was still in an OA position.

4.3.4 Direct occiput posterior position and mode of delivery

Of the fourteen fetuses who were in a direct or almost direct OP position (from 5 to 7 o'clock) at inclusion, 14 (71%; 95% CI: 42-90%) rotated to the OA position at delivery. The mode of delivery for these fourteen fetuses was eleven spontaneous deliveries (11/14, 79%; 95% CI: 49-94%), two instrumental deliveries (one OA and one OP at delivery) and one cesarean section (OP at delivery).

4.3.5 Oxytocin augmentation and occiput position at delivery

Eight of the 41 women needing oxytocin augmentation delivered a fetus in the OP position compared to 6/58 who did not (p=0.25).

4.3.6 Occiput position and fetal head station

In Table 7 the ultrasound measurements of HPD and AoP at the first and last examinations, according to the occiput position at inclusion are shown.

Table 7. Ultrasound measured fetal head station at the first and last examination according to fetal head position at first examination(Hjartardottir et al., 2020)

	OA (n=19)	LOT (n=15)	OP (n=52)	ROT (n=13)	*p* value
First examination					
AoP (°)	107 (82-123)	98 (87-117)	98 (73-128)	103 (88-114)	*0.023*
HPD (mm)	40 (24-56)	43 (37-56)	46 (29-66)	44 (31-54)	*0.049*
Last examination					
AoP (°)	128 (95-161)	110 (98-124)	106 (76-142)	116 (106-138)	*<0.0001*
HPD (mm)	27 (9-49)	40 (21-51)	41 (20-62)	33 (26-39)	*<0.0001*

Values are median (range)

There was an association between OA position at inclusion and lower stations (shorter head-perineum distance and wider angle of progression), both at the first and last examination. Table 8 shows the frequencies of the four different positions at four HPD measurement categories, and Table 9 the fetal positions at four different AoP categories.

Table 8. Fetal position at four categories of HPD(Hjartardottir et al., 2020)

	≤30 mm (n=57)	**31-40 mm (n=112)**	**41-50 mm (n=116)**	**>50 mm (n=51)**
Occiput position				
OA	43 (75)	41 (37)	19 (16)	2 (4)
LOT	2 (4)	11 (10)	18 (16)	6 (12)
OP	10 (18)	49 (44)	64 (55)	33 (65)
ROT	2 (4)	11 (10)	15 (13)	10 (20)

Values are n (%)

Table 9. Fetal position at four categories of AoP(Hjartardottir et al., 2020)

	<95° (n=68)	**95-109° (n=129)**	**110-124° (n=95)**	**≥125° (n=45)**
Occiput position				
OA	4 (6)	27 (21)	39 (41)	33 (73)
LOT	10 (15)	17 (13)	10 (11)	0 (0)
OP	46 (68)	67 (52)	37 (39)	9 (20)
ROT	8 (12)	18 (14)	9 (10)	3 (7)

Values are n (%)

When the fetal head had reached an HPD measurement of ≤ 30 mm or an AoP measurement of ≥125° (the level corresponding to clinical station +1 or lower) the occiput was anterior in 75% and 73% of women, respectively. Figures 40 and 41 show graphically the associations between fetal head station, occiput position and time to delivery at each ultrasound examination. The OA position did not become predominant until two hours before birth.

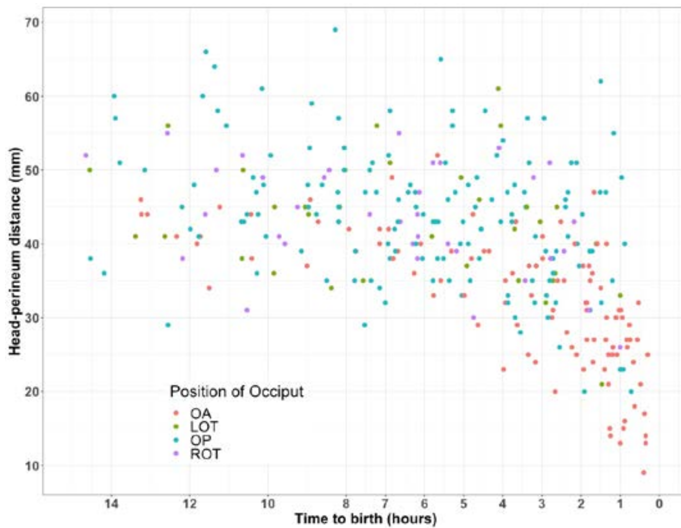

Figure 40. Fetal head station (head-perineum distance) and position assessed with ultrasound in relation to time to delivery.(Hjartardottir et al., 2020)

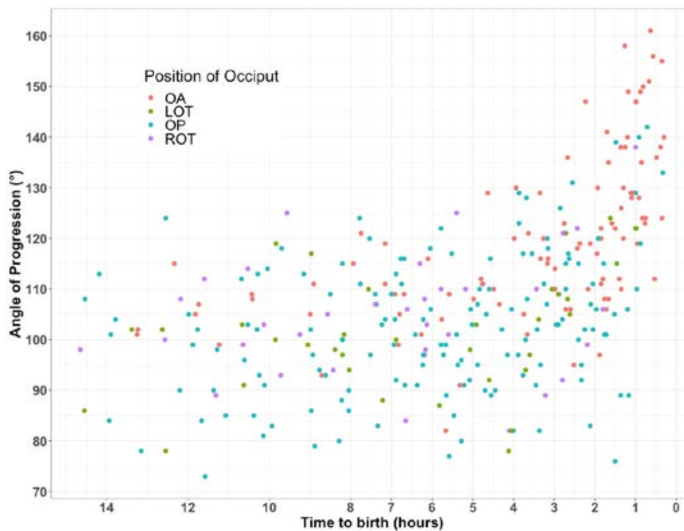

Figure 41. Fetal head station (angle of progression) and position assessed with ultrasound in relation to time to delivery.(Hjartardottir et al., 2020)

4.3.7 Occiput position and cervical dilatation

The frequency of the four different fetal head positions at each cm of clinically assessed cervical dilatation, is shown in **Figure 42**. The frequency of occiput posterior positions was >50% before full dilatation. When the position was assessed after women reached the second stage, the position was anterior in 53/80 (66%).

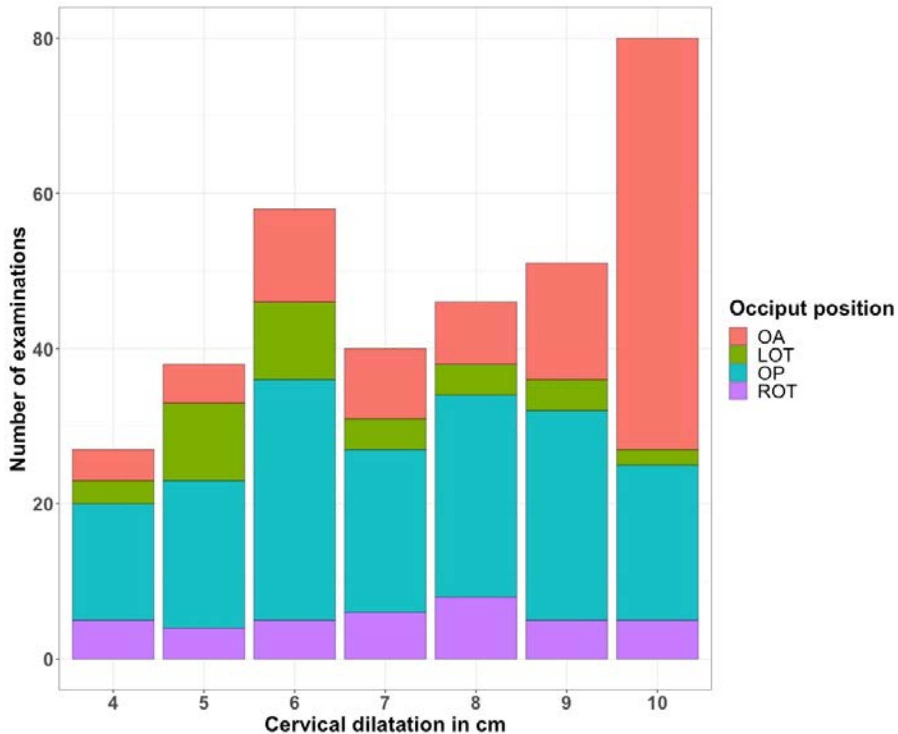

Figure 42. Fetal head position assessed with ultrasound in relation to clinically assessed cervical dilatation.(Hjartardottir et al., 2020)

4.3.8 Clinical assessment of fetal head position

At the time of the first paired examination the fetal head position could only be assessed clinically in 31/99 cases, and only 14 (45%, 95%CI: 28-89%) of these agreed with the ultrasound examination. At the last paired examination, the fetal head position could be defined clinically in 61/99, and 52 (85%, 95%CI: 73-93%) of these assessments agreed with the ultrasound assessed position.

4.4 Paper III

4.4.1 Prediction of spontaneous delivery

40/47 women with a fetus in a non-OP position at inclusion delivered spontaneously, compared with 35/52 women with a fetus in an OP position (*p*=0.06). The ROC curve analyses for the associations between HPD and AoP at inclusion in prediction of a spontaneous delivery are shown in **Figure 43**. HPD predicted spontaneous delivery with AUC=0.68 (95% CI: 0.55 to 0.80) and AoP with AUC=0.67 (95% CI: 0.55 to 0.80). The best cut-off level for predicting spontaneous delivery was HPD of ≤45mm and AoP of ≥93°. These levels were also used for stratification into groups for comparison of labor duration.Ultrasound measurement of cervical dilatation at inclusion could not predict a spontaneous delivery, with an AUC of 0.50 (95% CI: 0.38-0.63).

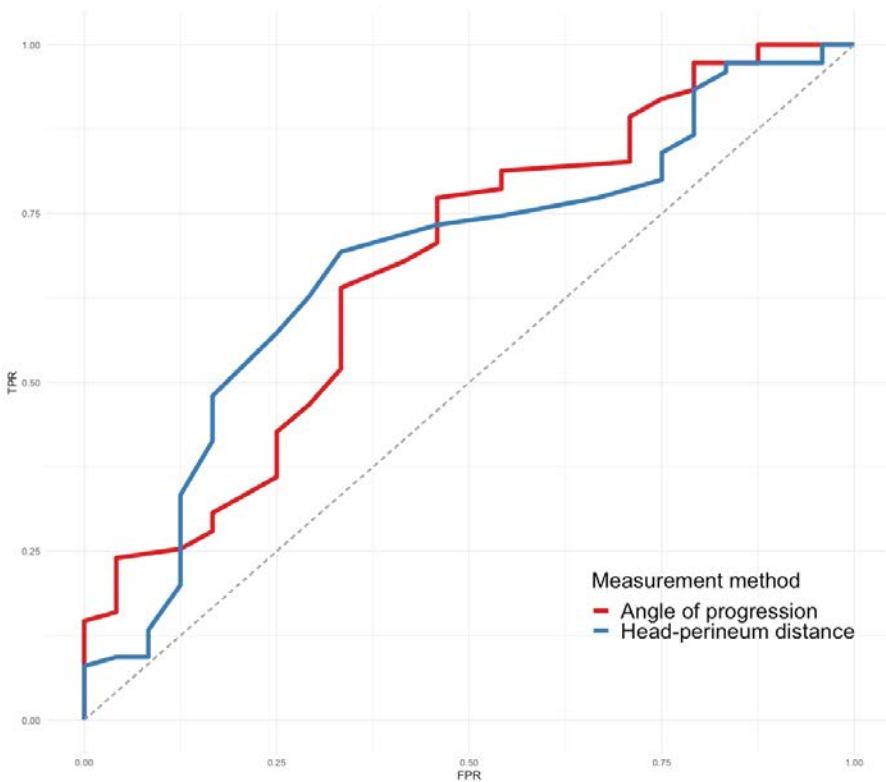

Figure 43. Receiver-operating characteristic (ROC) curves for angle of progression and head-perineum distance measurements, in the prediction of spontaneous vaginal delivery in nulliparous women on admission in active spontaneous labor at term.

The test characteristics of ultrasound measurements in predicting spontaneous delivery are presented in Table 10.

Table 10. Test characteristics of ultrasound measurements of head-perineum distance and angle of progression in predicting spontaneous vaginal delivery

	Sensitivity	Specificity	FPR	PPV	NPV	PLR	NLR
Head-perineum distance (mm)							
≤40	0.33 (0.23, 0.45)	0.88 (0.68, 0.97)	0.12 (0.03, 0.32)	0.89 (0.72, 0.98)	0.30 (0.19, 0.42)	2.67	0.76
≤45	0.67 (0.45, 0.84)	0.67 (0.45, 0.84)	0.33 (0.16, 0.55)	0.87 (0.75, 0.94)	0.41 (0.26, 0.58)	2.08	0.46
≤50	0.80 (0.69, 0.88)	0.25 (0.10, 0.47)	0.75 (0.53, 0.90)	0.77 (0.66, 0.86)	0.29 (0.11, 0.52)	1.07	0.80
≤60	0.97 (0.91, 1.00)	0.04 (0.00, 0.21)	0.95 (0.79, 1.00)	0.76 (0.66, 0.84)	0.33 (0.01, 0.91)	1.02	0.64
Angle of progression (°)							
≥110	0.24 (0.15, 0.35)	0.96 (0.79, 1.00)	0.04 (0.00, 0.21)	0.95 (0.74, 1.00)	0.29 (0.19, 0.40)	5.76	0.79
≥100	0.57 (0.45, 0.69)	0.67 (0.45, 0.84)	0.33 (0.16, 0.55)	0.84 (0.71, 0.93)	0.33 (0.20, 0.48)	1.72	0.64
≥93	0.79 (0.68, 0.87)	0.46 (0.26, 0.67)	0.54 (0.33, 0.74)	0.82 (0.71, 0.90)	0.41 (0.22, 0.61)	1.45	0.47
≥90	0.87 (0.77, 0.93)	0.29 (0.13, 0.51)	0.71 (0.49, 0.87)	0.79 (0.69, 0.87)	0.41 (0.18, 0.67)	1.22	0.46
≥80	1.00 (0.95, 1.00)	0.12 (0.03, 0.32)	0.88 (0.68, 0.97)	0.78 (0.69, 0.86)	1.00 (0.29, 1.00)	1.14	0.00

FPR, false-postitive rate; PPV, positive predictive value; NPV, negative predictive value; PLR, positive likelihood ratio; NLR, negative likelihood ratio

4.4.2 Duration of labor

At inclusion, fetal station expressed as ultrasound measured HPD was ≤45 mm in 60 women and >45 mm in 39. The estimated median time in active labor when HPD was ≤45 mm was 490 minutes vs. 682 min if the HPD >45 mm (log rank test, p=0.009), illustrated with Kaplan-Meier curves (1-survival) in **Figure 44**.

The HR for a spontaneous vaginal delivery showed a shorter duration associated with a smaller HPD (HR=1.90 (95%CI, 1.16 to 3.11)), but the association was not significant after adjusting for maternal age and BMI (HR =1.47, 95% CI, 0.83-2.60). (**Table 11**)

Fetal station expressed as AoP was ≥93° in 69 women and <93° in 30 women. The estimated median time in active labor was 506 min in the former vs. 732 min in the latter group (log rank test, p=0.008) shown in **Figure 45**. The HR for a spontaneous delivery associated with wider AoP values was 2.06 (95% CI, 1.19 to 3.56) and remained significant after adjusting for maternal age and BMI; HR 2.07 (95% CI, 1.15 to 3.72).

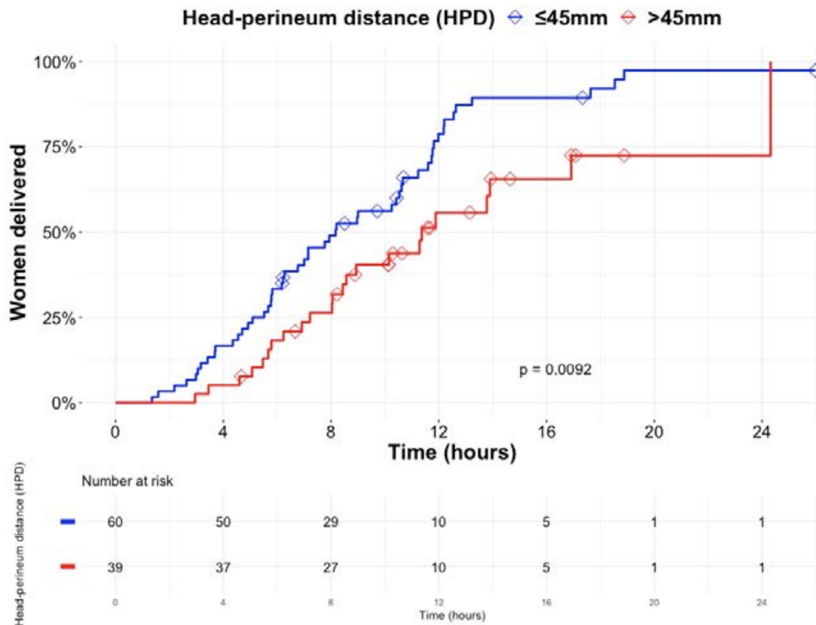

Figure 44. Kaplan-Meier curves of time from the first examination in the active phase to delivery. The curves are stratified as to head-perineum distance ≤45mm and >45mm. Cases with operative delivery were censored (diamonds on survival lines).

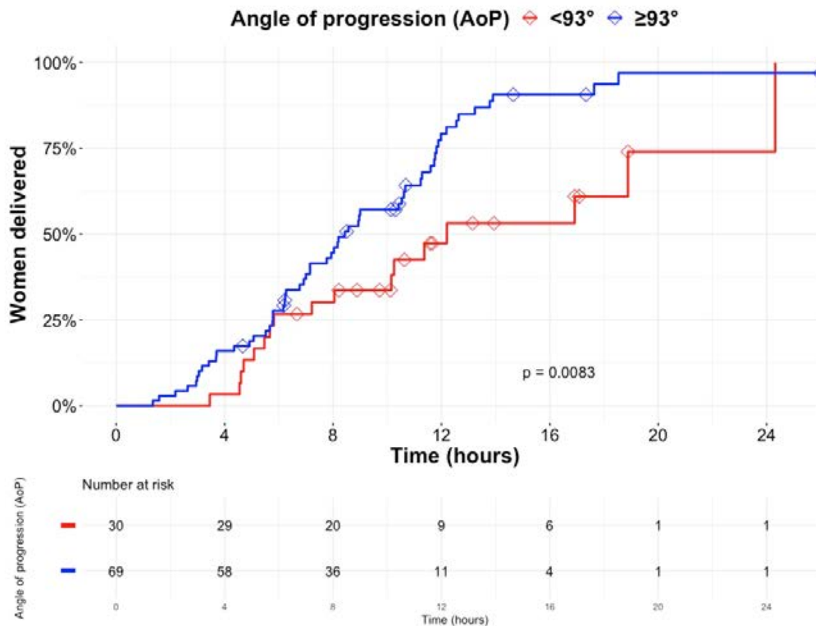

Figure 45. Kaplan-Meier curves of time from the first examination in the active phase to delivery. The curves are stratified as to angle of progression <93°and ≥93°. Cases with operative delivery were censored (diamonds on survival lines).

Of the fetuses 52/99 were in the OP position at inclusion. The estimated median time in active labor was not significantly associated with fetal position at inclusion, 506 min in non-OP positions vs. 677 min in OP positions (log rank test, *p*=0.07) illustrated as a Kaplan-Meier plot (1-survival) in **Figure 46**. The HR for a spontaneous delivery associated with non-OP positions was 1.51 (95% CI: 0.96 to 2.38), and it did not change after adjusting for maternal age and BMI; HR 1.54 (95% CI: 0.97 to 2.46).

Ultrasound assessment of cervical dilatation showed that 64 women had dilatation of 4-5 cm, 23 women were dilated ≥6 cm and in 12 women dilatation could not be measured. The estimated median duration of active labor was 429 min for dilatation of ≥6 cm and 704 for dilatation of 4-5 cm (log rank test, *p*=0.002), as illustrated in a Kaplan-Meier plot (1-survival) in **Figure 47**. The HR for spontaneous delivery associated with greater dilatation was 2.45 (95% CI, 1.38-4.36), and this was significant after adjusting for maternal age and BMI; HR 3.11 (95% CI, 1.68-5.77).

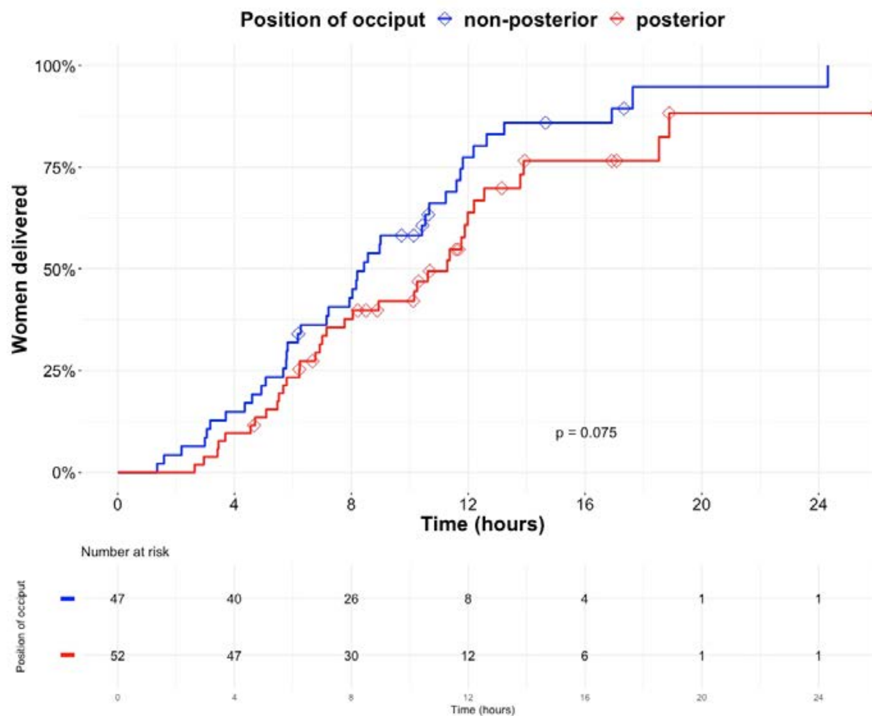

Figure 46. Kaplan-Meier curves of time from the first examination in the active phase to delivery. The curves are stratified as to non-occiput posterior and occiput posterior positions. Cases with operative delivery were censored (diamonds on survival lines).

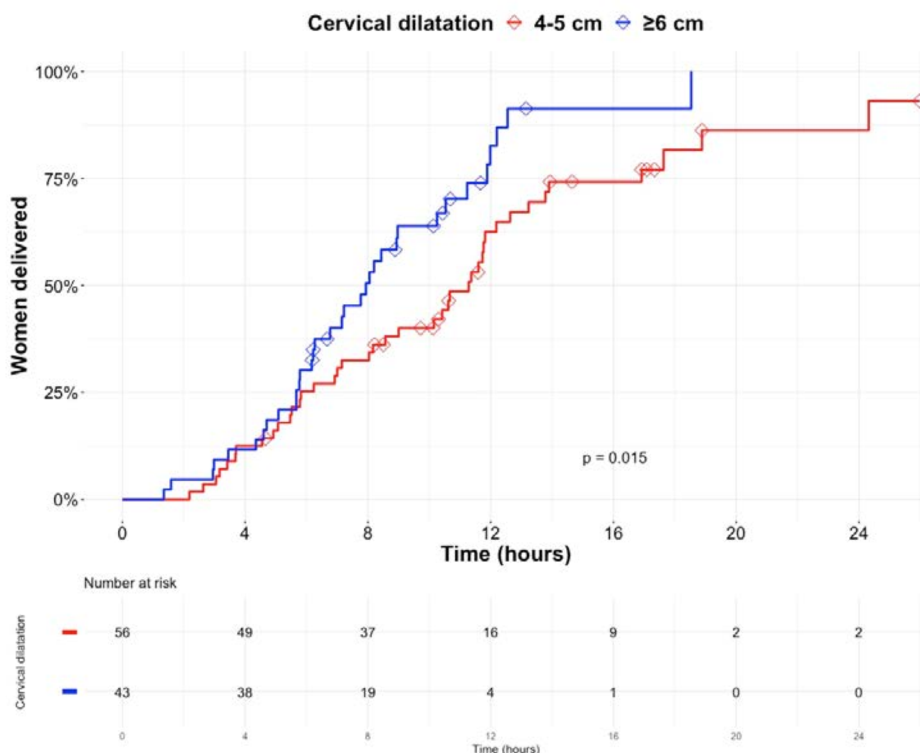

Figure 47. Kaplan-Meier curves of time from the first examination in the active phase to delivery. The curves are stratified as to ultrasound assessed cervical dilatation of 4-5 cm and ≥6 cm. Cases with operative delivery were censored (diamonds on survival lines).

4.4.3 Duration of the second stage

The estimated median duration of the second stage was 92 minutes if HPD was ≤45 mm at inclusion vs. 109 minutes if HPD was >45 mm (p=0.06). The HR for a spontaneous delivery related to smaller HPD values was 1.61 (95%CI, 0.97 to 2.64), and the association was not significant after adjusting for maternal age and BMI (HR =1.50, 95% CI, 0.85-2.65). The estimated median duration of the second stage was 93 minutes if the AoP was ≥93 degrees mm at inclusion vs. 124 minutes if AoP was <93 degrees (p=0.04). For larger AoP values the HR for spontaneous delivery was 1.76 (95% CI, 1.02 to 3.04) and 1.59 (95% CI, 0.88 to 2.88) after adjusting for maternal age and BMI (**Table 11**).

Occiput position and cervical dilatation at inclusion were not associated with the estimated durations of the second stage.

Table 11. Cox regression analysis for risk ("likelihood") of a spontaneous delivery in nulliparous women, examined at the diagnosis of the active phase of labor.

Parameter	Unadjusted HR	95% CI	Adjusted HR	95% CI
Active phase				
Non-occiput posterior	1.51	0.96-2.38	1.54	0.97-2.46
HPD ≤45 mm	1.90	1.16-3.11	1.47	0.83-2.60
AoP ≥93°	2.06	1.19-3.56	2.07	1.15-3.72
Cervical dilatation examined with ultrasound ≥ 6 cm	2.45	1.38-4.36	3.11	1.68-5.77
Second stage				
Non-occiput posterior	1.40	0.89-2.21	1.43	0.89-2.29
HPD ≤45 mm	1.61	0.97-2.64	1.50	0.85-2.65
AoP ≥93°	1.76	1.02-3.04	1.59	0.88-2.88
Cervical dilatation examined with ultrasound ≥ 6 cm	1.57	0.91-2.70	1.76	0.98-3.16
Active second stage				
Non-occiput posterior	1.45	0.92-2.28	1.54	0.97-2.46
HPD ≤45 mm	1.55	0.94-2.55	1.52	0.87-2.65
AoP ≥93°	1.86	1.05-3.32	1.97	1.06-3.68
Cervical dilatation examined with ultrasound ≥ 6 cm	1.43	0.83-2.47	1.50	0.84-2.68

HR with CI not crossing 1.0 were assumed significant
CI, confidence interval; HR, hazard ratio; HPD, head-perineum distance; AoP, angle of progression

The estimated median duration of the active second stage was 62 min if AoP was ≥93 degrees at inclusion vs. 75 min if AoP was <93 degrees (p=0.03). For larger AoP values the HR for spontaneous delivery was 1.86 (95% CI, 1.05 to 3.32) and after adjusting for age and BMI it was 1.97 (95% CI 1.06 to 3.68). None of the other parameters examined were associated with the estimated duration of active pushing (**Table 11**).

4.5 Paper IV

4.5.1 Study group characteristics

We recruited 44 women, but in four the interval between the examinations was more than 30 minutes so these examinations were excluded, leaving 40 examinations to be analyzed. The mean maternal age was 30 years, mean BMI was 26 kg/m^2, 28 (70%) were nulliparous and 19 (48%) had an epidural analgesia. The cervical dilatation was <4 cm in 10 women, 4-6 cm in 15, 7-9 cm in nine women, and there was full dilatation in six women. In 23 women the Voluson *i* device was the first equipment to be tested and in 17 women it was

the Philips VISIQ system. The median time between the start of examinations with each of the equipment was 10 minutes (range 1 to 26 min).See Paper IV.(Benediktsdottir et al., 2018)

4.5.2 Intra-observer reproducibility

The intra-observer variance was similar over the range of values measured. The mean HPD measurement for the pooled values (n=80) was 40.1, the median 40 (range 13-59), the ICC was 0.97 (95% CI 0.95-0.98) and the repeatability coefficient was 4.3 mm. For three examiners who had sufficient numbers of examinations (40, 18, and 16 examinations) that allowed intra-observer ICC to be tested, this was 0.97 (95% CI 0.96-0.99), 0.87 (95% CI 0.75-0.95) and 0.99 (95% CI 0.97 and 0.995) respectively.

4.5.3 Inter-device reproducibility

The combined inter-observer and inter-device agreement had an ICC of 0.86 (95% CI 0.74-0.93) with limits of agreement of -9.6 to 16.6 mm. There was a significant mean difference between the two devices of 3.5 mm (95% CI 1.4-5.7 mm). This difference did not vary in any systematic way over the range of values measured. There was a small tendency to shorter measurements from the first to the third measurement.

4.5.4 Clinical and ultrasound assessments compared

The correlation between the clinical assessments and the mean HPD was significant ($p < 0.01$, $r = 0.64$).

4.5.5 Visual analog score

The mean discomfort VAS score for the Voluson *i* device was 1.6 (median 1.0), for the Philips VISIQ the mean score was 2.4 (median 1.5), and for the clinical examination the mean was 4.1 (median 4.0) The combined mean VAS from both ultrasound devices was compared with the mean VAS score from the clinical examination, and there was a significant association with the lower pain score from the ultrasound examination ($p < 0.01$).

5 Discussion

5.1 Principal findings

In Papers I and II head descent and rotation in nulliparous women in spontaneous labor was described. Labor patterns, based on HPD and AoP measurements, were created and how they relate to cervical dilatation patterns and time remaining to delivery. Fetal head position was documented and how and when rotation occurs was described.

In Paper III ultrasound on admission to assess fetal head station and cervical dilatation showed an association with duration of labor, but assessment of occiput position did not. The assessments of fetal head station were the only parameters associated with operative deliveries.

In Paper IV excellent repeatability of HPD measurements was found and a good combined inter-observer and inter-device agreement. The limits of agreement were acceptable, but a 3.5 mm shorter HPD measurement was associated with using the Philips VISIQ compared with the Voluson *i.*

5.2 Descent patterns

Similar methods were used to create average descent and dilatation curves as described in recent studies on labor progression, which have applied polynomial regression backwards from a point 0.(Graseck et al., 2014; Inde et al., 2018; Shi et al., 2016; Suzuki et al., 2010; Zhang et al., 2010a) Most of these studies have used the time of diagnosis of full dilatation as point 0 but Graseck et al. who studied descent used the time when the fetal head reached +3 station as zero.(2014) As we wanted to study both the active first stage and the second stage, it was decided to use delivery as point 0. Using higher order polynomial models has been criticized by Cohen and Friedman, as it may smooth out subtle data trends.{Cohen, 2015 #204} All the figures were constructed using both 3rd and 4th degree polynomial models, and this did not change the overall patterns. Using 3rd degree models resulted in a degree of underfitting, and the 4th degree models demonstrated, in a better way, the fetal head descent towards the end of labor. Fourth degree polynomial regression was used, as it was found to be the best fit for the data.

In many ways there was good agreement with previous studies on clinical estimation of descent in labor, but there were important differences. A similar

static or very slow descent in the early active phase of labor, and then rapid descent towards the end, was demonstrated. The major difference compared to the studies of Friedman and Sachtleben(1965a, 1965b, 1965c, 1970), is that in their studies the rapid descent phase, when related to dilatation, seemed to start at around 4 cm dilatation, whereas in our study it started at around 8 cm dilatation. On the other hand, the descent phase duration seems to be similar, in that when this rapid phase starts it seems to result in delivery around 4 hours later.

In the clinical studies of both Graseck et al. and Zhang et al. the descent pattern was more gradual in onset.(2014; 2002) As the slope of the descent is more gradual, it is more difficult to see when the descent phase starts, in order to relate it to the time to delivery.

The other difference from the studies of Friedman is that we found that the fetal head was on average above the spinal plane throughout most of the active phase, or until 9 cm dilatation, whereas in his studies it had descended below the spinal plane when the active phase was diagnosed. The results of the more recent studies are in this respect more similar, in that the fetal head was not seen to descend below the spines until at 7 to 8 cm dilatation in the study of Zhang et al. and at 9 cm dilatation in the study of Graseck et al.

The reason for differences in descent patterns may be due to one or several factors. One factor is the study group, which was different in the study of Graseck et al. who presented the results of nulliparous women in both spontaneous and induced labors. Another factor that could influence the patterns is the inclusion criteria and exclusions. In the above-named studies many women were followed from an earlier stage of labor, and women were excluded when in advanced labor. Other investigators have studied the progress of labor including women with advanced dilatation.(Hendricks et al., 1970; Philpott & Castle, 1972a) Different definitions were also used to determine the beginning of the active phase (see section 1.5.3). As the labor curves were constructed based on the time of delivery, and then calculated backwards to the point of admission or inclusion, becomes less important than the actual progress during the last hours of labor. The almost identical shape of the descent curves for women included at ≥ 6cm dilatation vs. those with 4-5 cm, suggests that the descent phase is similar whether women are included in early labor or later, although the total duration of labor is different.

Differences in when descent occurs, may also be due to changes in maternal factors. Women studied 60-70 years ago had mostly normal BMI and were younger than the cohort we studied. A recent study by Hung et al.

suggests that the second stage of labor is longer now than it was only 25 years ago.(2015) This difference was found both in the median duration but even more pronounced in the upper 95th percentile of duration for women with a normal outcome.

Another important difference found, compared with previous studies of fetal station, is the higher initial head station. It is possible that this is a real finding, and that the changes mentioned above in the laboring population could be an explanation to this. On the other hand, it may be due to the different methodology of measurement of station. In view of the inconsistencies and problems associated with clinical assessments of station, discussed in the introductory chapter 1.6, it is likely that the ultrasound methods used in the studies presented in this thesis, better represent the true station than the results from clinical studies. Although ultrasound methods are not without inaccuracies, as demonstrated in Paper IV, very large margins of error have been demonstrated when clinical methods are tested.(Dupuis et al., 2005c) Comparing the clinical and ultrasound methods, correlation was found between the two methods (see 4.1.3 and Figure 29) but a very large spread of ultrasound measurement for each step of clinical station assessment. The correlation seemed no longer present at station +1 and +2 where HPD measurements were not seen to change, and AoP measurements increased at +2 cm. This could possibly be due to a small number of clinical estimates at these steps of station (only 7 measurements for each step), but it could also be due to the presence of caput which increases as the head descends, making estimation of station more difficult and inaccurate. It is questionable whether digital methods of assessment of station are accurate enough for modern obstetric practice, and it might be time now to abandon them in preference to more objective methods, at least where ultrasound equipment is readily available. Certainly, more objective methods would be important when judging slow progress towards the end of the first stage, or during the second stage, as secondary arrest of dilatation and failure to descend are signals of labor difficulties and possible risks to the mother and baby. Recent studies suggest that the second stage of labor may take longer than previously thought, and that it is safe to reconsider these time limits.(Gimovsky & Berghella, 2016; Hung et al., 2015) Having reliable and objective measurements of descent would be an invaluable tool in studying and following the second stage of labor, when progress can no longer be judged by changes in cervical dilatation.

5.3 Position and timing of rotation

The aim was to describe the occiput positions prospectively and how and when rotation occurred. The results differed from many previous studies, in that the posterior position was found to be more frequent than previously thought, the most frequent positions found at 4 and 8 o´clock. The majority of fetuses were in occiput posterior positions during most of the active phase and not transverse or anterior. The reasons for this may in part be due to differences in definition, but in part due to the more reliable results that the use of ultrasound offers.

A very fine gradation of results was used, i.e. half hourly markings on a clock face. The position was then defined according to Akmal et al., which divides the circle into unequal wedges.(2004a) (Figure 22) This gives a strict definition of transverse positions, as only those in which the fetal head is at 3 or 9 o‘clock with each half hour anteriorly and posteriorly being grouped as transverse. In turn all positions anterior to 9:30 to 2:30 are grouped as anterior, and all positions posterior to 3:30 and 8:30 are grouped as posterior. As discussed in the introductory chapter 1.5.5, these definitions have been discussed for hundreds of years and will probably continue to be debated. What is important is to describe the positions as accurately as possible, if they are to be used as any measure of progress. We used both transabdominal and transperineal methods to improve accuracy. Both methods give reliable results but differ in terms of their applicability depending on the depth of fetal head engagement. It was decided to use the TA method for determination if both results were available and there was non-agreement. It was discussed whether to use the TP method as the preferred one, but as the examiners were trained in fetal medicine with many years of experience in transabdominal scanning, it was felt it would be a very reliable method. When the transabdominal view was not sufficiently clear, no results were noted. In these cases, the transperineal view could always define the position.

The results confirmed the findings of previous studies showing the unreliable nature of clinical estimations of position. At inclusion this was very poor, but improved as labor progressed. At best, it agreed with ultrasound in half of cases at the last examination. This suggests that there must be an error of estimation of position in all the existing studies reporting clinical assessments of position. Knowledge on position in labor has been based on the x-ray studies of Caldwell and Steele & Javert from the 1930'ies (described in chapter 1.5.5), and we expected our results to be similar. However, they reported more transverse positions and anterior positions than we do now. This

can be explained by different definitions of position, but also difficulties described in determining the exact position when it was not directly transverse or antero-posterior. It is also not clear, exactly at which stage in labor most of the x-rays were performed, and this can of course change the results.

With the objective observations and precise description of fetal head position, a pattern of engagement and rotation can be suggested and explained in the following way: Before labor the fetal head is usually in a transverse position. When the head flexes and descends further into the pelvis, the best available diameter is slightly oblique and posterior to the transverse plane due to the protrusion of the promontorium, and less resistance slightly lateral to each side of the sacrum. When reaching the ischial spines, which are situated posterior to the midline of the birth canal, the head begins to rotate as the least resistance is then offered anterior to the ischial spines. The pelvic floor acts as a sling, pushing against which the fetal head glides to the widest antero-posterior outlet of the birth canal.

The obstetricians practicing in the 19th century also suggested that the fetal head was best accommodated in the oblique diameters of the pelvis on either side of the sacral promontory during engagement and descent, and not the transverse ones.(Scanzoni, 1867; Spiegelberg, 1878).

The data presented in this thesis demonstrates that rotation from the most frequent occiput posterior position does not occur until below the spinal plane, and at full dilatation in nulliparous labors. It is difficult to know which part of this process comes first, descent or rotation, but it is likely that both occur simultaneously. Furthermore, no difference was observed in the descent patterns when the fetal head was in the occiput posterior or transverse position, in women who delivered spontaneously. A higher fetal head station during the active phase was found compared with anterior positions, but there was a very similar pattern of rapid descent towards the end of labor. This needs to be considered and emphasized when discussing occiput posterior positions and the risks that are commonly associated with them. When labor is in the early stages and progress is normal, the fetal head position is of little importance and posterior position should not give cause for concern. Interestingly, our findings agree best with the frequencies of position and description of rotation from the clinical studies of Calkins et al.(1939b) His description of rotation, is the only description found of the timing of internal rotation and the level at which it occurs in nulliparous women.(Eastman, 1950) He also warned against undue worry regarding occiput posterior positions, which he found to be a normal phase in internal rotation during labor. It is only when there is lack of

descent where the position of the occiput becomes important. We do not know whether the lack of descent is due to the position or vice versa, that the head does not rotate due to lack of descent, but the final result is failure to progress normally during the late first stage or second stage of labor. It is important to take note of these findings of normal labors reported in our studies, that occiput posterior should not be taken as a negative sign in labor, unless other signs of delayed progress, especially during the second stage, become apparent. Having ultrasound equipment available bedside, leading to the easy diagnosis of OP position during the first stage, might lead to unnecessary intervention if this is not recognized.

No fetuses in the OA position were seen to malrotate to an OT or OP position, agreeing with other studies that in most cases the OP position at birth is due to failure to rotate from an OP position, or more rarely rotation to OP from an OT position,(Adam et al., 2014; Souka et al., 2003) and cannot confirm the findings of Gardberg et al. that an OP position at birth is due to a malrotation from an OA position. It was of interest to observe that in 6 cases rotation was through more than 180° from an original OT or OP position across the 6 o´clock position to the other side of the pelvis, ending in an OA position. All of these labors ended with spontaneous deliveries. No prior reports of this degree of rotation could be found.

5.4 Predicting outcome on admission

The population studied was too small to draw strong conclusions regarding delivery mode. However, it does give some ideas on which to base further studies of the use of ultrasound to predict outcome. The duration of labor stages estimated with the methods of survival analysis, suggest an association with fetal head station measured with ultrasound at diagnosis of the active phase. This was more pronounced when AoP was used to measure station. The unadjusted HPD results were significant but the significance disappeared after adjusting for age and BMI. This might be due to an influence of BMI in the method of measuring HPD, where the soft tissue of the perineum might be of different thickness in women with higher BMI. Torkildsen et al. in his study on using HPD and AoP to predict delivery mode in women with prolonged first stage of labor, found a non-significantly larger HPD measurement in women with high BMI but also associated with a smaller AoP.(2011) Using survival analysis, they predicted vaginal delivery with both methods in women with both high and low BMI.

The effects of the fetal head station at inclusion are also reflected in the second stage duration. After correcting for age and BMI, AoP ≥93° was associated with a shorter duration of the total time remaining in labor and of both the total and the active second stage, reflected in significantly increased likelihood of spontaneous delivery compared with narrower angles.

The duration of labor phases was not affected by the posterior position of the fetal head on inclusion, and this agrees with the observations of the descent patterns when stratified according to occiput position.

As could be expected the duration of time remaining in labor was associated with cervical dilatation on admission, but no association was found in the length of the second stage and knowing the dilatation on admission was not predictive of spontaneous delivery.

Although associations between factors measurable with ultrasound and labor outcomes were found, they are not specific enough to use on their own for prediction of mode of delivery. The ROC curve analysis with an AUC of 0.67-0.68 in prediction of spontaneous delivery, may be useful in selecting a group with low risk of operative delivery who may benefit from reassurance and be offered a low risk labor environment. Larger groups of women need to be studied to examine the association between fetal head station and cesarean delivery, as care needs to be taken in not making assumptions based on such low numbers as were the case in this cohort. It may also be of greater value to assess the change between two examinations or over a given time during labor, as has been suggested and studied by others.(Souka et al., 2003; Wilkes et al., 2003)

5.5 Patterns of cervical dilatation

Clinically assessed cervical dilatation patterns were used to construct labor curves. Both the overall dilatation curve and the curve for only those delivering spontaneously were very similar to the curves obtained in recent studies(Ferrazzi et al., 2015; Inde et al., 2018; Oladapo et al., 2018; Shi et al., 2016; Suzuki et al., 2010; Zhang et al., 2010a), and the S shape of the curve found by Friedman was not demonstrated. This may well be due to different methodologies used in their construction as discussed in chapter 5.2. However, specifically using 2nd, 3rd or 4th degree models to plot the curves for cervical dilatation against time, did not show any difference in the shape of the curve. The S shape can be observed in the dilatation curves in the cases ending with instrumental deliveries or cesarean section. It is possible that due to changes in obstetric practice since the 1950'ies, this cannot be seen any

more in dilatation curves for women delivering spontaneously. Interventions in the group of women with slower labors towards the end of the first stage, may now lead to cesarean deliveries. In the first cohort of Friedman et al. there was only one cesarean section out of 100 cases.(1954) All other investigators both nearer in time to Friedman(Hendricks et al., 1970; Philpott & Castle, 1972a) and more recent ones(Inde et al., 2018; Shi et al., 2016; Suzuki et al., 2010; Zhang et al., 2010a), have found an average labor curve which shows constant acceleration, or more hyperbolic in form, and have not been able to demonstrate the S shape. The stage of labor at which observations begin can also be the cause of different shapes of the curve. We decided to include women admitted to labor with more advanced dilatation, whereas Friedman et al. wanted to begin their observations earlier in their labors. This may have excluded women destined to have a different progress and may well be reflected in the different shape of the labor curves.

There was a large variation in individual cervical dilatation curves (see Supplemental Figure 1 in Paper I). This finding was stressed in the study by Ferrazzi et al., who studied an "ideal" group of women who were of normal weight, healthy and labored without any intervention or epidural.(2015) They could not find that the rate of cervical dilatation at different stages of labor were predictive of this rate at a later stage, stressing the unpredictability of labor progress. They question the obstetric practice of trying to fit laboring women into an average mold with few treatment options, other than oxytocin stimulation and membrane rupture when progress is outside the accepted limits. They point out the need for further studies into the causes for variations in progress and when duration of labor becomes abnormal. Such studies should focus on maternal and feto-placental hormonal and metabolic factors as well as mechanical uterine, pelvic and fetal factors.

We did not find a linear association between cervical dilatation and fetal head station, as suggested in the clinical study of descent in labor by Hamilton et al.(2016), but found that a second-degree model had a significantly better fit. Hamilton et al. suggested that a mathematical formula based on their findings might be of value, in assessing whether descent was within the 95th percentile for a given dilatation. However, they discuss the subjective nature used to determine dilatation and station clinically, and that the newer ultrasound-based techniques may be more accurate and a different relationship might be revealed. Further studies of this association between dilatation and station are warranted, as it might be a useful parameter to assess labor progress.

5.6 Reproducibility and clinical applicability of head-perineum distance measurements

Before applying new methods, they need to be tested in settings resembling, as much as possible, the clinical settings they may be applied in and not only in research environments. There is always a risk that a method showing promise in research settings, tested by experts, proves to be less useful and accurate when taken into use by non-experts working in everyday clinical practice. The HPD measurement method was first described by Eggebø et al.,(2006) then further tested by his group and had shown low intra- and inter-observer variability.(Torkildsen et al., 2012; Tutschek et al., 2013) In this study the method was further tested for repeatability for both very experienced and novel ultrasound operators, and very low intra-observer variation was found. The pooled results had an ICC of 0.97 with individual ICCs varying from 0.87 to 0.99.

The combined inter-observer and inter-device agreement with a different ultrasound equipment than previously described was good with an ICC of 0.86. The results reflected both a factor of inter-observer and inter-device variation which may amplify the measurement error. The reproducibility was similar to the results from the previous studies mentioned above.(2006; 2012) However, there was a systematic bias observed, where a significantly shorter HPD measurement by a mean of 3.5 mm was found when the Philips VISIQ was used compared to the Voluson *i,* and the limits of agreement were slightly wider than previous studies had shown. This shows that the method is prone to some error when used by different operators and equipment.

The difference between the two types of equipment could possibly be explained by the order of which the devices were tested, as the Voluson *i* was the first device more often than the Philips VISIQ, and a tendency to shorter measurements from the first to the third attempt was observed. As labor might be progressing between the measurements this could be reflected in these results. The other possibility for this difference might be the shape of the transducer. It is plausible that this is the case when viewing and using the different transducers, as the Philips VISIQ transducer is notably thinner. This may allow it to come closer to the fetal head when the perineal tissues are compressed. Supporting this latter explanation, in preference to the effect of labor progress, are the findings from Paper I, demonstrating that descent is a late event during the labor process. Most of the women had not reached the second stage when they were examined, so it is unlikely that the fetal head had begun to descend to any degree during the short time it took to test the

two devices. Examinations where >30 minutes passed between examinations with the two devices were also excluded, to minimize the effect of labor progress.

The wide limits of agreement and a difference of 3.5 mm could be of clinical significance in using HPD as a tool for measuring and monitoring fetal descent. This needs to be put into context with the clinical methods used today. The studies attempting to quantify the clinical measurement error suggest that it can be large. A clinical study by Bergsjø and Koss suggested that in over 10% of cases the difference between examiners can be 2 cm or more.(1982) Another study by Dupuis using a simulator found an error of at least 1 cm in estimating fetal head station in 36 to 88% of cases depending on station and experience.(2005c) A misdiagnosis of a mid to low station when in fact station was high, was found in 22% and 16% of examinations by residents and attending physicians respectively.

Studies attempting to compare ultrasound measurements to clinical assessments also suggest that there is a large variation in clinical assessments.(Tutschek et al., 2013; Yuce et al., 2015). Similar to the findings of Yuce et al. (see section 1.8.4) a large spread of HPD measurements was shown when the station was assessed clinically, as demonstrated in Figure 29, where at clinical station -1 the HPD was measured from 13 to 57 mm. Even with limits of agreement as wide as -9.6 to 16.6 mm, the HPD measurement is an improvement from the inaccurate clinical assessment.

The difference of 3.5 mm between equipment needs to be allowed for when applying smaller transducers, as it may create a false impression of a slightly lower station when decisions are being made to perform instrumental deliveries. As there are many other factors that need to be evaluated when a decision is made to perform an instrumental delivery or a caesarean section, this difference may not be crucial. Bearing in mind the usual practice to measure fetal head station clinically, with a much larger error involved, this simple measurement is likely to be an advantage in terms of the safety of the procedure.

When considering the clinical applicability of using HPD measurements to follow the individual woman´s labor progress, the reproducibility is probably of less concern as it is likely that the same equipment will be used throughout, and at least in part, by the same operator. For this purpose, it is encouraging that intra-observer variation is low and does not seem to depend on a high level of training.

No systematic difference in variation across the range of values measured could be demonstrated, which is important when considering that this measurement technique may well become common in all labor stages and before labor onset.

In addition to the above research findings, we have found the technique easy to learn and teach to both doctors and midwives. It is the preferred method to measure fetal head station for clinical staff, after they were introduced to intrapartum ultrasound in connection with these clinical studies.

The study shows similar results as other investigators have found, regarding the acceptability of the method for the women examined.(Alvarez-Colomo & Gobernado-Tejedor, 2016; Y. T. Chan et al., 2016; Rizzo et al., 2019; Seval et al., 2016; Usman et al., 2019; Wiafe et al., 2020) A very low pain score comparable to, at most, a mere discomfort, has been found by all investigators. This has also been the experience of all the operators using ultrasound in labor, that it is a much more easily tolerated procedure than the vaginal examinations. Having it confirmed in a scientific methodical way is important when the method is introduced or promoted to new users.

5.7 Strengths and limitations

5.7.1 Papers I-III

The strength of these studies is the prospective, longitudinal design and the well-defined group of women examined. As labor patterns are very different between parous and non-parous women, it was decided to prioritize nulliparous women. As everyone taking care of women in labor knows, nulliparous labors are the longest and carry the greatest risk of unplanned cesarean deliveries. More knowledge of labor patterns for nulliparas was therefore needed and only women in spontaneous labor were included as induction can have an effect on the progress of labor.(Harper et al., 2012)

A well-defined entry criterion of ≥4 cm dilatation was used, which at the time was considered diagnostic for having entered the active phase. This criterion is debated, as discussed above (Section 1.5.3), some would suggest this is too early and others use the criteria of rapidly changing cervical dilatation. This will have an effect on total labor duration and on the length of the active phase, but should not have an effect on the labor curves since they were based on the point of delivery and then calculated backwards.

Inclusion of women with advanced dilatation may be considered by some as a limitation, as their full labor progress cannot been studied. No

assumptions can be made for labor progress in women who have not yet been diagnosed to be in labor, but leaving women with advanced dilatation out of observational studies of spontaneous labors, would be introducing bias.

The small number of women is a limitation and we would not suggest that the labor curves or our predictions were taken directly into clinical practice, but the results are certainly worth basing further studies on. The many similarities with previous clinical studies suggest that, although the numbers are small, the labor patterns are a good reflection of nulliparous labors, as discussed in section 5.2 and 5.5.

An added strength for internal validation is the finding of very similar results in terms of outcomes when compared with Robson group 1 at Landspitali University Hospital.(Jónasdóttir & Eiríksdóttir, 2020; Robson, 2001) At the present the CS rate is 6.5% and the instrumental delivery rate is 16.9 % in this group, very similar to the results in the study group. The low cesarean section rate at this hospital can be considered a limitation for external validation, but we believe it reflects high quality obstetric practice, supported by good outcomes for the fetus and mother. In Iceland perinatal mortality rate is among the lowest in the world (2.9/1000 born babies in 2018, 10 year average 3.5/1000)(Jónasdóttir & Eiríksdóttir, 2020), and we feel it would be of benefit to invite other units wanting to obtain similar results, to be introduced to the practices needed to obtain them. Similar studies will need to be done in other settings with different populations and practices.

Inclusion was non-consecutive and this could be considered a limitation and cause for bias. The reason for this was that recruitment could only be on days when the examiners were available for the full length of labor duration, but were also not in charge of clinical care during labor. This meant that inclusion occurred on an irregular basis but otherwise we are not aware of bias introduced by the method of inclusion.

5.7.2 Paper IV

This study has the main strength that it studies the application of the ultrasound technique in clinical practice. The small sample size is a limitation but is however similar to other reproducibility studies.(Ghi et al., 2010; Tutschek et al., 2011; Valentin & Bergelin, 2002) Another limitation is the unequal distribution of the order in which the two devices were tested.

The different levels of ultrasound expertise of the examiners in Study IV is a strength. Different levels of expertise were not found to have an effect on intra- or inter-observer variation. This is similar to the findings of Dückelman et

al.(2010) It also strongly suggests that although the ultrasound examinations in Studies I-III were performed by obstetricians with fetal medicine expertise, it would not have a major effect on the reproducibility of the results if performed by less experienced examiners. In study IV between 10 and 40 supervised examinations seemed to provide sufficient training for novel examiners.

6 Conclusions

In this thesis ultrasound methods to follow labor progress were shown to give information which was more detailed than possible when using clinical methods. Fetal head descent and rotation were shown to follow distinctive patterns which were described. These patterns and new knowledge can be used in an informative way to guide labor management and further study. Thus, the null hypothesis can be rejected.

The aim of Paper I was to describe the descent of the fetal head through the pelvic cavity, longitudinally, using ultrasound measurements. Labor progression was described prospectively in a group of nulliparous women with spontaneous onset of labor at term with a single, cephalic fetus. The ultrasound methods HPD and AoP demonstrated distinctive patterns of fetal head descent which differed according to mode of delivery. In women delivering spontaneously there was continuous rapid descent beginning at the end of the active first stage, in women delivering with vaginal instrumental assistance there was more gradual descent, and no descent was seen in women who were delivered with cesarean section. Clinical assessments of station were inaccurate, when compared to ultrasound measurements.

The aim of Paper II was to investigate longitudinally fetal head rotation patterns with ultrasound, and relate these to labor phases and fetal head positions at delivery. Fetal head position could be determined at every examination, and rotation was described using ultrasound methods. Most commonly fetal head was in the occiput posterior position during the first stage of labor and rotation occurred in the majority of women at full dilatation, below the spinal plane. Clinical assessments of position were frequently not possible and inaccurate.

The aim of Paper III was to test the value of ultrasound as an admission test for women in active labor, and whether HPD, AoP, fetal head position and cervical dilatation assessed with ultrasound, could predict duration of labor phases and spontaneous delivery. The delivery mode was not different when the fetal head was in the occiput posterior position at inclusion, but there was an association between ultrasound measurements of fetal head station, estimated median duration of remaining time in labor, and the likelihood of vaginal delivery.

The main aim of Paper IV was to test the reproducibility of the HPD measurements, both as intra-observer variability and inter-device variability, in women in labor. The second aim was to compare these measurements with clinical measurements of fetal head station, and lastly to examine the acceptability of the method for laboring women. HPD measurements were shown to have very good repeatability for both novel and experienced examiners. Different devices and operators may influence reproducibility, but it is likely to be less than the reproducibility of clinical methods. There was a significant correlation between the clinical assessments and the mean HPD. The pain score associated with ultrasound examinations was significantly lower, compared to clinical vaginal examinations.

One hundred years ago there was great enthusiasm for radiological methods for assessing women´s pelvises before labor or during early labor. It was thought that by measuring the pelvic anatomy the contracted pelvis could be diagnosed and the woman spared a labor that would inevitably end in a cesarean section, or other even more dire complications, including fetal and/or maternal death. It is now known that this technique did not turn out to be as useful as hoped, and its predictive value for most laboring women was very little and could even do harm by judging some women, needlessly, to be unable to give birth vaginally. At the time ultrasound had not been invented and I am sure that obstetricians at this time would have been pleased to be presented with a non-invasive tool that could help them to assess the passing of the fetus through the maternal pelvis. Time will tell whether the technique of ultrasound will be the tool we have been waiting for, but it certainly holds promise as demonstrated in the studies upon which this thesis is based. The novel ultrasound techniques have been further standardized with reproducibility studies. Fetal head descent has been described in spontaneous labors in nulliparous women and how and when rotation occurs. This adds new knowledge of the physiology of labor and suggests patterns that could be the basis for further research. The great variation in individual labors has also been noted and, as yet, no single parameter studied can accurately identify those women who will not be able to give birth vaginally.

6.1 Future prospectives

Nothing in life is to be feared, it is only to be understood. Now is the time to understand more, so that we may fear less.

-Marie Curie

The study of human labor does not end here. Answering one question unlocks the door to a whole new set of questions that need to be answered. The quote to Marie Curie can be transferred to the field of obstetrics. In childbirth there are so many things still feared, because we do not understand them. It is not only the pregnant women who fear childbirth, it is also us, the obstetricians who live in the constant fear of a bad outcome, and how we practice our specialty is in some degree governed by this fear. There is no doubt that some of the prerequisites needed to practice obstetrics safely are a matter of dexterity, learning a manual skill from an expert teacher. Some obstetricians worry that this manual skill is a vanishing art. Many critics of the new ultrasound methods have maintained that the addition of ultrasound will replace digital vaginal examinations and result in further loss of manual dexterity, but the reverse is probably true.(Rozenberg et al., 2008) Having not only a tactile sense through the fingers to build an image of the situation, but also being able to use the eyes having reliable and objective measurements, is going to help a new generation of obstetricians and midwives to gain better understanding and make them more secure in their assessments on which to base their interventions, if needed. We need not fear more understanding, it will lead to new discoveries that we do not yet foresee. The main thing is to continue to ask questions and seek the answers.

There are still many unanswered questions and topics that wait to be explored concerning the use of ultrasound to follow labor progress and I will only name a few.

Will we be able to use the information gained to improve the existing partographs?(Hassan et al., 2014) This seems obvious, but we do not yet know whether this will lead to better outcomes of labor. This needs to be studied in large groups in a scientific manner, testing their value to ensure that they are not in any way inferior to the curves in use.(Cohen & Friedman, 2019, 2020) The best methods for comparisons in medicine are randomized controlled trials, but these have proven difficult to do in obstetrics as the most serious adverse outcomes are very rare, and a huge number of women need to be included in order to see differences in these outcomes. Other outcomes are

easier to investigate, such as the effect on operative delivery rates, infection rates, or women´s satisfaction, and they could be the object of study.

Can we use ultrasound methods instead of vaginal examinations? There is one ongoing study in Germany and another one about to start here in Iceland. As part of this study the views of midwives and women to this new technique will be explored.

New methods have been suggested, such as the transabdominally assessed supra-pubic descent angle, and are under investigation now. This could be of interest to obstetricians who are more familiar with the transabdominal ultrasound technique.(Iversen & Eggebo, 2019)

Similar studies to the ones presented here are needed in other groups of women, such as in parous women, women in induced labors and women with previous cesarean deliveries.

The latent phase has not been studied widely and this is understandable since its definition is so debated and unclear. Studies using ultrasound to decide which women to admit to the labor ward have shown promise, and this needs to be further explored.(Cuerva et al., 2019; Wiafe et al., 2018) The idea of an effacement curve to study progress during the latent phase has been suggested, and this might be ideally measured with ultrasound methods.(Agah et al., 2018)

Sometimes it is wise to revisit old knowledge. The obstetricians practicing in the 19th century have left information which has led to new questions. Does it make a difference on which side the occiput engages? This has not been included in any modern textbooks and so not considered anymore. There is evidence in the data collected for the studies presented, that this may be the case, and that engagement on the right side leads to slower labors and increased need for interventions. This needs to be explored further.

As for the future, your task is not to foresee it, but to enable it.

- Antoine de Saint-Exupéry, from "Citadelle" (1948)

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Original publications

Paper I

OBSTETRICS

Fetal descent in nulliparous women assessed by ultrasound: a longitudinal study

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BACKGROUND: Ultrasound measurements offer objective and reproducible methods to measure the fetal head station. Before these methods can be applied to assess labor progression, the fetal head descent needs to be evaluated longitudinally in well-defined populations and compared with the existing data derived from clinical examinations.

OBJECTIVE: This study aimed to use ultrasound measurements to describe the fetal head descent longitudinally as labor progressed through the active phase in nulliparous women with spontaneous onset of labor.

STUDY DESIGN: This was a single center, prospective cohort study at the Landspitali - The National University Hospital of Iceland, Reykjavik, Iceland, from January 2016 to April 2018. Nulliparous women with a single fetus in cephalic presentation and spontaneous labor onset at a gestational age of ≥37 weeks, were eligible. Participant inclusion occurred during admission for women with an established active phase of labor or at the start of the active phase for women admitted during the latent phase. The active phase was defined as an effaced cervix dilated to at least 4 cm in women with regular contractions. According to the clinical protocol, vaginal examinations were done at entry and subsequently throughout labor, paired each time with a transperineal ultrasound examination by a separate examiner, with both examiners being blinded to the other's results. The measurements used to assess the fetal head station were the head-perineum distance and angle of progression. Cervical dilatation was examined clinically.

RESULTS: The study population comprised 99 women. The labor patterns for the head-perineum distance, angle of progression, and cervical dilatation differentiated the participants into 75 with spontaneous deliveries, 16 with instrumental vaginal deliveries, and 8 cesarean deliveries. At the inclusion stage, the cervix was dilated 4 cm in 26 of the women, 5 cm in 30 of the women, and ≥6 cm in 43 women. One cesarean and 1 ventouse delivery were performed for fetal distress, whereas the remaining cesarean deliveries were conducted because of a failure to progress. The total number of examinations conducted throughout the study was 345, with an average of 3.6 per woman. The ultrasound-measured fetal head station both at the first and last examination were associated with the delivery mode and remaining time of labor. In spontaneous deliveries, rapid head descent started around 4 hours before birth, the descent being more gradual in instrumental deliveries and absent in cesarean deliveries. A head-perineum distance of 30 mm and angle of progression of 125° separately predicted delivery within 3.0 hours (95% confidence interval, 2.5—3.8 hours and 2.4—3.7 hours, respectively) in women delivering vaginally. Although the head-perineum distance and angle of progression are independent methods, both methods gave similar mirror image patterns. The fetal head station at the first examination was highest for the fetuses in occiput posterior position, but the pattern of rapid descent was similar for all initial positions in spontaneously delivering women. Oxytocin augmentation was used in 41% of women; in these labors a slower descent was noted. Descent was only slightly slower in the 62% of women who received epidural analgesia. A nonlinear relationship was observed between the fetal head station and dilatation.

CONCLUSION: We have established the ultrasound-measured descent patterns for nulliparous women in spontaneous labor. The patterns resemble previously published patterns based on clinical vaginal examinations. The ultrasound-measured fetal head station was associated with the delivery mode and remaining time of labor.

Key words: angle of progression, cesarean delivery, fetal head position, fetal head station, head-perineum distance, transabdominal ultrasound, transperineal ultrasound

Introduction

Proper descent of the fetal head during labor is a prerequisite for vaginal delivery. How this process is followed and assessed, is fraught with difficulty because the landmarks on the fetal head and in the pelvis can be hard to identify. Clinical vaginal examination is prone to considerable subjectivity by the individual examiner. The spinal plane is not an actual anatomic plane in the pelvis, but an imaginary plane with only 2 anatomic reference points, the ischial spines,[1] which are, moreover, not in the pelvic midline where the station of the fetal head is gauged. The leading bony reference point on the fetal head should be easier to identify, but the presence of molding and caput succedaneum can make the examiner erroneously consider the head to have descended to a lower level than actually true. Therefore, other methods of assessment have been suggested.[2–5]

Knowledge of fetal head descent during labor comes mainly from the classic series of studies by Friedman and coworkers in 1965,[6–8] describing the patterns of descent based on clinical, digital estimations of the fetal head station in the pelvic cavity. This work was essential for the World Health Organization (WHO) partograph and the WHO has recommended the partograph, until 2018, with an alert line of 1 cm cervical dilatation per hour and an action line displaced by 4 hours as suggested by Philpott et al.[9–12]

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AJOG at a Glance

Why was this study conducted?

The clinical methods used for assessing the fetal head station are subjective and have limited accuracy. Ultrasound measurement is an objective means for assessing the fetal head station. This study therefore aimed to describe the fetal head descent in nulliparous women with spontaneous labor onset.

Key findings

The ultrasound-assessed fetal head stations at both the first and last examination were significantly associated with the delivery mode. Both a head-perineum distance of 30 mm and an angle of progression of 125° independently predicted delivery within 3.0 hours (95% confidence interval, 2.5–3.8 and 2.4–3.7 hours, respectively). The fetal head station remained unchanged early during the active phase of labor but showed a pattern of rapid descent during the last 4 hours of labor, regardless of the initial cervical dilatation or occiput position.

What does this add to what is known?

The ultrasound patterns for fetal head descent in nulliparous women were described. The head-perineum distance and angle of progression predicted the remaining time to delivery. The longitudinally measured head-perineum distance and angle of progression independently produced similar labor patterns.

There has been a renewed focus on the progression of labor in recent years, revisiting the classic Friedman cervix dilatation and descent curves[13–16] in the light of changes in obstetrical practices and populations.[17–20] Less attention has been paid to the descent of the fetal head than to cervical dilatation, although this was an integral part of the labor curves presented by Friedman and his coworkers.[13,14,17–20] The fetal head station and position remain the qualities by which progress during the second stage of labor are judged. Recent clinical studies of fetal head descent have been conducted to compute mathematical models relating cervical dilatation to the fetal head station.[21–23] The patterns of descent from these studies were obtained and described using the accepted clinical methods. Ultrasound measurements have been suggested to be a more objective and accurate method for assessing the fetal head station and as having the potential to replace clinical methods.[23–40] This study aimed to use ultrasound measurement methods to describe fetal head descent longitudinally throughout the active phase of labor in nulliparous women with a spontaneous onset of labor at term.

Materials and Methods

We performed a prospective cohort study at the Landspitali - The National University Hospital of Iceland, Reykjavík, Iceland, from January 2016 to April 2018. The study population comprised 100 nulliparous women with spontaneous onset of labor, a single fetus in the cephalic presentation, and a gestational length of ≥37 weeks who were included nonconsecutively. The study population corresponded to the definition of group 1 in the Robson 10-group classification system.[41] One woman withdrew her consent and was excluded. All the women received oral and written information about the study on admission to the labor ward and written consent was obtained before inclusion. Inclusion occurred on admission for women with an established active phase of labor or at the start of the active phase for women admitted during the latent phase of labor. An active phase was defined at the time of recruitment as a fully effaced cervix, dilated to at least 4 cm, in the presence of regular contractions in accordance with the actual WHO recommendations.[9,10] All examinations were performed as paired clinical and ultrasound examinations throughout labor. Two obstetricians trained in transperineal scanning conducted the ultrasound examinations shortly before or after the clinical assessments (within 15 minutes). Cervical dilatation was examined clinically. The ultrasound examiners and clinical staff were blinded to each other's results. The ultrasound examiners were not involved in the clinical decisions during the labors.

The midwife caring for each woman performed a clinical examination at recruitment and thereafter as clinically indicated in accordance with the local hospital guidelines that recommended vaginal examinations at least every 4 hours. If the cervical dilatation was not satisfactory, defined as crossing the WHO partogram action line, the first option to augment labor progression was to rupture the membranes in case they were intact, with subsequent reassessment after 2 hours. Following a diagnosis of slow progression with ruptured membranes, a low-dose oxytocin infusion was used with subsequent reassessment after 4 hours. With no change in cervical dilatation after a period of 4 hours with adequate contractions, cesarean delivery was considered. An examination was also performed if the woman felt the urge to push, or at the midwife's discretion. No upper limit for the duration of the active phase existed at the hospital, but the duration of the second stage of labor for a nullipara should not be longer than 4 hours with or 3 hours without epidural analgesia. The active pushing phase should not be longer than 2 hours. Signs of fetal distress on cardiotocography monitoring were investigated further with fetal scalp pH or lactate samples.

During each examination, the midwife judged the cervical dilatation in centimeters and the fetal head station using the scale of −5 to +5 cm above and below the ischial spines. All the ultrasound examinations were performed by 2 experienced ultrasound examiners (H.H. and S.B.), and the findings were recorded on a separate sheet of paper. A GE Voluson i ultrasound machine (GE Medical Systems, Zipf, Austria) with a 3.5 to 7.5 MHz 3D curved multifrequency transabdominal transducer was

used for both the transabdominal and transperineal scans.

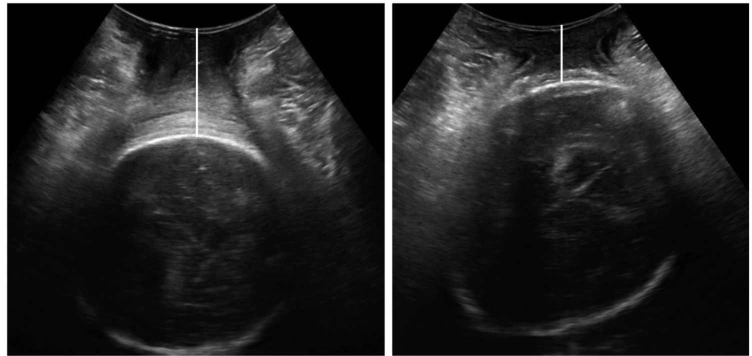
The fetal head descent was assessed by a transperineal ultrasound. The measurements obtained were the head-perineum distance (HPD) and angle of progression (AoP). The HPD was measured in the frontal plane (transverse plane related to the perineum) as the shortest distance from the transducer to the fetal skull (Figure 1, Video 1). The soft tissue was compressed with the transducer until it met resistance against the pubic bone.[28,42] The AoP was measured in the sagittal plane as the angle between the longitudinal axis of the pubic symphysis and a line from the inferior edge of the symphysis tangentially to the fetal head contour (Figure 2, Video 2).[43]

The fetal head position was determined using both the transabdominal and the transperineal approach. The transabdominal examination was preferred whenever reference structures could be visualized. The position of the occiput was marked on a clockface-like graph with half-hourly markings. The fetal head position was categorized as occiput anterior (OA; ≥10 and ≤2 o'clock), left occiput transverse (LOT; >2 and <4 o'clock), occiput posterior (OP; ≥4 and ≤8 o'clock), and right occiput transverse (ROT; >8 and <10 o'clock) positions, as described previously by Akmal et al.[44,45] The fetal spine, orbits, midline structures, and choroid plexus were used to determine the position. The epidural analgesia used at the hospital consisted of intermittent doses of 2.5 mg/mL bupivacaine and 5μg/mL sufentanil.

The main objective of this study was to describe the labor patterns for HPD and AoP in nulliparous women and investigate whether these differed by the delivery mode. Furthermore, this study aimed to build prediction models to estimate the time to delivery by HPD and AoP for women who deliver vaginally.

All ultrasound measurements were done online in the labor room and stored on the ultrasound device. The results and summaries of the outcome of the labors were later transferred into a database using the REDCap electronic data capture tools hosted at the hospital.[46] The study was approved by the Landspitali Ethics Committee under-reference number 26/2015.

FIGURE 1
Measurement of the head-perineum distance



Transverse transperineal images (frontal plane related to woman) illustrating the measurement of the head-perineum distance (41 mm in the left image and 21 mm in the right image).

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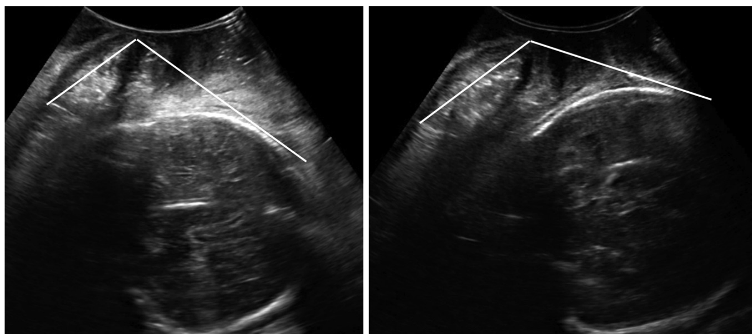
Statistical analysis

To establish the labor patterns, the time of delivery was used as a fixed reference point. From that point, the time was calculated backward. Labor curves, with the 95% confidence intervals (CIs) shaded, were constructed with a fourth degree polynomial model for each of the measurement variables, namely cervical dilatation, HPD, and AoP for the whole group, and also according to the delivery mode, namely spontaneous delivery, instrumental deliver, and cesarean delivery. For spontaneous deliveries, the labor curves were constructed according to both epidural use and oxytocin augmentation and stratified by the fetal head position and cervical dilatation at the first examination. We compared the HPD and AoP measurements to the cervical dilatation and time remaining to delivery for women delivering vaginally using a mixed effects model. For descriptive purposes we used an HPD measurement of 36 mm and an AoP of

FIGURE 2
Measurement of the angle of progression



Sagittal transperineal images illustrating the measurement of the angle of progression (110 degrees in the left image and 130 degrees in the right image).

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TABLE 1
Characteristics of the study population

Maternal characteristics	Cesarean delivery (n=8)	Instrumental delivery (n=16)	Spontaneous delivery (n=75)
Maternal age, y	31 (24–40)	28 (20–38)	26 (18–38)
BMI at first visit, kg/m^2	26 (23–36)	25 (17–35)	22 (17–36)
Gestational age, wk	40.5 (37.3–41.6)	40.5 (38–41.7)	39.9 (37–41.9)
Labor characteristics			
Oxytocin augmentation	7 (88)	12 (75)	22 (29)
Epidural analgesia	7 (88)	11 (69)	43 (57)
Length of labor, h	12.8 (8.9–26)	10.2 (4.7–18.9)	7.8 (1.4–24.3)
Newborn characteristics			
Birthweight, g	3790 (3200–4310)	3890 (2750–4540)	3520 (2480–5000)
Apgar score at 1 min	8.5 (5–10)	8 (2–9)	9 (2–10)
Apgar score at 5 min	10 (9–10)	9 (8–10)	10 (5–10)

Data are presented as median (range) or number (percentage).

BMI, body mass index.

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116° as representing the midpelvic or spinal plane based on previously published studies.[47,48] The Shapiro-Wilk test for normality was used for the AoP and HPD measurements. The AoP measurements were not normally distributed, and therefore we estimated the differences in the median cervical dilatation, AoP, and HPD by the mode of delivery with the Kruskal-Wallis test. The correlation between HPD and AoP was estimated from a Spearman's correlation coefficient and also the correlation between the clinical fetal head station and the HPD and AoP, respectively.

The data were analyzed with the statistical software package R Core Team (The R Foundation, Vienna, Austria) (2018; https://www.R-project.org/).

Results

Study population

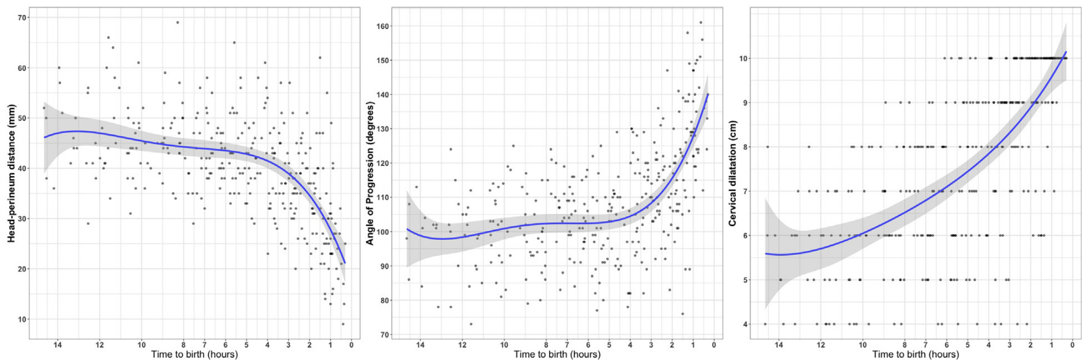
The final study population comprised 99 women: 75 had a spontaneous delivery, 15 delivered with vacuum extraction, 1 with forceps, and 8 with a cesarean delivery. At inclusion, the cervix was dilated to 4 cm for 26 women, 5 cm for 30 women, and ≥6 cm for 43 women. The characteristics of the study population, classified according to the delivery mode, are given in Table 1. The mean duration of the active phase of labor for women with spontaneous delivery was 8.4 (95% CI, 7.3–9.4) hours, 10.5 (95% CI, 8.3–12.7) hours for instrumental deliveries, and 14.3 (95% CI, 9.7–18.8) hours for the cases ending with a cesarean delivery. A total of 345 paired examinations were done, varying from 1 to 8 examinations for each woman depending on the length of labor, with an average of 3.6 examinations for each woman. Two women were only examined once, 97 women were examined at least twice, 66 women were examined 3 times, 49 women were examined 4 times, 24 women were examined 5 times, 15 women were examined 6 times, and 3 women had 8 examinations. Six cesarean deliveries were performed owing to an arrest of cervical dilatation, 1 for arrest of descent during the second stage of labor, and 1 for fetal distress during the second stage of labor (after a prolonged first stage). Details of these labors are given in Supplemental Table 1. One ventouse delivery was performed owing to fetal distress, whereas the other instrumental deliveries were all performed after a prolonged second stage of labor or arrest of descent.

Labor patterns

Figure 3 is a scatterplot illustrating the variation and mean change in the HPD, AoP, and cervical dilatation from inclusion to delivery. Figure 4 shows the pattern of descent for the same data that were classified according to the mode of delivery into spontaneous, instrumental, and cesarean deliveries. The patterns of descent show that on average the fetal head was stationed above the midpelvic plane, which is >36 mm for HPD and <116° for AoP during the early stages of the active phase, but began to descend just before full cervical dilatation was reached. In spontaneous deliveries we observed a steep and continuous descent represented by decreasing HPD measurements and increasing AoP measurements. The descent began on average at a cervical dilatation of 7 cm, around 6 hours before birth, and became more accelerated at a cervical dilatation of around 8 cm, 4 hours before birth. A more gradual descent was seen in the labor curves for instrumental vaginal deliveries and virtually no descent in the cases ending with cesarean delivery. Individual descent curves for women with a spontaneous delivery are shown in Supplemental Figure 1 and illustrate the large individual variation.

The pattern of clinically-assessed cervical dilatation shows a linear slope

FIGURE 3
Labor curves of descent using ultrasound and dilatation assessed clinically



Labor curves showing the fetal head station measured with ultrasound as the head-perineum distance measured in millimeters (left image), angle of progression measured in degrees (middle image), and cervical dilatation assessed clinically in centimeters (right image) over time in nulliparous women with spontaneous onset of labor. The birth is at 0 hours and the time from birth was calculated backward. The 95% confidence intervals are shaded.

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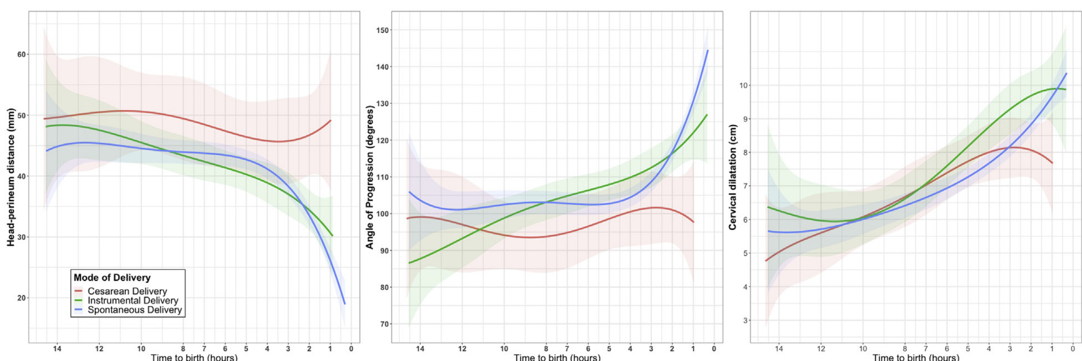
which was steepest for spontaneous deliveries and slightly less steep in the cases ending with instrumental vaginal deliveries (Figure 4). A similar slope tapering off and then stopping at a mean of 8 cm cervical dilatation, around 4 hours before delivery, was seen in the cases ending with a cesarean delivery. Individual dilatation curves are shown in Supplemental Figure 1.

Both the HPD and AoP measurements at the first and last examination showed a higher fetal head station at the first and last measurement in women ending with an operative delivery, and this was even more pronounced in women needing a cesarean delivery (Table 2). Mixed effects models comparing the cervical dilatation and the fetal head station measurements on the basis of the HPD and AoP in women delivering vaginally showed that the relationship was not linear and that a second degree model had a better fit (*P* value for comparisons of first and second degree models was <.001). At a cervical dilatation of 8 cm, the prediction for the HPD measurement was 40 mm (95% CI, 39−42) and for the AoP it was 106° (95% CI, 104−108). At full cervical

FIGURE 4
Labor curves of descent and dilatation by mode of delivery



Labor curves showing the fetal head station measured with ultrasound as the head-perineum distance measured in millimeters (left image), angle of progression measured in degrees (middle image), and cervical dilatation assessed clinically in centimeters (right image) over time in nulliparous women with spontaneous onset of labor, stratified by mode of delivery. The birth is at 0 hours and time from the birth was calculated backward. The 95% confidence intervals are shaded.

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TABLE 2
Cervical dilatation and ultrasound measurements of fetal head station at first and last examination differentiated into mode of delivery

Measurements at first examination	Cesarean delivery (n=8)	Instrumental delivery (n=16)	Spontaneous delivery (n=75)	*P* value
Cervical dilation, cm	5 (4–7)	5 (4–8)	5 (4–10)	.48
Angle of progression, degrees	88 (73–105)	95 (78–112)	102 (81–128)	.01
Head-perineum distance, mm	56 (34–66)	47 (35–57)	43 (24–64)	.02
Measurements at last examination				
Cervical dilation, cm	8 (6–10)	10 (5–10)	10 (5–10)	.01
Angle of progression, degrees	104 (76–123)	114 (99–155)	123 (82–161)	.01
Head-perineum distance, mm	47 (33–62)	36 (14–51)	30 (9–57)	.001

Data are presented as median (range).

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dilatation this model predicted the HPD to be 29 mm (95% CI, 28–31) and the AoP to be 126° (95% CI, 124–129) (Supplemental Table 2).

A prediction of time remaining to delivery based on the HPD and AoP values using mixed effect models showed that for women delivering vaginally, an HPD measurement of 40 mm predicted delivery in 5.5. hours (95% CI, 5.1–6.1 hours) and for an AoP of 110° the corresponding values were 5.2 hours (95% CI, 4.7–5.7 hours). An HPD of 30 mm and AoP of 125° both predicted delivery within 3.0 hours (95% CI for HPD, 2.5–3.8; 95% CI for AoP, 2.4–3.7 hours). Detailed information is shown in Table 3.

Figure 5 illustrates the HPD and AoP descent curves differentiated by the ultrasound-assessed fetal positions at the first measurement in the women who delivered spontaneously. The fetal head station was highest for fetuses in an OP position. The pattern of rapid descent was similar for all the positions and seemed to occur around 4 hours before birth. Oxytocin augmentation was used in 41% of women and these women had a slower descent (Figure 6). Figure 7 shows the HPD and AoP descent patterns for women who received epidural analgesia. Descent was only slightly slower in the 62% of women who received epidural analgesia. The descent patterns for women included with 4 to 5 cm cervical dilatation were not different compared with those included at a more advanced cervical dilatation (Figure 8).

TABLE 3
Predicted time to delivery according to the head-perineum distance and angle of progression in women delivering vaginally

Head-perineum distance (mm)	Predicted time to delivery (h)	95% confidence interval (h)
60	10.5	9.4–11.6
50	8.0	7.3–8.8
40	5.5	5.1–6.1
30	3.0	2.5–3.8
20	0.6	0.0–1.6
Angle of progression (°)		
80	9.5	8.7–10.4
95	7.4	6.7–8.0
110	5.2	4.7–5.7
125	3.0	2.4–3.7
140	0.8	0.0–1.8

Data are presented as number or median (range).

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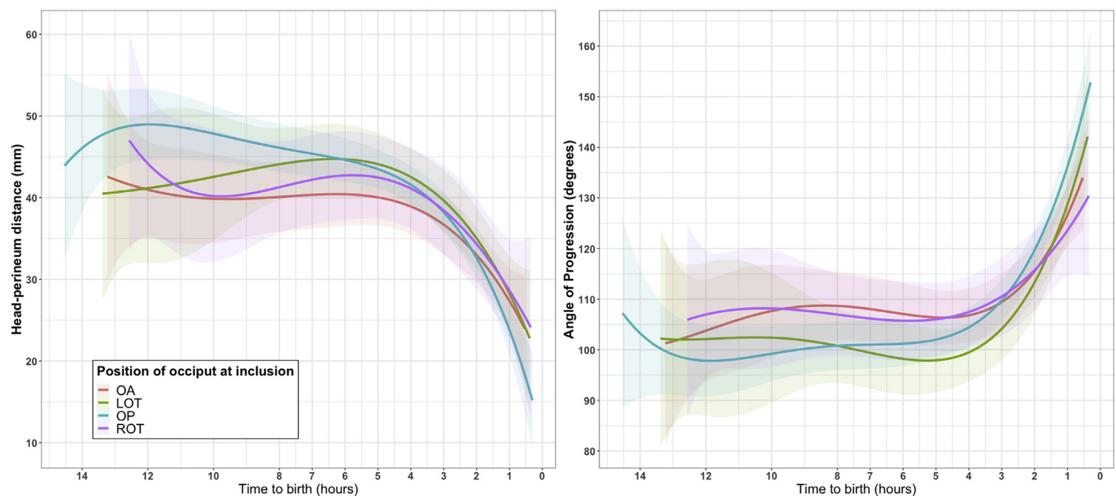
The HPD and AoP are independent methods but are correlated ($r=-0.80$; $P<.001$) and gave similar mirror image patterns. The correlation between the clinically-assessed fetal head station and the HPD was $r=-0.75$; $P<.001$ and between the fetal head station and the AoP was $r=0.75$; $P<.001$. The association between the clinically-assessed fetal head station and ultrasound measurements is shown in Supplemental Figure 2.

Comment

Principal findings

The results of this study described longitudinally assessed fetal head descent using ultrasound measurements among nulliparous women in spontaneous labor. We were able to create curves for the fetal head descent, stratified by mode of delivery, and for spontaneous deliveries we created curves stratified by both the

FIGURE 5
Labor curves of head descent stratified by occiput position at inclusion



Labor curves showing patterns of fetal head station measured with ultrasound as the head-perineum distance measured in millimeters (left image) and angle of progression measured in degrees (right image) over time in nulliparous women with spontaneous onset of labor at term and also delivering spontaneously, stratified by the fetal occiput position at inclusion. The birth is at 0 hours and time from the birth was calculated backward. The 95% confidence intervals are shaded.

LOT, left occiput transverse; *OA*, occiput anterior; *OP*, occiput posterior; *ROT*, right occiput transverse.

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occiput position and cervical dilatation at inclusion, and for epidural use and oxytocin augmentation. We found a significant association between the measured AoP and HPD at the first and last examination and the mode of delivery. The AoP and HPD measurements could be used to predict the time to vaginal delivery and we have related them to the degree of cervical dilatation. These results confirm the feasibility of following fetal head descent during labor by ultrasound.

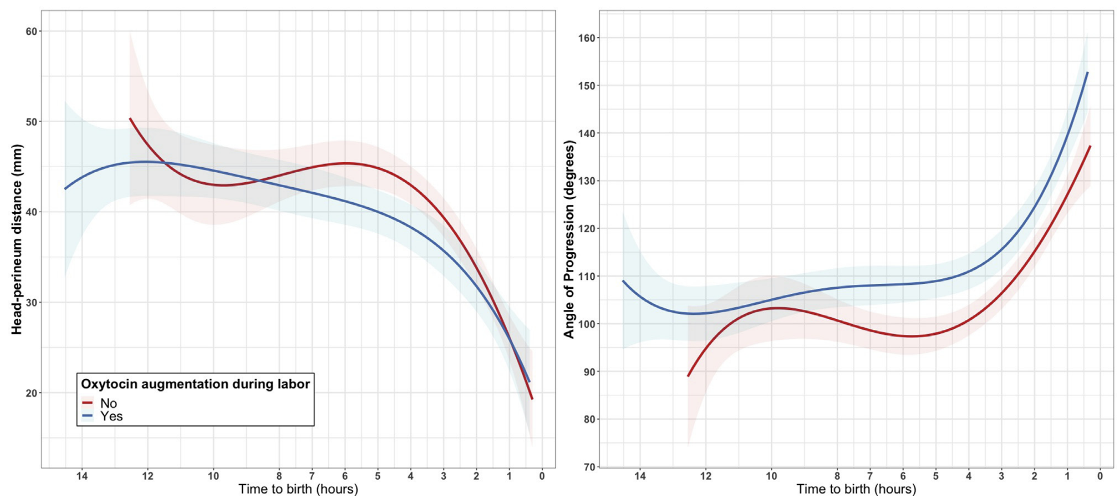
Clinical significance

Reducing the number of vaginal examinations during labor is important, both because of the discomfort and pain associated with them and to reduce the risk of infection.[49,50] Compared with clinical vaginal examinations, measuring the HPD and AoP is easy, noninvasive, and causes little discomfort, as confirmed by acceptability studies.[51–54] Ultrasound images can be stored and used as an objective documentation. The idea of a sonopartogram has already been advanced.[55] Being able to predict both the outcome of labor and the time remaining in labor is important for both the woman in labor and her care provider. By describing the labor patterns for the AoP and HPD, and their associations with the mode of delivery, time remaining in labor and the cervical dilatation, we have shown that a transperineal ultrasound is a feasible method to follow the progression of labor and can complement clinical vaginal examinations.

Research implications

Friedman published the graphic analysis of labor in 1954[13] and the patterns of cervical dilatation and fetal descent in 1965.[6–8] Although Friedman considered both cervical dilatation and fetal descent to be of equal clinical importance, there has since been a universal emphasis on following labor progress based on the assessments of cervical dilatation in preference to fetal head descent. Vaginal delivery requires full cervical dilatation, but it is equally important to achieve fetal head descent down to the pelvic floor. Labor, moreover, does not end at full dilatation. Clinical palpation of the fetal head station is subjective and has limited reliability.[5,53,56,57] The American College of Obstetricians and Gynecologists' classification of the clinical assessment of fetal station has therefore been questioned owing to the inaccuracy of the method.[58] Researchers studying fetal descent have also called for a more objective measure of the fetal head station than offered by a clinical examination.[8,23] Ultrasound methods also have limitations with interobserver and interdevice variability,[53,59] but are more accurate than clinical examinations. The use of ultrasound has therefore been encouraged as a more objective method in recent years.[47,53,60] The objective nature of the AoP has also been correlated to anatomic landmarks, using magnetic resonance imaging and computed tomography techniques.[48,61]

FIGURE 6
Labor curves of head descent startified by use of oxytocin



Labor curves showing the patterns of fetal head station measured with ultrasound as the head-perineum distance measured in millimeters (left image) and angle of progression measured in degrees (right image) over time in nulliparous women with spontaneous onset of labor at term and also delivering spontaneously, stratified by oxytocin augmentation during labor. The birth is at 0 hours and time from the birth was calculated backward. The 95% confidence intervals are shaded.

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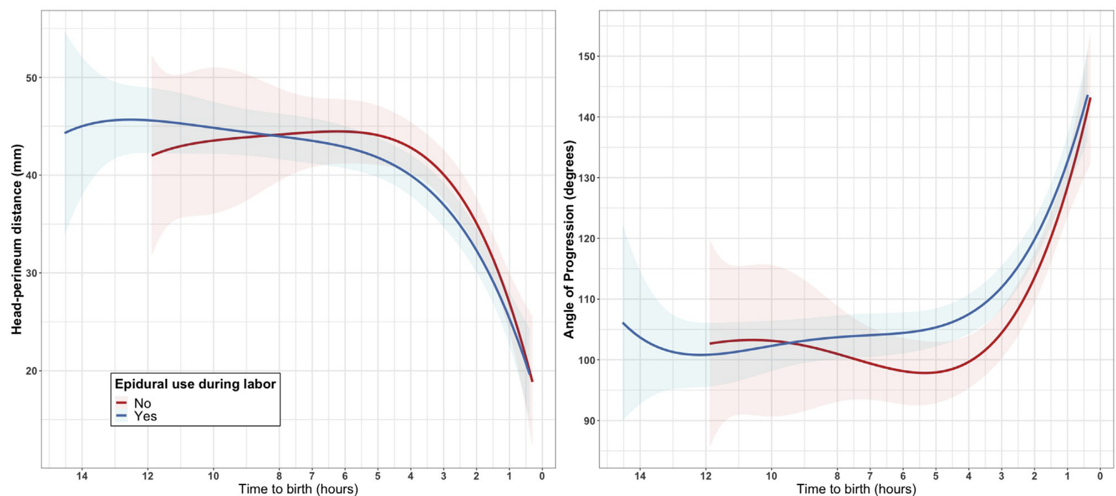
Visual comparisons show that the ultrasound descent pattern is similar in shape to the clinical curves published by Friedman.[8] The ultrasound-assessed fetal head station was slightly higher and above the midpelvis level initially. In the original clinical data, the fetal head was, on average, considered to have advanced below the maternal spinal plane when the active phase of labor had been reached.[8] There are fundamental methodological differences between comparing the clinical assessment of the spinal plane and the results obtained when using the HPD and AoP values to determine fetal head descent, but attempts have been made to relate the 2.[1,47,48,61,62] Another variation is the relationship between cervical dilatation and rapid descent. The descent started, on average, at 4 cm dilatation according to Friedman's curves and reached its maximum rate of descent at an average of 6 cm dilatation. We found rapid descent to start around 7 to 8 cm dilatation but in both cases leading to delivery around 4 hours later. The duration of the active phase of labor was shorter in Friedman's curves: 4.9 hours vs 8.4 hours in this study. This difference may be caused by different definitions for the start of the active phase of labor. By Friedman's definition the active phase begins at variable degrees of cervical dilatation, but we defined the start of the active phase at a dilatation of 4 cm in accordance with the actual WHO recommendations. The difference observed may also be caused by changes in the obstetrical population or practice.[21–23] Taking into account that the forces which drive the rapid and progressive descent may contrive to build up to a decisive turning point later in the cervical dilatational process of labor. This may be more important than the actual cervical dilatation and calls for more time to be allowed during an otherwise normal labor.

We found that second degree models described the relationship between the cervical dilatation and ultrasonically-measured fetal head station better than the linear models in women delivering vaginally. This differs from the findings of Hamilton et al[23] who found a linear relationship between the cervical dilatation and clinically-assessed fetal head station.

When the fetal head was in the OP position at the first measurement, the fetal head station was higher throughout the early part of the active phase of labor. However, this did not seem to affect the pattern of rapid descent toward the end of labor, which was similar for all the initial occiput positions in women delivering spontaneously.

We defined active labor as regular contractions with a fully effaced and 4 cm dilated cervix, which, at the time, was the WHO definition of active labor. Since then the WHO has changed its definition to a 5 cm dilatation[63] and Zhang et al[17] recommended a dilatation of 6 cm as the start of the active phase. As we used the time of delivery as the reference point and then calculated

FIGURE 7
Labor curves of head descent stratified by epidural use



Labor curves showing the patterns of the fetal head station measured with ultrasound as the head-perineum distance measured in millimeters (left image) and angle of progression measured in degrees (right image) over time in nulliparous women with spontaneous onset of labor at term and also delivering spontaneously, stratified by the use of epidural analgesia. The birth is at 0 hours and time from the birth was calculated backward. The 95% confidence intervals are shaded.

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backward, similar to the methodology used by Zhang et al,[17] we do not believe these differences in definition have any bearing on the patterns of descent supported by our findings of almost identical descent patterns for women included at 4 to 5 cm cervical dilatation compared with those included at a dilatation of ≥6 cm.

To get a complete picture of nulliparous women in spontaneous labor we did not exclude women with advanced dilation on admission. This represents the reality of spontaneous labors. Excluding these women would have resulted in a selected population of women having slow labors.

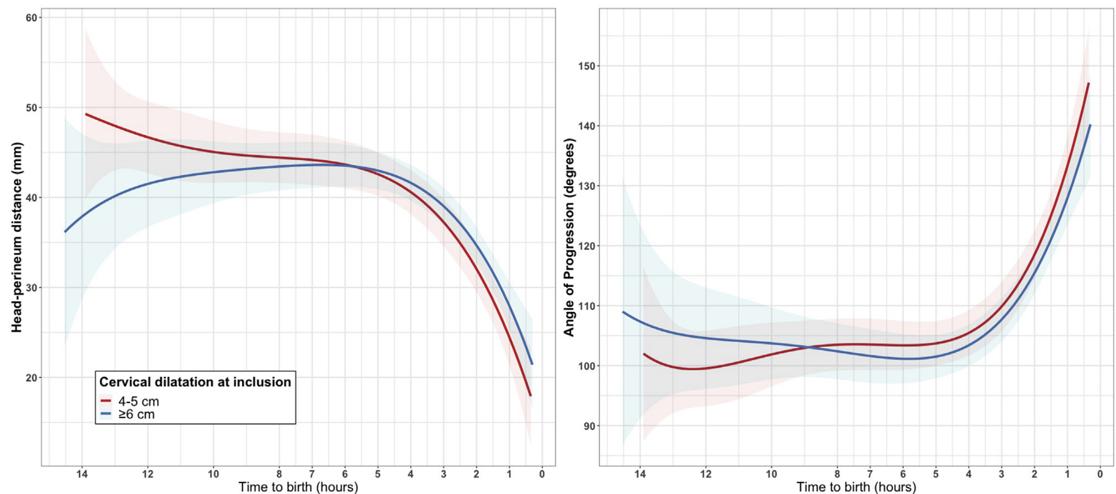
We decided to do paired clinical and ultrasound examinations, and to follow the hospital protocol for vaginal examinations during labor, namely at least every 4 hours, as we felt that this would be sufficient to construct labor patterns for the whole group. Having a strict protocol of more frequent examinations would have given us more accurate knowledge of the clinical progression for each individual woman.

Studies have shown conflicting results about the effects epidural analgesia has on the progression of labor.[64–78] In our study group, 62% of the women were given epidural analgesia. There were no differences between the fetal head levels during the early part of the active phase of labor associated with epidural use in women delivering spontaneously, but the curve of fetal head descent was slightly more sloping in these women. This is in line with the results of a recent study using ultrasound methods to monitor fetal head descent.[36] A study following women in induced labors with ultrasound measurements of the fetal head descent, has also demonstrated different patterns of labor progression in women who delivered vaginally and those needing cesarean delivery.[79]

Oxytocin augmentation was used in 41% of the women and a slower descent was observed in these labors. This is not surprising because a slow progress is the indication for oxytocin augmentation. Although it would be ideal to study only spontaneous, unstimulated labors, it would be unethical to withhold treatment for labor inertia. The protocol for augmentation used was the agreed upon protocol at our hospital and the cesarean delivery rate in the study corresponds to the 8% cesarean delivery rate for group 1 in the Robson 10-group classification system at our hospital. We therefore think that the internal validity was good. However, the external validity may be limited by a relatively low overall cesarean delivery rate of 15.3% in Iceland.[80] Similar studies should be performed in other countries and other populations. In our cohort, only 1 cesarean delivery was performed because of fetal distress but this was at full dilatation following slowly progressing dilatation with oxytocin augmentation.

We reported both the HPD and AoP measurements for research purposes because these methods are

FIGURE 8
Labor curves of head descent stratified by cervical dilatation at inclusion



Labor curves showing the patterns of the fetal head station measured with ultrasound as the head-perineum distance measured in millimeters (left image) and angle of progression measured in degrees (right image) over time in nulliparous women with spontaneous onset of labor at term and also delivering spontaneously, stratified by the cervical dilatation at inclusion. The birth is at 0 hours and time from the birth was calculated backward. The 95% confidence intervals are shaded.

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complimentary and reinforce the results when considered together. Although there are methodological differences between the 2, with the AoP using the symphysis as a reference point and the HPD representing the remaining distance for the fetal head to pass to the pelvic outlet, they have been shown to be well correlated.[81] The methods were also correlated in our study and showed similar labor pattern curves, suggesting that these measurements could be used interchangeably. The correlation between the ultrasound measurements and clinical assessments in our study was good at high stations, but not at low stations (Supplemental Figure 2).

Strengths and limitations

The strengths of this study were the prospective, longitudinal design and a well-defined population of spontaneously laboring nulliparous women recruited during the active phase of labor. The ultrasound examiners were both fetal medicine specialists, which adds to the quality of the examinations. This could also be considered a weakness because the results might not be directly applicable to the average labor ward staff. It has, however, been shown that these skills are easily obtained.[60] The nonconsecutive nature of inclusion may be considered a limitation, but the participants were recruited on the given days when the ultrasound examiners were available and we are not aware of any selection bias. The small sample size, especially regarding the operative delivery numbers, limits the generalizability of the results and further studies in both parous and nonparous women in spontaneous and induced labor are needed.

Conclusions

We used tested, objective, intrapartum ultrasound methods to describe the pattern of fetal head descent in nulliparous women delivering at term. The patterns resemble previously published clinical patterns. Ultrasonically measured fetal head station was associated with the mode of delivery and with the remaining time in labor. The results of this study may encourage further studies on fetal descent as measured with ultrasound in other well-defined groups of women in labor and in other settings. ∎

Acknowledgments

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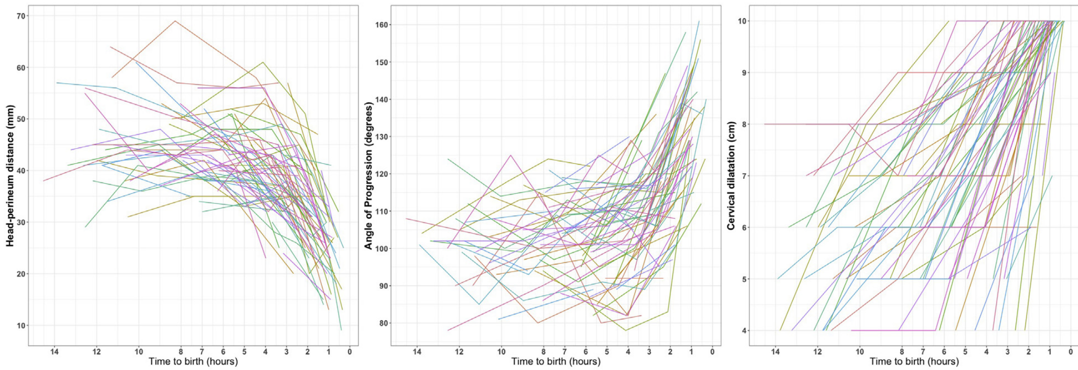
SUPPLEMENTAL FIGURE 1
Individual patterns of head descent and cervical dilatation



Labor curves showing the individual patterns of fetal head station as measured with an ultrasound as the head-perineum distance measured in millimeters (left image), angle of progression measured in degrees (middle image), and cervical dilatation assessed clinically in cm (right image) over time in nulliparous women with spontaneous onset of labor at term. Only the curves of women who delivered spontaneously are shown. The birth is at 0 hours and time from the birth was calculated backward.

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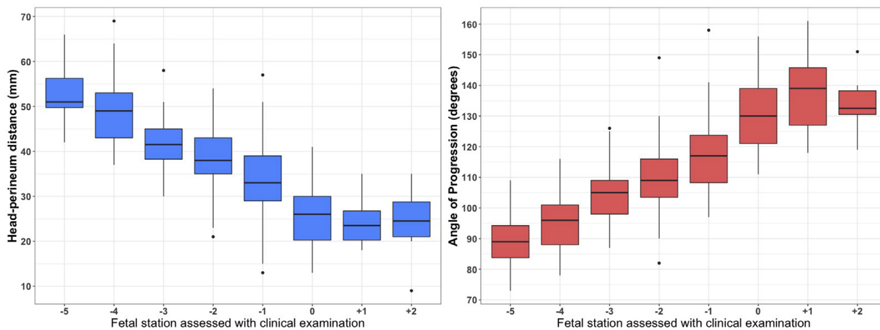
SUPPLEMENTAL FIGURE 2
Association between ultrasound and clinical methods to assess fetal station



A boxplot showing the association between the clinically assessed fetal head station and the fetal head station as measured with ultrasound as the head-perineum distance measured in mm (left image) and the angle of progression measured in degrees (right image).

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SUPPLEMENTAL TABLE 1

Details of the labors for women needing a cesarean delivery

Case	Cervical dilation at inclusion (cm)	Cervical dilatation at delivery (cm)	Occiput position at inclusion	Occiput position at delivery	HPD at inclusion (mm)	HPD at last examination (mm)	AoP at inclusion (°)	AoP at last examination (°)	Length of active phase of labor I (h:min)	Length of second stage (h:min)	Indication
1	4	6	OA	OA	43	34	98	122	17:15		FP
2	5	6	OP	OP	48	47	91	89	10:06		FP
3	6	10	OP	OP	59	49	79	110	08:40	04:53	FP
4	5	8	OP	OP	60	40	84	107	13:55		FP
5	7	9	OP	OP	60	55	84	89	11:35		FP
6	4	10	ROT	OP	52	46	98	100	14:24	00:38	FD
7	5	6	OP	OP	66	62	73	76	11:20		FP
8	4	8	OP	OP	34	33	105	123	25:22		FP

AoP, angle of progression; *FD*, fetal distress; *FP*, failure to progress; *HPD*, head-perineum distance; *OA*, occiput anterior; *OP*, occiput posterior; *ROT*, right occiput transverse.

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SUPPLEMENTAL TABLE 2

The predicted ultrasound-measured fetal head station at each centimeter of cervical dilatation

Cervical dilatation (cm)	Predicted HPD (mm)	95% CI (mm)	Predicted AoP (°)	95% CI (°)
4	44	42—47	102	98—105
5	46	44—47	99	96—101
6	45	44—47	98	96—100
7	44	42—45	101	98—103
8	40	39—42	106	104—108
9	36	34—37	115	113—117
10	29	28—31	126	124—129

Data are presented as number or median (range).

AoP, angle of progression; *CI,* confidence interval; *HPD,* head-perineum distance.

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Paper II

OBSTETRICS

When does fetal head rotation occur in spontaneous labor at term: results of an ultrasound-based longitudinal study in nulliparous women

Hulda Hjartardóttir, MD; Sigrún H. Lund, PhD; Sigurlaug Benediktsdóttir, MD; Reynir T. Geirsson, MD, PhD; Torbjørn M. Eggebø, MD, PhD

BACKGROUND: Improved information about the evolution of fetal head rotation during labor is required. Ultrasound methods have the potential to provide reliable new knowledge about fetal head position.

OBJECTIVE: The aim of the study was to describe fetal head rotation in women in spontaneous labor at term using ultrasound longitudinally throughout the active phase.

STUDY DESIGN: This was a single center, prospective cohort study at Landspitali - The National University Hospital of Iceland, Reykjavík, Iceland, from January 2016 to April 2018. Nulliparous women with a single fetus in cephalic presentation and spontaneous labor onset at ≥37 weeks' gestation were eligible. Inclusion occurred when the active phase could be clinically established by labor ward staff. Cervical dilatation was clinically examined. Fetal head position and subsequent rotation were determined using both transabdominal and transperineal ultrasound. Occiput positions were marked on a clockface graph with 24 half-hour divisions and categorized into occiput anterior (≥10- and ≤2-o'clock positions), left occiput transverse (>2- and <4-o'clock positions), occiput posterior (≥4- and ≤8 o'clock positions), and right occiput transverse positions (>8- and <10-o'clock positions). Head descent was measured with ultrasound as head-perineum distance and angle of progression. Clinical vaginal and ultrasound examinations were performed by separate examiners not revealing the results to each other.

RESULTS: We followed the fetal head rotation relative to the initial position in the pelvis in 99 women, of whom 75 delivered spontaneously, 16 with instrumental assistance, and 8 needed cesarean delivery. At inclusion, the cervix was dilated 4 cm in 26 women, 5 cm in 30 women, and ≥6 cm in 43 women. Furthermore, 4 women were examined once, 93 women twice, 60 women 3 times, 47 women 4 times, 20 women 5 times, 15 women 6 times, and 3 women 8 times. Occiput posterior was the most frequent position at the first examination (52 of 99), but of those classified as posterior, most were at 4- or 8-o'clock position. Occiput posterior positions persisted in >50% of cases throughout the first stage of labor but were anterior in 53 of 80 women (66%) examined by and after full dilatation. The occiput position was anterior in 75% of cases at a head-perineum distance of ≤30 mm and in 73% of cases at an angle of progression of ≥125° (corresponding to a clinical station of +1). All initial occiput anterior (19), 77% of occiput posterior (40 of 52), and 93% of occiput transverse positions (26 of 28) were thereafter delivered in an occiput anterior position. In 6 cases, the fetal head had rotated over the 6-o'clock position from an occiput posterior or transverse position, resulting in a rotation of >180°. In addition, 6 of the 8 women ending with cesarean delivery had the fetus in occiput posterior position throughout the active phase of labor.

CONCLUSION: We investigated the rotation of the fetal head in the active phase of labor in nulliparous women in spontaneous labor at term, using ultrasound to provide accurate and objective results. The occiput posterior position was the most common fetal position throughout the active phase of the first stage of labor. Occiput anterior only became the most frequent position at full dilatation and after the head had descended below the midpelvic plane.

Key words: active phase, angle of progression, cesarean delivery, fetal head position, head-perineum distance, progress of labor, transabdominal ultrasound, transperineal ultrasound

Introduction

The position of the fetal head during labor is an important factor to consider when there are signs of labor protraction or arrest disorders. Occiput posterior (OP) and transverse positions have been associated with poorer outcomes of labor for both the mother and fetus.[1–3] At present, position is predominantly assessed clinically, and although some obstetricians become skilled at this examination,[4,5] many operators never acquire it fully. The use of ultrasound has been shown to be more accurate in determining fetal head position[6–11] and has a shorter learning curve than clinical examinations,[12] and the introduction of this skill has been encouraged. With this compelling evidence, ultrasound will probably become common practice, and it will be essential to have reliable data about what constitutes normal findings in labor in terms of occiput positions.

EDITORS' CHOICE

The study of fetal head rotation during labor has not been the subject of many studies since Calkins et al[13] published their results on internal rotation based on clinical examinations of women in labor in 1939. This has formed the basis of our knowledge and been quoted in textbook chapters on the mechanism of labor ever since.[14,15] Ultrasound can be applied repeatedly during labor to assess the fetal head position accurately with a combination of transabdominal and transperineal approaches.[7–9,16–22]

This offers the opportunity to study fetal head rotation in great detail and relates it to other factors, such as fetal station, cervical dilatation, labor phases,

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AJOG at a Glance

Why was this study conducted?

Clinical examination of the fetal head position has limited accuracy. Ultrasound can reliably assess fetal head position. The study was conducted to describe the fetal head rotation using ultrasound in nulliparous women with spontaneous labor onset.

Key findings

More than 50% of fetuses were in the occiput posterior position throughout the first stage of labor. The occiput anterior (OA) position only became the most common position below the midpelvic plane. Of initial occiput positions, all anterior, 93% transverse, and 77% posterior positions were delivered in the OA position.

What does this add to what is known?

New and detailed information about fetal head rotation in nulliparous women is presented. Fetal head rotation most often occurs at full dilatation and below the midpelvic plane. Rotation could be >180° for some fetuses.

and mode of delivery. As labor progresses differently between nulliparous and parous women and between induced and spontaneous labors, it is important to study clearly defined groups of women.[23] The objective of this study was to describe fetal head rotation longitudinally with ultrasound throughout the active phase of labor in nulliparous women with spontaneous onset of labor at term.

Materials and Methods

This was a single center, prospective, cohort study at Landspitali - The National University Hospital of Iceland, Reykjavík, Iceland, during the period of January 2016 to April 2018. All women received oral and written information on admission to the labor ward and gave written consent before inclusion. Nulliparous women with a spontaneous start of labor at ≥37 weeks' gestation and with a single fetus in cephalic presentation were eligible, corresponding to group 1 in the 10-group classification system proposed by Michael Robson.[24] Inclusion was nonconsecutive and occurred on admission for women with an established active phase of labor or when that phase could be established in women admitted during the latent phase. The active phase was defined as a fully effaced cervix, dilated at least 4 cm, in the presence of regular contractions in accordance with the actual World Health Organization (WHO) recommendations.[25,26] Clinical and ultrasound examinations were paired throughout labor by 2 separate examiners, blinded to each other's results. The midwife caring for the woman performed a clinical examination at recruitment and then as clinically indicated, in accordance with the hospital guidelines recommending vaginal examinations at least every 4 hours, recording cervical dilatation in centimeters on a specially designed medical record. Whenever the fetal occiput position could be assessed clinically, it was marked on a clockface graph with 24 half-hour divisions.

All ultrasound examinations were performed within 15 minutes of the clinical examination by experienced ultrasound examiners (H.H. and S.B.) who were not involved in the clinical care of the laboring woman. A Voluson i ultrasound machine (GE Medical Systems, Zipf, Austria) with a 3.5- to 7.5-MHz 3-dimensional curved multifrequency transabdominal transducer was used for both transabdominal and transperineal scans.

Fetal head position was determined using both the transabdominal[27] and the transperineal[28] approaches. The transabdominal examination was preferred whenever reference structures could be visualized. The occiput position was marked on a similar clockface graph for the clinical examinations. Fetal head positions were categorized as occiput anterior (OA; ≥10- and ≤2-o'clock positions), left occiput transverse (LOT; >2- and <4-o'clock positions), OP (≥4- and ≤8-o'clock positions), and right occiput transverse positions (ROT; >8- and <10-o'clock positions).[29] The fetal spine, orbits, midline structures, and choroid plexus were used to determine the position by ultrasound.[22]

To assess fetal head station, transperineal ultrasound was used, and the measurements obtained were head-perineum distance (HPD) and angle of progression (AoP). HPD was measured in the frontal plane (transverse plane related to the perineum) as the shortest distance from the transducer to the fetal skull. The soft tissue was compressed with the transducer until it met with resistance against the pubic bone.[18,30] AoP was measured in the sagittal plane as the angle between the longitudinal axis of the pubic symphysis and a line from the inferior part of the symphysis tangentially to the fetal head contour.[31] The spinal plane is considered to be at an AoP level of 116° and at an HPD of 36 mm.[22]

All data were collected and managed using Research Electronic Data Capture tools hosted at the hospital.[32] The study was approved by the Landspitali Ethics Committee, reference number 26/2015.

Statistical analysis

To describe the association between fetal head station and fetal head position against time, the delivery time was used as a fixed reference point. From that point, time was calculated backward. The Shapiro-Wilk test for normality was used for the AoP and HPD measurements. As the AoP measurements were not normally distributed, the differences in median AoP and HPD measurements by occiput position at inclusion were estimated with the Kruskal-Wallis test. The Fisher exact test was used to compare proportions. Other results are presented descriptively, and data were analyzed using the statistical software package R Core Team (R Foundation for Statistical Computing, Vienna, Austria; URL: https://www.R-project.org/; R: a

TABLE 1
Characteristics of the study population stratified by occiput position on inclusion

Characteristics	OA n=19	LOT n=15	OP n=52	ROT n=13
Maternal characteristics				
Maternal age, y	31 (18–40)	27 (22–38)	26 (18–38)	26 (23–34)
Oxytocin augmentation	7 (37)	5 (33)	23 (44)	6 (46)
Epidural analgesia	10 (53)	6 (40)	37 (71)	8 (62)
Gestational age, wk	39 (37–42)	40 (39–42)	40 (37–42)	40 (37–42)
Newborn characteristics				
Birthweight	3530 (2480–5000)	3690 (2930–4480)	3530 (2750–4660)	3440 (2560–4330)
Apgar score at 1 min	9 (8–9)	9 (3–9)	9 (2–10)	7 (4–9)
Apgar score at 5 min	10 (9–10)	10 (5–10)	10 (8–10)	9 (8–10)
Labor characteristics				
Mode of delivery				
Cesarean delivery	1 (5)	0 (0)	6 (12)	1 (8)
Instrumental delivery	1 (5)	1 (7)	11 (21)	3 (23)
Spontaneous delivery	17 (90)	14 (93)	35 (67)	9 (69)
Length of labor, h	7.9 (1.4–17.3)	8.0 (3.1–17.6)	8.9 (2.6–26)	9.7 (2.2–24.3)

Data are presented as median (interquartile range) or number (percentage).

LOT, left occiput transverse; *OA*, occiput anterior; *OP*, occiput posterior; *ROT*, right occiput transverse.

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language and environment for statistical computing, 2018).

Results

Study population

Of the 100 women initially included, 1 withdrew her consent and was excluded. Characteristics of the study population, differentiated by occiput position at the first examination, are presented in Table 1. At inclusion, the cervix was dilated 4 cm in 26 women, 5 cm in 30 women, and ≥6 cm in 43 women. A total of 340 paired clinical and ultrasound examinations were done, varying from 1 to 8 examinations for each woman, depending on the length of labor. Furthermore, 4 women were examined only once, 93 women at least twice, 60 women 3 times, 47 women 4 times, 20 women 5 times, 15 women 6 times, and 3 women 8 times.

Fetal head position throughout the active phase of labor

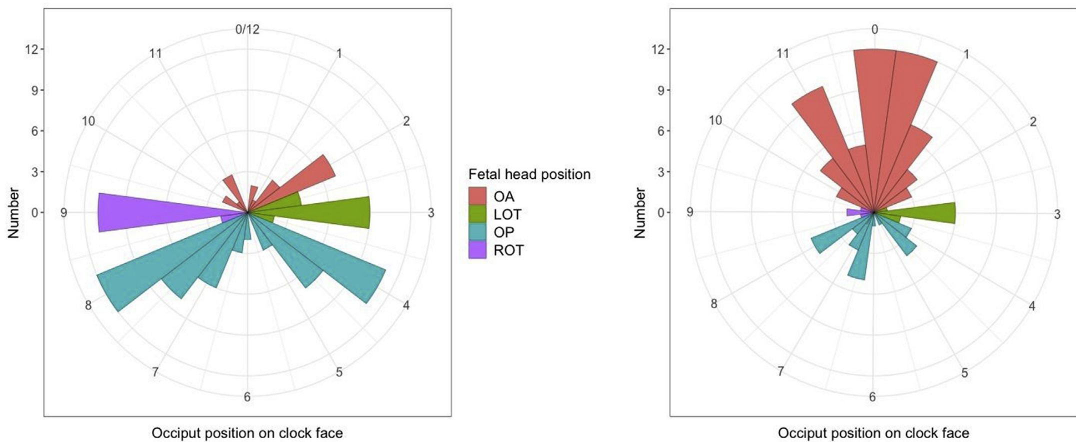
Figure 1 (left image) shows the frequency and detailed distribution of the position of the fetal head at the first ultrasound examination. The OP position was the most common position at the first examination (52 of 99). Of the other fetuses, 19 were OA, 15 LOT, and 13 ROT. Of those classified as OP, most were at the 4- or 8-o'clock positions. Fetal head position could only be clinically assessed in 31 of 99 cases at the time of the first paired examination, and only 14 of these examinations (45%; 95% confidence interval [CI], 28–89) agreed with the ultrasound examination.

Fetal position at each examination is presented in Table 2. Individual rotation patterns showed that the occiput was either in the left or right side position throughout labor in most cases, but in 6 cases, the occiput was seen to rotate over the 6-o'clock position. In Figure 1 (right image), the detailed distribution and frequency of positions of the fetal head at the last ultrasound examination before birth are shown, when 61 of 99 fetuses were in the OA position, 9 in the LOT position, 25 in the OP position, and 4 in the ROT position. Fetal head position could be assessed clinically in 61 of 99 cases at the time of the last paired examination, and 52 of these examinations (85%; 95% CI, 73–93) agreed with the ultrasound-assessed position.

All fetuses in the OA position at the first examination were delivered in the OA position. From an initial OT position, 26 of 28 fetuses (93%; 95% CI, 75–99) rotated to the OA position, whereas 2 cases in the right-sided OT positions were in the OP position at delivery. Of the initial OP positions, 40 of 52 fetuses (77%; 95% CI, 63–87) were delivered in the OA position. All 61 fetuses in the OA position at the last examination and all 13 fetuses in the LOT position were delivered in the OA position. Of the 4 fetuses in the ROT positions at the last examination, 2 were delivered in the OA position, and 12 of the 25 fetuses in the OP position were delivered in the OA position.

All the 6 cases seen to rotate over the 6-o'clock position ended as spontaneous OA deliveries (rotating >180°). Furthermore, 2 cases rotated from the

FIGURE 1
Fetal head position at the first and last examinations



The circular bar graphs show the distribution and frequency of each occiput position at the first (left image) and at the last (right image) ultrasound examinations of nulliparous women in the active phase of labor with spontaneous onset at term. Each *bar* represents a marking on a clockface with half-hour intervals. The frequency at each position is counted from the center outward, the scale being represented on the y-axis. The *bars* are colored according to the classification of the occiput position.

LOT, left occiput transverse; *OA*, occiput anterior; *OP*, occiput posterior; *ROT*, right occiput transverse.

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left side to the right side (initially at the 3:30 position and 4-o'clock position) and 4 cases from the right side to left side (initially at the 6:30 position and 7-, 8-, and 9-o'clock positions).

Occiput position and mode of delivery

Overall, 75 women had a spontaneous delivery, 15 fetuses were delivered with vacuum extraction, 1 fetus was delivered with forceps, and 8 fetuses were delivered by cesarean delivery. Furthermore, 6 of the fetuses that were delivered by means of cesarean delivery were in the OP position at the first examination, 1 was in the OA position, and 1 was in the ROT position. At the last examination before birth, all 6 fetuses at the OP position remained in the OP position, the one in the ROT position had rotated to the OP position, and the one in the OA position remained in the OA position.

Direct occiput posterior position and mode of delivery

Of note, 14 fetuses were in the direct or almost direct OP position (from a 5- to 7-o'clock position) at inclusion, and 10 of the 14 fetuses (71%; 95% CI, 42—90) rotated to the OA position at delivery. Of the 14 fetuses, 11 were delivered spontaneously (79%; 95% CI, 49—94), 2 were delivered with instrumental assistance (1 in the OA position and 1 in the OP position at delivery), and 1 was delivered via cesarean delivery (in the OP position at delivery).

Oxytocin augmentation and occiput position at delivery

Of the women needing oxytocin augmentation, 8 of 41 women delivered a fetus in the OP position vs 6 of 58 women who did not receive oxytocin.

TABLE 2
Fetal position at each examination

Position	First n=99	Second n=93	Third n=60	Fourth n=47	Fifth n=20	Sixth n=15	Seventh n=3	Eighth n=3	Last n=99
Occiput anterior	19	28	19	24	6	8	0	2	61
Left occiput transverse	15	13	6	2	1	0	0	0	9
Occiput posterior	52	42	28	19	10	6	1	1	25
Right occiput transverse	13	10	7	2	3	1	2	0	4

Data are presented as number.

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The difference was not significant (P=.25).

Occiput position and fetal head station

Table 3 shows the ultrasound measurements of the fetal head station at the first and last examinations according to the occiput position at inclusion. OA position at inclusion was associated with lower stations (shorter HPD and wider AoP) at both the first and last examinations. Table 4 and Table 5 show the association between fetal position and station in all examinations. The occiput position was anterior in 75% of cases when HPD was ≤30 mm and in 73% of cases when AoP was ≥125° (corresponding to a clinical station of +1). The associations among fetal head station, occiput position, and time to delivery at each ultrasound examination are presented in Figure 2. The OA position did not become predominant until 2 hours before birth.

Occiput position and cervical dilatation

The relation between clinically assessed cervical dilatation and fetal head position is shown in Figure 3. OP positions persisted in >50% of cases throughout the first stage of labor but were anterior in 53 of 80 cases (66%) examined by full dilatation.

TABLE 3
Ultrasound measuring fetal head station at first and last examinations according to fetal head position at the first measurement

	OA (n=19)	LOT (n=15)	OP (n=52)	ROT (n=13)	*P* value
First examination					
AoP	107 (82–123)	98 (87–117)	98 (73–128)	103 (88–114)	.02
HPD	40 (24–56)	43 (37–56)	46 (29–66)	44 (31–54)	.05
Last examination					
AoP	128 (95–161)	110 (98–124)	106 (76–142)	116 (106–138)	<.01
HPD	27 (9–49)	40 (21–51)	41 (20–62)	33 (26–39)	<.01

Data are presented as median (interquartile range). The differences in median AoP and HPD measurements by fetal head position at inclusion were estimated with the Kruskal-Wallis test.

AoP, angle of progression; *HPD*, head-perineum distance; *LOT*, left occiput transverse; *OA*, occiput anterior; *OP*, occiput posterior; *ROT*, right occiput transverse.

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Comment

Principal findings

Determining the fetal head position with ultrasound during labor was easy and could always be done. We found that the OP position was the most common position at the first examination, but most of the OP positions were at the 4- or 8-o'clock position (Figure 1). The OP position remained the most common one until the cervix was fully dilated and the fetal head had descended below the midpelvic plane. All fetuses starting in the OA position were delivered in the OA position, 93% of fetuses starting in transverse positions rotated to the OA position, and 77% of fetuses starting in the OP position rotated and were delivered in the OA position.

Clinical significance

As ultrasound is being used increasingly during labor, accurate knowledge on fetal head position and rotation is needed. It is one of the factors observed in assessing labor progress, and deviations from the normal should guide the obstetrician and midwife to timely and correct interventions. Ultrasound could conceivably lead to an increased frequency of interventions if these mechanics are not well described.[33] We observed that the fetal head position could only be correctly identified in a minority of cases at inclusion, but even at the last examination, only around two-thirds of the clinical staff felt they could determine the position but with increasing accuracy. This is very much in agreement with other studies,[6–8,34,35] but Iversen et al[4] have shown that this can be improved with structured clinical assessment.

As shown in this study, at the start of the active phase of spontaneous labor, the OP position was common. This is important knowledge when estimating progress in established labor. In accordance with clinical knowledge, it is only persistent OP position that is likely to lead to delayed and difficult labor.[36] The OP position should not by itself be considered a negative sign. The fetal head should not be expected to rotate to the OA position until toward the end of labor, when the cervix is fully dilated and the head has descended below the midpelvic plane.

TABLE 4
Fetal head position at the level of the head-perineum distance

Position	>50 mm (n=51)	41–50 mm (n=116)	31–40 mm (n=112)	≤30 mm (n=57)
Occiput anterior	2 (4)	19 (16)	41 (37)	43 (75)
Left occiput transverse	6 (12)	18 (16)	11 (10)	2 (4)
Occiput posterior	33 (65)	64 (55)	49 (44)	10 (18)
Right occiput transverse	10 (20)	15 (13)	11 (10)	2 (4)

Data are presented as number (percentage).

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TABLE 5
Fetal head position at the level of the angle of progression

Position	<95° (n=68)	95°–109° (n=129)	110°–124° (n=95)	≥125° (n=45)
Occiput anterior	4 (6)	27 (21)	39 (41)	33 (73)
Left occiput transverse	10 (15)	17 (13)	10 (11)	0 (0)
Occiput posterior	46 (68)	67 (52)	37 (39)	9 (20)
Right occiput transverse	8 (12)	18 (14)	9 (10)	3 (7)

Data are presented as number (percentage).

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Research implications

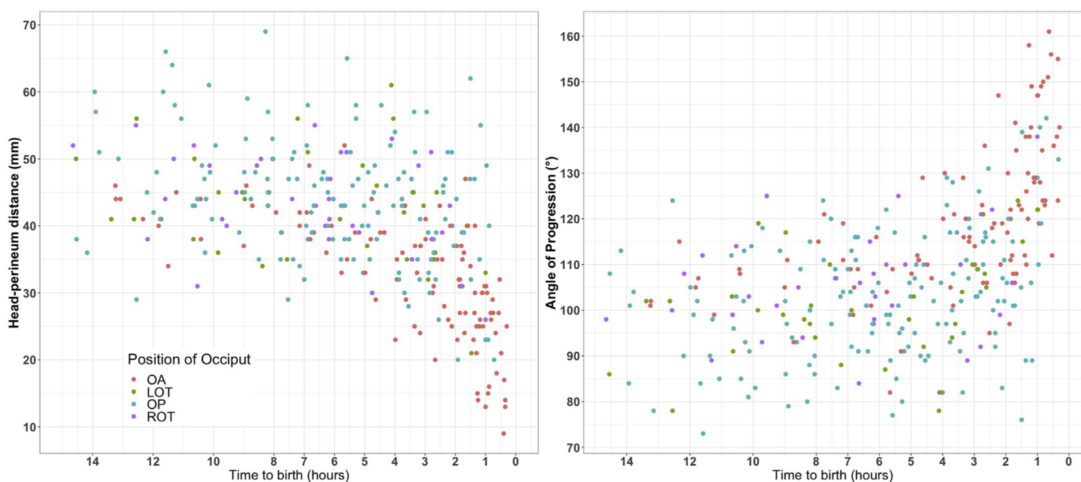
Occiput position at the first examination

Our findings of the high frequency of the OP position early in the active phase of labor differ from previous studies. The results from the original radiological studies by Caldwell et al[37] suggested that approximately 20% of fetuses were in the OP position; the results had the same frequency as the OA position, but OT positions were considered predominant. Steele and Javert,[38] also using radiology, found the fetus to be in OT position in over 60% of cases. The populations examined in these studies were, however, not very clearly defined or timed in relation to labor stages, and the technique used may not have given exact positions other than classifying them as OA, OP, or OT positions. Any degree of deviation from those positions may be open to interpretation because the landmarks inside the fetal skull could not be identified as accurately as now with ultrasound. The clinical study of Calkins[13] from 1939 showed the occiput to be posterior or in the direct transverse position in 50% of nulliparous women in early labor.

Several ultrasound studies have described the occiput position at induction or admission in spontaneous labor with frequencies of OP position varying from 15% to 38%.[7,20,39–45] The most obvious explanations for such percentage discrepancies are differences in how the OP position was defined. Some authors divided the pelvis into 4 parts,[44] some into 8 equal parts where the OP position would extend from the 5:15 position to the 6:45 position[7,20] or into 2 parts, anterior or posterior.[39] We used the definition proposed by Akmal et al[29,43,46] in which the OP position extends from 4- to 8-o'clock position. In the aforementioned studies, only transabdominal ultrasound examinations were used to determine the position, which can be inaccurate when the head is deeply engaged. We therefore combined transabdominal and transperineal scanning to improve accuracy.

Some variation may also be explained by different timing of the examinations. If examined before labor onset, the head is

FIGURE 2
Fetal head station and position in relation to time to delivery



The dot plot shows the fetal head station measured as head-perineum distance in millimeter (left image) and angle of progression in degrees (right image) on the y-axis in relation to time to delivery on the x-axis. The women examined were nulliparous in the active phase of labor with spontaneous onset at term. Delivery is at point 0, and the time to delivery is calculated backward. The dots are colored according to the classification of the occiput position.

LOT, left occiput transverse; *OA*, occiput anterior; *OP*, occiput posterior; *ROT*, right occiput transverse.

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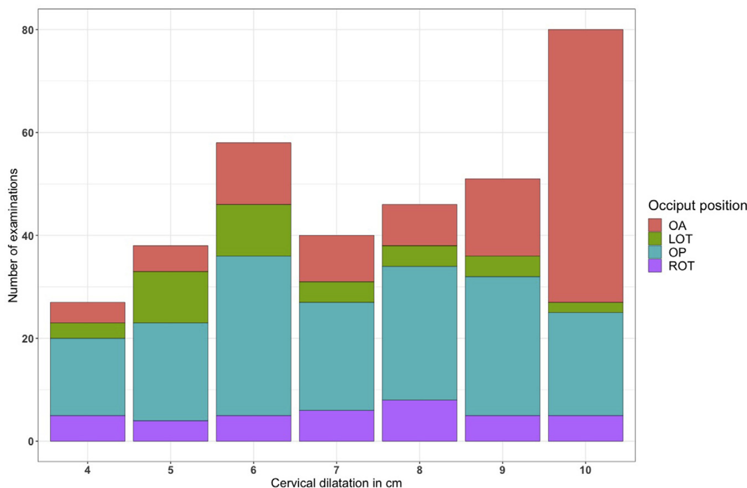
FIGURE 3
Fetal head position in relation to cervical dilatation



The bar graph shows the number of ultrasound examination at each cervical dilatation in centimeters. The women examined were nulliparous in the active phase of labor with spontaneous onset at term. The *bars* are colored according to the classification of the occiput position.

LOT, left occiput transverse; *OA*, occiput anterior; *OP*, occiput posterior; *ROT*, right occiput transverse.

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most often in the transverse position at the inlet, but during the negotiation of the pelvic cavity, the occiput may have to fit into the hollow posterior aspect at each side of the sacral promontory, which may explain the higher frequency in our study conducted in established labor.

Occiput rotation during labor

Of note, 3 longitudinal ultrasound studies have examined fetal rotation.[20,45,47] The populations studied in 2 of them were a mixed group of nulliparous and multiparous women, and all included women in both spontaneous and induced labors with a limited number of repeated examinations being reported or a large dropout owing to uninterpretable ultrasound scans so it is not possible to form a full picture of when the rotation occurs from these studies. To avoid this, we included only nulliparous women with spontaneous labor onset and combined abdominal and perineal ultrasound approaches. This allowed the presentation of more detailed information about the exact fetal position and when the rotation occurs during labor. Our results agree with those of Adam et al[47] and Souka et al[20] in that a fetus in the anterior fetal head position at admission in labor does not malrotate to an OP position and the results of Lieberman et al[45] that fetal head rotation is a late occurrence during labor.

Our findings that 77% of OP positions during labor rotated to be delivered in the OA position confirm the results of other studies of mixed groups of nulliparous and multiparous women in various stages of active labor.[20,44,46,47] This was similar for the group that were near to direct OP at inclusion (from the 5- to 7-o'clock position) where 71% of cases rotated to the OA position.

Oxytocin use could possibly have an effect on the rotational forces during labor, but we did not observe a difference in the frequency of persistent OP position in connection with oxytocin use.

Only 2 of 12 OP deliveries were in the OT position on admission, whereas all the others had an original OP position. This confirms the view of several authors that an OP position at delivery results from failed rotation from an original OP position at the pelvic inlet[20,46–48] rather than being a malrotation from an OT or OA position as suggested by Gardberg et al.[39]

The frequency of rotation of more than 180° has not been described before but was seen in 5% (95% CI, 2–12) of our study population.

Occiput position and head descent

We have demonstrated the higher station of the fetal head in the OP and OT positions in early labor. The rotation from the common OP position to the OA position did not occur until the head began to descend, and the OA position was not predominant until below the midpelvic plane. It is not clear whether the descent precedes the rotation, but it is likely that this happens simultaneously.

Occiput position and cervical dilatation

We also confirmed the association between fetal head rotation and cervical dilatation ascertained during the clinical examinations. The OP position was the most common position up to the point when cervical dilatation had been completed (Figure 3). Only then could the OA position be demonstrated in >50% of cases. This is a further confirmation of the late occurrence of fetal head rotation to the OA position, which only becomes the most common position within approximately 2 hours before birth. In a cross-sectional study by Akmal et al,[46] the frequency of OP, OA, and OT positions was very similar during the first stage of labor, but the OA position predominated with 64% of cases at full dilatation. Similar results were obtained by Souka et al[20] (74% of cases in the OA position at full dilatation).

Strengths and limitations

The main strength of our study was the prospective, longitudinal design examining a well-defined group of nulliparous women in spontaneous labor throughout the active phase. We used objective and reliable methodology and combined transabdominal and transperineal

ultrasound examinations for defining the exact fetal position. The definition of the active phase at 4 cm dilatation was according to the WHO criteria recommended during the recruitment period. We are aware of recent suggestions of changing the definition to 5[49] or 6 cm,[50] but because we use delivery as the fixed reference point, the definition of active labor will not have had an important impact. The relatively limited sample size was a weakness, especially regarding the operative delivery numbers. The external validity needs to be confirmed by further studies in similarly well-defined groups of parous women and women in induced labor. The experience of the 2 ultrasound operators in fetal medicine was a strength for validating the results but might be considered a weak point for external validation. It has, however, been demonstrated that the skills needed for examining women in labor with ultrasound are easily obtained[51] and have a shorter learning curve than vaginal examination skills.[12] The varying degree of experience in clinical vaginal examinations by the labor ward staff might likewise be considered a weakness. This does, however, represent the situation in most labor wards, and this is likely to be improved with the ultrasound methods described in the study. A further weakness was our inability to examine the active phase from the start by some women who were admitted late in labor. This came from the way women were recruited into the study, but it also represents the reality among spontaneously laboring women. Excluding those women would have created a selection bias. Although we included fetal station and rotation in our study, fetal attitude and flexion of the fetal head were not considered as a possible and additional variable for labor progress. The occiput-spine angle is easy to measure in OA positions, but more challenging in OP positions.[52]

Conclusions

We have followed and given a detailed description of the rotation of the fetal head throughout the active phase of labor in nulliparous women in spontaneous labor, using accurate, objective ultrasound methods. The OP position was the most common position throughout the first stage, and the OA position only became most frequent at full dilatation and after the head had descended below the midpelvic plane. No fetus was seen to rotate from the OA position to the OP position, and most of the initial OT and OP positions rotated to the OA position, but commonly late in labor.

Highlights

- Ultrasound was used to examine fetal head rotation longitudinally during the active phase of labor.
- More than 50% of fetuses were in the OP position throughout the first stage of labor.
- The OA position only became the most common position below the midpelvic plane.
- All initially anterior, 93% transverse, and 77% posterior positions were delivered in the OA position.
- Fetal head rotation most often occurs at full dilatation and below the midpelvic plane.
- Rotation could be >180° for some fetuses. ■

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Paper III

Can ultrasound on admission in active labor predict labor duration and a spontaneous delivery?

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Structured Abstract

Background

Identifying predictive factors for a normal outcome at admission in the labor ward would be of value for planning labor care, timing interventions and in preventing labor dystocia. Clinical assessments of fetal head station and position at the start of labor have some predictive value but the value of ultrasound methods for this purpose has not been investigated. Studies using transperineal ultrasound before labor onset show possibilities of using these methods to predict outcome.

Objective

To investigate if ultrasound measurements during the first examination in the active phase of labor were associated with the duration of labor phases and the need for operative delivery.

Study Design

This was a secondary analysis of a prospective cohort study at Landspitali University Hospital, Reykjavik, Iceland. Nulliparous women at ≥37 weeks with a single fetus in cephalic presentation and spontaneous labor onset were eligible. The recruitment period was from January 2016 to April 2018.

Women were examined by a midwife on admission and included if in established active phase defined as regular contractions with a fully effaced cervix, open four cm or more. An ultrasound examination was performed by a separate examiner within 15 minutes, both examiners were blinded to the other's results. Transabdominal and transperineal ultrasound were used to assess fetal head position, cervical dilatation and fetal head station expressed as head-perineum distance and angle of progression.

Duration of labor was estimated as the hazard ratio for spontaneous delivery using Kaplan-Meier curves and Cox regression analysis. The hazard ratios were adjusted for maternal age and BMI. The associations between study parameters and mode of delivery were evaluated using receiver-operating characteristic curves.

Results

Median time to spontaneous delivery when head-perineum distance was ≤45 mm was 490 minutes compared to 682 min when >45mm (log rank test, p=0.009, but the adjusted HR for shorter HPD was 1.47; 95% CI; 0.83 to 2.60). For angle of progression ≥93° the median duration was 506 minutes compared to 732 min when <93° (log rank test, p=0.008, adjusted HR for AoP was 2.07; 95% CI: 1.15 to 3.72). The median time to delivery for non-occiput posterior positions was 506 minutes compared with 677 minutes for occiput posterior positions (log rank test, p=0.07, adjusted HR 1.52; 95% CI: 0.96-2.38) Median time to delivery was 429 minutes for dilatation of ≥6 cm and 704 minutes for dilatation of 4-5 cm (log rank test, p=0.002, adjusted HR 3.11; 95% CI: 1.68 to 5.77).

Spontaneous deliveries were 75, 16 were instrumental vaginal (one forceps and 15 ventouse) and eight were cesarean deliveries. Head-perineum distance was associated with spontaneous delivery with AUC=0.68 (95% CI; 0.55 to 0.80) and angle of progression with

AUC=0.67 (95% CI; 0.55 to 0.80). Ultrasound measurement of cervical dilatation or position at inclusion were not significantly associated with a spontaneous delivery.

Conclusions

Ultrasound examinations showed that fetal head station and cervical dilatation was associated with the duration of labor but measurements of fetal head station were the variables best associated with operative deliveries.

Abbreviations: OP, occiput posterior; HR, hazard ratio; CI, confidence intervals; AUC, area under the curve; HPD, head perineum distance; AoP, angle of progression.

Keywords: Angle of progression, fetal head station, head perineum distance, labor, transperineal ultrasound, delivery time

Introduction

The length of labor is highly individual. Prolonged labor is known to increase the risk of adverse outcomes for the mother and fetus and is associated with a negative birth experience.[1, 2] Slow progress in labor occurs in 13-37% of nulliparous women and dystocia is a frequent indication for cesarean section during labor.[3-5] It would be advantageous to be able to predict which women will deliver vaginally when they enter labor. Various factors have been used to try to predict the need for cesarean section before labor, especially before labor induction[6-9] or in women who have had a previous cesarean section. Very few studies have been done among women expecting to go into spontaneous labor or when they are admitted to a labor ward.[10-12] Among the factors investigated are maternal characteristics such as age, height, BMI and gestational age, but also clinical factors such as cervical dilatation and station and position of the fetal head. Although cervical dilatation is relatively easily assessed with digital vaginal palpation, assessments of both head station and position have been shown to be subjective and often inaccurate.[13-16]

Transabdominal and transperineal ultrasound is increasingly used as an adjunct to clinical assessment during labor, since fetal head position and descent into the pelvic cavity are more accurately determined with ultrasound than digitally.[16-18] The International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) has published guidelines for the use of ultrasound in labor.[19] We have shown that these methods can be used to follow labor progress in terms of fetal head station and position.[20, 21] Identifying predictive factors for a normal outcome early in the labor process would be desirable and of value for planning labor care, allowing for better targeted interventions and resources when labor dystocia is more likely to arise. Previous studies using transperineal ultrasound before spontaneous or induced labor have shown that it is possible to use these methods to predict outcome.[22-24] A prediction model in normal and prolonged nulliparous labors has even been

constructed.[25] We aimed to investigate how ultrasound assessments during the first examination in the active phase of labor were associated with duration of labor phases and delivery mode.

Materials and methods

This was a secondary analysis of a prospective cohort study at Landspitali University Hospital in Reykjavík, Iceland, between January 2016 and April 2018. We examined 99 women with ultrasound longitudinally through the active phase of labor. The fetal head descent and fetal rotation patterns in this group have been published.[20, 21] In this study we concentrate on the predictive value of the first ultrasound examination.

Women over the age of 18 with a single fetus in cephalic presentation and a spontaneous start of labor at gestational age ≥37 weeks were eligible and recruited in a non-consecutive manner. The study population corresponded to the definition of group 1 in the Robson 10-group classification system (nulliparous women in spontaneous labor).[26] Oral and written information about the study was provided by a midwife on admission to the labor ward and written consent obtained before inclusion.

Active labor was defined by a clinical examination as a fully effaced cervix, open at least four centimeters in the presence of regular contractions in agreement with the actual WHO recommendations.[27, 28] Women were included after the initial examination if they were in established active phase or when the active phase was diagnosed in the women who had been admitted in the latent phase.

A midwife examined cervical dilatation clinically at admission. An ultrasound examination was then done by one of two obstetricians trained in both transabdominal and transperineal scanning within 15 minutes. Results of the ultrasound examination were not revealed to the labor ward staff and the ultrasound examiners were not involved in clinical decisions regarding the laboring women.

The main outcome measure was duration of the active phase of labor estimated as the likelihood for spontaneous delivery and expressed by a hazard ratio (HR). Secondary outcomes were duration of the second stage, duration of active pushing phase and mode of delivery. Independent test variables were the ultrasound findings of head-perineum distance (HPD), angle of progression (AoP), fetal head position and cervical dilatation. The guidelines at the hospital have no upper limit for the duration of the active phase of labor, but the second stage should not be longer than four hours and active pushing no longer than two hours.

The ultrasound device used was Voluson *i* (GE Medical systems, Zipf, Austria) with a 3.5-7.5- MHz 3D curved multi-frequency transabdominal transducer. The ultrasound examination comprised both a transabdominal and transperineal scan. To

determine the fetal head position, the transabdominal approach was used first. For this purpose, views of the fetal spine, orbits, midline structures of the fetal head and the choroid plexus were obtained. When this was not possible, due to deep engagement of the fetal head, the transperineal approach was used to determine position, obtaining views of the midline structures, the thalami and the choroid plexuses. The fetal head position was defined as the position of the occiput marked on a clock face graph with half-hour intervals. The occiput posterior position was categorized as ≥04:00 and ≤08:00 o'clock as described by Akmal et al.[29, 30]

Further, during the transperineal scan, AoP, HPD and cervical dilatation were assessed. AoP was measured in the sagittal plane as the angle between the longitudinal axis of the pubic symphysis and a line from the most inferior edge of the symphysis tangentially to the lowest contour of the fetal head.[31] The HPD was measured in the frontal plane (transverse plane related to perineum) as the shortest distance from the transducer to the fetal skull as previously described.[24, 32] After measuring HPD, the transducer was tilted posteriorly until the cervix could be seen.[33-35] Both the anterior-posterior and transverse diameters of the cervical dilatation were measured and the mean value used for calculations. All measurements were done in-between contractions.

All data were collected and managed using REDCap electronic data capture tools hosted at Landspitali University Hospital.[36] The study was approved by the Landspitali Ethics Committee, reference no. 26/2015.

Statistical analysis

The associations between spontaneous vaginal delivery vs. all operative deliveries related to ultrasound assessed HPD, AoP and cervical dilatation as continuous variables were evaluated using receiver-operating characteristic (ROC) curves. To find the best cut-off levels of HPD and AoP for predicting spontaneous delivery, Youden´s J statistic was employed.

To evaluate differences in the time interval from inclusion to spontaneous vaginal delivery according to fetal head station, position and cervical dilatation, we used Kaplan-Meier methods and Cox regression analyses. The Kaplan-Meier method was used to generate plots for fetal head station categories, for OP vs. non-OP positions and for cervical dilatation <4-5 cm vs. ≥6 cm. The plots were compared with a log rank test. Cox regression analyses were used to calculate hazard ratios (HR) as an estimate of the likelihood ("risk") of spontaneous delivery using the same categories for HPD, AoP, cervical dilatation and occiput positions for comparison. Cesarean sections and operative vaginal deliveries were censored.

We used the statistical software package R Core Team (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Results

Study population

One hundred women were included, but one woman withdrew her consent. The study population characteristics and labor outcomes are given in Table 1. Clinically assessed cervical dilatation at inclusion was four cm in 26 women, five in 30, six in 19, seven in 16 and eight in six women and in two women the dilatation was nine and ten cm. At inclusion, 49 women had confirmed rupture of membranes.

Table 1. Characteristics of the study population of 99 nulliparous women with a singleton fetus at term, examined with ultrasound early in the active phase of labor.

Characteristics	Median (range) or n (%)
Age	27.0 (18-40)
Body mass index (kg/m^2)	23.3 (16.7-36.3)
Oxytocin augmentation	41 (41.4)
Epidural analgesia	61 (61.6)
Spontaneous delivery	75 (75.8)
Ventouse delivery	15 (15.2)
Forceps delivery	1 (1.0)
Cesarean section	8 (8.1)
Blood loss (ml)	400 (100-2000)
Episiotomy	13 (13.3)
Degrees of perineal tear	
None	19 (19.2)
1°	22 (22.2)
2°	53 (53.5)
3°	5 (5.1)
Birthweight (g)	3540 (2480-5000)
Apgar score at 1 min	9 (2-10)
Apgar score at 5 min	10 (5-10)
Gestational age (days)	280 (259-293)

Spontaneous delivery

In all, 75/99 women achieved a spontaneous delivery, and 24 were delivered operatively; eight with a cesarean and 16 with an instrumental vaginal delivery. All but one of the operative deliveries were owing to prolonged first or second stage of labor (further details can be found in a longitudinal study describing the patterns of fetal head descent).[21] Of the 52 women that had a fetus in the OP position at inclusion, 35 (67%) delivered spontaneously compared with 40/47 (85%) women who had a fetus in a non-OP position (p=0.06). The ROC curve analyses for the associations between HPD and AoP at inclusion in prediction of a spontaneous delivery are shown in Figure 1. HPD was associated with spontaneous delivery with AUC=0.68 AUC (95% CI: 0.55 to 0.80) and AoP with 67% AUC=0.67 (95% CI: 0.55 to 0.80). The best cut-off level for predicting spontaneous delivery was HPD of ≤45mm and AoP of ≥93°. These levels were also used for

stratification into groups for comparison of labor duration. Ultrasound measurement of cervical dilatation was not associated with a spontaneous delivery, with an AUC of 0.50 (95% CI, 0.38-0.63).

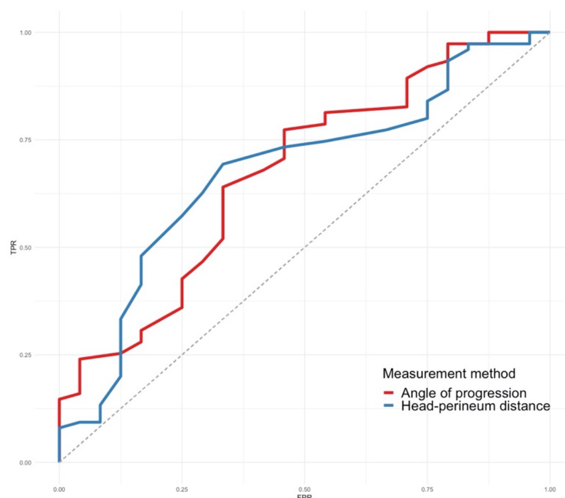

Figure 1: Receiver-operating characteristic (ROC) curves for angle of progression and head-perineum distance measurements in the prediction of spontaneous vaginal delivery in nulliparous women on admission in active spontaneous labor at term.

The test characteristics of ultrasound measurements in predicting spontaneous delivery are presented in Table 2.

Table 2: Test characteristics of ultrasound measurements of head-perineum distance and angle of progression in predicting spontaneous vaginal delivery

	Sensitivity	Specificity	FPR	PPV	NPV	PLR	NLR
Head-perineum distance (mm)							
≤40	0.33 (0.23, 0.45)	0.88 (0.68, 0.97)	0.12 (0.03, 0.32)	0.89 (0.72, 0.98)	0.30 (0.19, 0.42)	2.67	0.76
≤45	0.67 (0.45, 0.84)	0.67 (0.45, 0.84)	0.33 (0.16, 0.55)	0.87 (0.75, 0.94)	0.41 (0.26, 0.58)	2.08	0.46
≤50	0.80 (0.69, 0.88)	0.25 (0.10, 0.47)	0.75 (0.53, 0.90)	0.77 (0.66, 0.86)	0.29 (0.11, 0.52)	1.07	0.80
≤60	0.97 (0.91, 1.00)	0.04 (0.00, 0.21)	0.95 (0.79, 1.00)	0.76 (0.66, 0.84)	0.33 (0.01, 0.91)	1.02	0.64
Angle of progression (°)							
≥110	0.24 (0.15, 0.35)	0.96 (0.79, 1.00)	0.04 (0.00, 0.21)	0.95 (0.74, 1.00)	0.29 (0.19, 0.40)	5.76	0.79
≥100	0.57 (0.45, 0.69)	0.67 (0.45, 0.84)	0.33 (0.16, 0.55)	0.84 (0.71, 0.93)	0.33 (0.20, 0.48)	1.72	0.64
≥93	0.79 (0.68, 0.87)	0.46 (0.26, 0.67)	0.54 (0.33, 0.74)	0.82 (0.71, 0.90)	0.41 (0.22, 0.61)	1.45	0.47
≥90	0.87 (0.77, 0.93)	0.29 (0.13, 0.51)	0.71 (0.49, 0.87)	0.79 (0.69, 0.87)	0.41 (0.18, 0.67)	1.22	0.46
≥80	1.00 (0.95, 1.00)	0.12 (0.03, 0.32)	0.88 (0.68, 0.97)	0.78 (0.69, 0.86)	1.00 (0.29, 1.00)	1.14	0.00

FPR, false-postitive rate; PPV, positive predictive value; NPV, negative predictive value; PLR, positive likelihood ratio; NLR, negative likelihood ratio

Duration of labor

At inclusion fetal station expressed as ultrasound measured HPD was ≤45 mm in 60 women and >45 mm in 39. The estimated median time in active labor when HPD was ≤45 mm was 490 minutes vs. 682 min if the HPD >45 mm (log rank test, *p*=0.009). The probability of being delivered is illustrated with Kaplan-Meier curves (1-survival) in Figure 2.

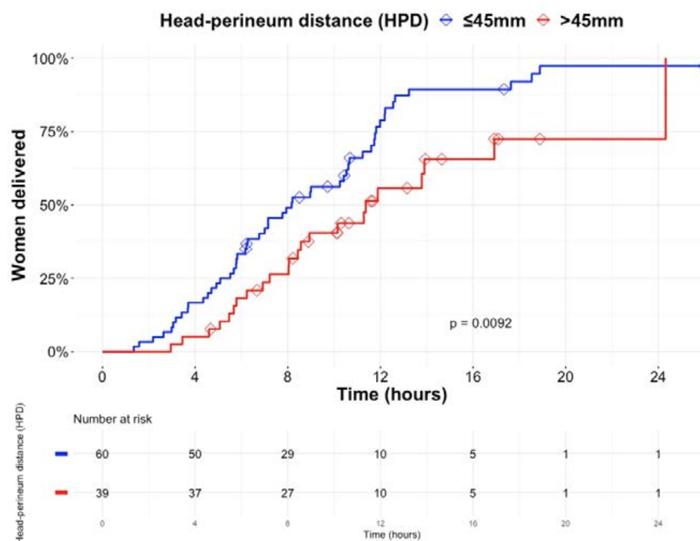

Figure 2: Kaplan-Meier curves of time from the first examination in the active phase to delivery in 99 nulliparous women in spontaneous labor. The curves are stratified as to head-perineum distance ≤45mm and >45mm. Cases with operative delivery were censored (diamonds on survival lines).

The HR for a spontaneous vaginal delivery showed a shorter duration of labor associated with smaller HPD (HR=1.90 (95%CI, 1.16 to 3.11), but the association was not significant after adjusting for maternal age and BMI (HR =1.47, 95% CI, 0.83-2.60).

Fetal station expressed as AoP was ≥93° in 69 women and <93° in 30 women. The estimated median time in active labor was 506 min in the former vs. 732 min in the latter group (log rank test, *p*=0.008) and the probability of being delivered is shown in Figure 3. The HR for a spontaneous delivery associated with wider AoP values was 2.06 (95% CI, 1.19 to 3.56) and remained significant after adjusting for maternal age and BMI; HR 2.07 (95% CI, 1.15 to 3.72).

Of the fetuses 52/99 were in the OP position at inclusion. The estimated median time in active labor was not significantly associated with fetal position at inclusion, i.e. 506 min in non-OP positions vs. 677 min in OP positions (log rank test, *p*=0.07). The HR for a spontaneous delivery associated with non-OP positions illustrated as a Kaplan-Meier plot (1-survival) in Figure 4 was 1.51 (95% CI, 0.96 to 2.38) and it did not change after adjusting for maternal age and BMI; HR 1.54 (95% CI, 0.97 to 2.46).

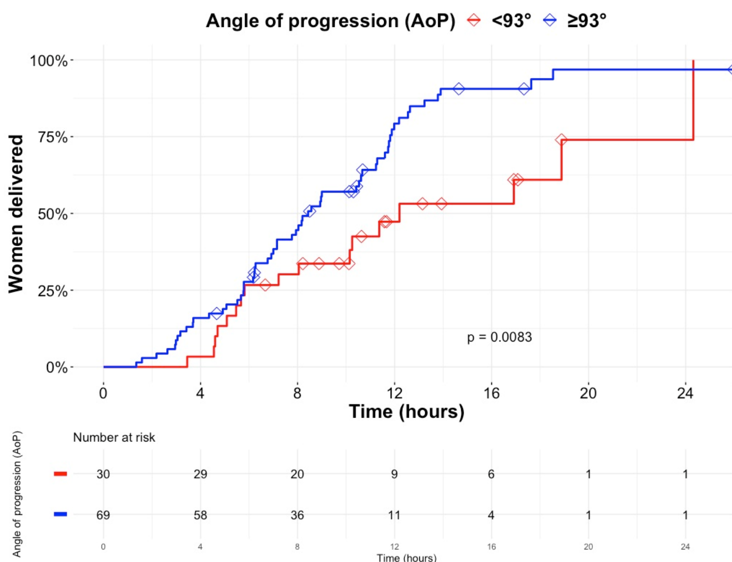

Figure 3: Kaplan-Meier curves of time from the first examination in the active phase to delivery in 99 nulliparous women in spontaneous labor. The curves are stratified as to angle of progression ≥93° and <93. Cases with operative delivery were censored (diamonds on survival lines).

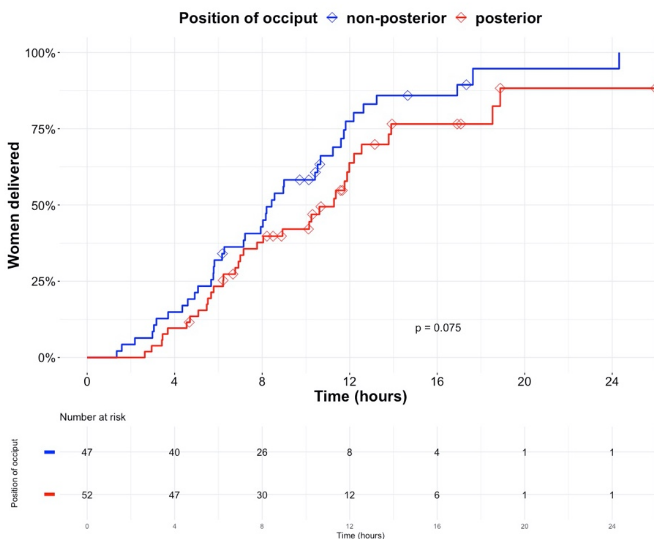

Figure 4: Kaplan-Meier curves of time from the first examination in the active phase to delivery in 99 nulliparous women in spontaneous labor. The curves are stratified as to non-occiput posterior and occiput posterior positions. Cases with operative delivery were censored (diamonds on survival lines).

Ultrasound assessment of cervical dilatation showed that 64 women had dilatation of 4-5 cm, 23 women were dilated ≥6 cm and in 12 women dilatation could not be measured. Dilatation could be assessed in 40/49 with ruptured membranes versus 45/48 with intact membranes, *p*=0.26. The estimated median duration of active labor was 429 min for dilatation of ≥6 cm and 704 for dilatation of 4-5 cm (log rank test, *p*=0.002). The HR for spontaneous delivery associated with greater dilatation illustrated as a Kaplan-Meier plot (1-survival) in Figure 5 was 2.45 (95% CI, 1.38-4.36) and after adjusting for maternal age and BMI the HR was 3.11 (95% CI, 1.68-5.77).

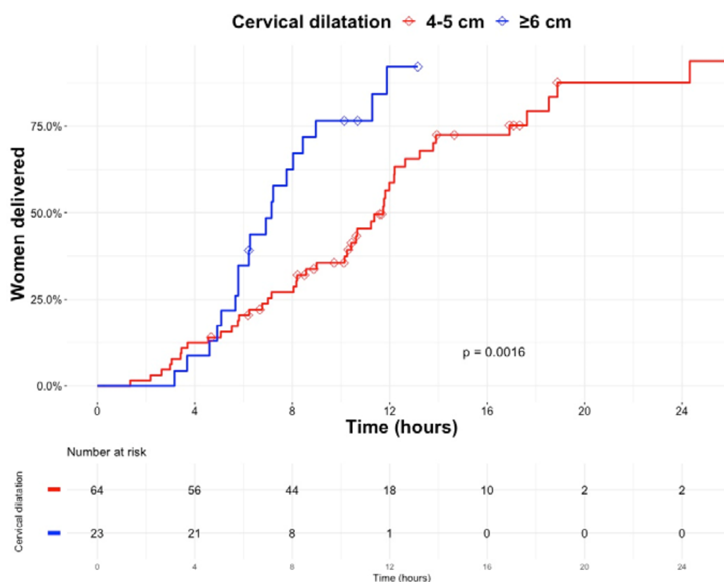

Figure 5: Kaplan-Meier curves of time from the first examination in the active phase to delivery in 99 nulliparous women in spontaneous labor. The curves are stratified as to ultrasound assessed cervical dilatation of 4-5 cm and ≥6 cm. Cases with operative delivery were censored (diamonds on survival lines).

Duration of the second stage

The estimated median duration of the second stage was 92 minutes if HPD was ≤45 mm at inclusion vs. 109 minutes if HPD was >45 mm (*p*=0.06). The HR for a spontaneous delivery related to smaller HPD values was 1.61 (95%CI, 0.97 to 2.64), but the association was not significant after adjusting for maternal age and BMI (HR =1.50, 95% CI, 0.85-2.65). The estimated median duration of the second stage was 93 minutes if the AoP was ≥93 degrees at inclusion vs. 124 minutes if AoP was <93 degrees (p=0.04). For larger AoP values the HR for spontaneous delivery was 1.76 (95% CI, 1.02 to 3.04) and was 1.59 (95% CI, 0.88 to 2.88 after adjusting for maternal age and BMI.

Occiput position and cervical dilatation at inclusion were not associated with the estimated duration of the second stage.

The estimated median duration of the active second stage was 62 min if AoP was ≥93 degrees at inclusion vs. 75 min if AoP was <93 degrees (p=0.03). For larger AoP values the HR for spontaneous delivery was 1.86 (95% CI, 1.05 to 3.32) and after adjusting for age and BMI it was 1.97 (95% CI 1.06 to 3.68). None of the other parameters examined were associated with the estimated duration of active pushing (Table 3).

Table 3: Cox regression analysis for risk ("likelihood") of a spontaneous delivery in nulliparous women examined at the diagnosis of the active phase of labor

Parameter	Unadjusted HR	95% CI	Adjusted HR	95% CI
Active phase				
Non-occiput posterior	1.51	0.96-2.38	1.54	0.97-2.46
HPD ≤45 mm	1.90	1.16-3.11	1.47	0.83-2.60
AoP ≥93°	2.06	1.19-3.56	2.07	1.15-3.72
Cervical dilatation examined with ultrasound ≥ 6 cm	2.45	1.38-4.36	3.11	1.68-5.77
Second stage				
Non-occiput posterior	1.40	0.89-2.21	1.43	0.89-2.29
HPD ≤45 mm	1.61	0.97-2.64	1.50	0.85-2.65
AoP ≥93°	1.76	1.02-3.04	1.59	0.88-2.88
Cervical dilatation examined with ultrasound ≥ 6 cm	1.57	0.91-2.70	1.76	0.98-3.16
Active second stage				
Non-occiput posterior	1.45	0.92-2.28	1.54	0.97-2.46
HPD ≤45 mm	1.55	0.94-2.55	1.52	0.87-2.65
AoP ≥93°	1.86	1.05-3.32	1.97	1.06-3.68
Cervical dilatation examined with ultrasound ≥ 6 cm	1.43	0.83-2.47	1.50	0.84-2.68

HR with CI not crossing 1.0 were assumed significant

CI, confidence interval; HR, hazard ratio; HPD, head-perineum distance; AoP, angle of progression

Comment

Principal Findings

Fetal head station measured with ultrasound as HPD and AoP in the early active phase of labor was associated with both the time remaining in labor and with the duration of the second stage. HPD and AoP were associated with a spontaneous delivery with AUC=0.68 and 0.67, respectively. Ultrasound assessed cervical dilatation in the early active phase of labor was significantly associated with labor duration, but not with delivery mode. Fetal head position at the first examination in the active phase was neither associated with duration of labor nor delivery mode.

Results in context

The prediction of mode of delivery in nulliparous women using clinical factors on

admission in labor has been investigated.[10, 11, 37-39] Turcot et al. found that cervical dilatation on admission could predict operative delivery but less than one third of women had a cervical dilatation ≥4 cm at inclusion.[39] Janssen et al. found that less advanced cervical dilatation and higher fetal station predicted cesarean delivery and a model developed based on these and a few other factors predicted cesarean delivery with AUC=0.71.[11] However, in their study only one quarter of the women were included at >4 cm. Wilkes et al. found that a change in cervical dilatation and station 2 h after admission was better in predicting cesarean delivery than the initial dilatation and station.[38] de Souza et al. studied nulliparous and multiparous women in both spontaneous and induced labor at less than 7 cm dilatation and a prediction model based on clinical factors on admission predicted cesarean delivery with AUC=0.78, but that prediction was better when using information obtained during labor.

The value of transperineal ultrasound in predicting labor outcomes has previously been investigated before the onset of labor and in laboring women.[22-25, 40-42] In these studies the cohorts have comprised mixed groups of parous and nulliparous women and labors with spontaneous and induced labors. Marsoosi et al. studied 70 nulliparous and parous women and suggested that AoP might predict vaginal delivery when measured on admission in active labor.[40] Chor et al. studied hourly changes of several clinical and ultrasound parameters in nulliparous women in both induced and spontaneous labor and found that changes in progression distance could be of use for predicting cesarean delivery due to non-progressive labor.[42] Chan et al. studied nulli- and multiparous women in active, induced and spontaneous labor and suggested that a combination of AoP and HPD could be used to predict time to a normal spontaneous delivery.[41] Torkildsen et al studied women in prolonged labor and found HPD and AoP to predict vaginal delivery with AUC of 0.81 and 0.76 respectively.[5] Eggebø et al. studied nulliparous women in prolonged labor and found that a model combining maternal factors known to be associated with delivery mode with ultrasound factors could be useful in predicting vaginal delivery.[25] Fetal head position was found to be of value in predicting cesarean delivery in nulliparous women with a prolonged first stage in another study by Eggebø et al. but did not predict operative vaginal delivery nor remaining time in labor.[43] Comparisons with these studies suggest that the value ultrasound in assessing fetal head station and reliably confirming position may be greater in predicting operative delivery when labor is prolonged than at the outset of a spontaneous labor.

Ultrasound AoP and HPD are different but interrelated methods for assessing fetal head station. We included both in our study and found good correlation between the methods as shown before.[44] Both methods may be associated with the duration of labor and delivery mode because there was only modest variation of the respective predictive values and their confidence limits. Both approaches have in previous studies been found to be of value to indicate the likelihood of successful descent of the fetal head through the birth

canal and thus vaginal delivery.[5, 31, 32, 45-48]

Ultrasound measurements of cervical dilatation are more challenging than assessment of position and measurements of HPD and AoP, especially after rupture of the membranes. Objective measurements are possible after training, and good repeatability has been shown.[33] Ultrasound cannot replace clinical assessment of cervical dilatation at late stages, but has the potential to be used as an admission test.[35]

Clinical Implications

Our results show the expected variation of duration of the active phase of labor and that cervical dilatation at admission is associated with the duration of labor. In addition, we show that assessing the fetal head station with ultrasound has a role as it is not only associated with duration of the active phase and the second stage but also with spontaneous vaginal delivery. We can confirm suggestions from previous studies that the position of the fetal head at the diagnosis of the active phase does not seem to have an effect on the duration of labor or the mode of delivery.[17, 22]

Based on our results, measuring HPD and AoP on admission in the active phase of labor could identify those women who are at low risk of intervention and assessed as being more likely to have shorter durations of labor. These women could then be reassured and offered a low risk environment but other women who are assessed as having a higher risk, based on measurements showing high fetal head station, could be observed more closely for signs of slow progress in terms of fetal descent and cervical dilatation. They could also be better informed of more realistic expectations of labor duration and offered more effective pain relief as soon as active labor is diagnosed. Other supportive measures could also be ensured, such as one-to-one midwifery care. Our results do not suggest that we have, as yet, a reliable method to find those women who ultimately will need an operative delivery as progress is so individual. Given the late occurrence of fetal head descent and rotation observed in our longitudinal study of the same group of women[20] it is possible that change over time is a better predictor of outcome than a spot assessment at admission, as suggested by other researchers.[38, 39, 49, 50]

Research Implications

We investigated the association between ultrasound and spontaneous vaginal deliveries instead of cesarean delivery as we only had eight such deliveries. Results based on such small numbers could be subject to greater errors so this should be studied in larger groups. It is possible that fetal head station is more strongly associated with cesarean delivery than all operative deliveries. If confirmed the results could be used to construct a labor admission test helping to stratify risk along with other demographic and pregnancy risk factors.

Strengths and Limitations

A strength of our study was the homogenous group of spontaneously laboring nulliparous women recruited and assessed when the active phase was diagnosed. We were also able to report on ultrasound measurements of cervical dilatation as well as fetal position and station using methods that can be regarded as established. The ultrasound examiners were fetal medicine experts, which is a strength in documenting the potential value of ultrasound, but also a potential limitation for external validation. At the present time, only few obstetricians and midwives are trained in these methods, but that is likely to change. In 2018 WHO changed the definition of the active phase of labor, and recommended that cervical dilatation should be at least five cm at the start of the active phase.[51] We used the WHO criteria recommended at the time when the study was planned and executed; regular contractions, cervix effaced and dilatation of ≥4 cm.[27] Women were also recommended to stay at home until contractions were regular.

That women had varying degrees of cervical dilatation at inclusion could be considered a limitation. We had no way of knowing the actual length of the active phase among most of the women because they were already in established labor on admission. On the other hand, this reflects the reality of labor and we were keen to observe whether outcomes could be predicted at the time of the ultrasound examination. Other limitations were the observational design and the size of the cohort. The low cesarean section rate in this population was in line with usual audits from our hospital, but differs from many other departments; which may limit the external validation.

Conclusions

We found that ultrasound assessments of fetal head station on entry to the labor ward in the active phase were associated with labor duration and the duration of the second stage and to be modestly associated with spontaneous delivery. Cervical dilatation assessed with ultrasound at the same time was associated with the duration of labor but not with spontaneous delivery. Ultrasound assessments of fetal head position were neither associated with labor duration nor the mode of delivery. Ultrasound can be used to categorize women into low- and high-risk groups, but it cannot, reliably, define a subset of women needing operative delivery.

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Paper IV

AOGS
Acta Obstetricia et Gynecologica Scandinavica

AOGS ORIGINAL RESEARCH ARTICLE

Reproducibility and acceptability of ultrasound measurements of head–perineum distance

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Key words
Delivery, head–perineum distance, labor, perineum, ultrasound

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Conflict of interest
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Abstract

Introduction. We aimed to test the reproducibility of head–perineum distance (HPD) measurements using two different ultrasound devices and five examiners, to compare ultrasound measurements and clinical assessments and to study if ultrasound examinations were acceptable for women in labor. *Material and methods.* A reproducibility study was performed at Lund University Hospital, Sweden and Landspitali University Hospital, Iceland from February 2015 to February 2017. The study population comprised 40 healthy women in labor. HPD was measured with three replicate measurements from each woman with two different ultrasound devices, and the measurements were compared with clinical assessments. Acceptability was tested with a visual analog scale (VAS), and the mean VAS score from both ultrasound devices was compared with the VAS score from clinical palpation. *Results.* The median time interval between start of examinations with devices was 10 min (range 1–26 min). The intra-observer repeatability coefficient was 4.3 mm and the intraclass correlation coefficient was 0.97 (95% CI 0.95–0.98). The intraclass correlation coefficient between the two devices was 0.86 (95% CI 0.74–0.93) and limits of agreement were −9.6 mm to 16.6 mm. However, we observed a significant mean HPD difference between devices (3.5 mm; 95% CI 1.4–5.6 mm). Clinical assessments and the mean measurements of HPD were correlated ($r = 0.64$, $p < 0.01$). We found significant differences in acceptability in favor of ultrasound. The mean VAS score for both ultrasound devices was 2.0 vs. 4.1 for clinical examination ($p < 0.01$). *Conclusion.* We found excellent intra-observer repeatability, good correlation but significant difference between devices. Women reported less discomfort with ultrasound than with clinical examinations.

Abbreviations: HPD, head–perineum distance; ICC, intraclass correlation coefficient; VAS, visual analog scale.

Introduction

Repeated clinical vaginal examinations are established as standard care in surveillance of labor progress (1), but clinical evaluation of fetal head position and station are inaccurate and poorly reproducible (2,3). As examination can cause discomfort, unnecessary examinations should be avoided (4).

Transperineal ultrasound can improve the accuracy of assessing fetal head station in the birth canal, and different sonographic measurements have been proposed;

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progression distance (5), angle of progression (6), head–perineum distance (HPD) (7,8) and intrapartum transperineal ultrasound head station (9).

Ultrasound measurements can predict delivery mode and success of vacuum extractions in nulliparous women (10–12), and ultrasound has the potential to become an important tool for clinicians during decision making (13). As ultrasound experts will not be available on call 24/7, ultrasound examinations must be easy to perform, applicable and acceptable to all women.

Reproducibility of measurements depends on the equipment and the experience of the examiners. Reproducibility studies can be done offline on stored acquisitions (14,15), but these studies seldom reflect every day clinical practice. Hence, reproducibility studies in clinical practice are warranted. In the present study, we wanted to test the reproducibility of HPD measurements performed by five examiners using two different ultrasound devices, reflecting everyday clinical practice. We also wanted to compare ultrasound measurements with clinical examinations and to study if ultrasound examinations were acceptable for women in labor.

Material and methods

Forty-four healthy women in labor underwent transperineal ultrasound examination of HPD. They had been admitted to the labor ward with regular contractions and were in the latent or active phase of labor. Scans were performed by five examiners using two different ultrasound devices in Lund University Hospital in Sweden and Landspitali University Hospital in Reykjavik, Iceland from February 2015 to February 2017. Two examiners were obstetricians with long ultrasound experience, but the three other examiners (two midwives and one junior doctor) had limited ultrasound experience. The two midwives had performed around 50 HPD measurements before they participated in the study, but the junior doctor had only done 10. The first author supervised all the other examiners before the start of the study. The ultrasound devices were Voluson *i* (GE Medical Systems, Zipf, Austria) with a 3.5- to 7.5-MHz 3D curved multifrequency transabdominal transducer and Philips VISIQ ultrasound system (Philips, Amsterdam, the Netherlands) with a C5-2 broadband curved array transducer – lightweight USB connector. The length of the Voluson *i* transducer was 70 mm and the width 45 mm. The Philips VISIQ device has a transducer directly plugged into a tablet. The length of this transducer was 62 mm and the width 17 mm. The longitudinal curvature of the two transducers was similar. The Philips VISIQ device was found to be suitable for this study because it is small and easy to transport between labor rooms. The same devices (Voluson *i* and Philips VISIQ) were used in Sweden and Iceland. The order of the use of ultrasound devices (first or last device) was randomly distributed.

Women were placed in a semi-recumbent position with the legs flexed at the hips and knees. HPD was measured in the axial plane (a transverse transperineal scan) as the shortest distance from the outer bony limit of the fetal skull to perineum as illustrated in Figures 1 and 2. The transducer was covered with a glove and placed in the posterior fourchette between the labia majora, and the soft tissue compressed completely against the pubic bones. The transducer was angled until the skull contour was seen as clearly as possible, indicating that the ultrasound beam was perpendicular to the fetal skull. The shortest distance possible to obtain between the transducer (perineum) and the fetal skull was measured. This distance represented the remaining part of the birth canal for the fetus to pass.

Measurements of HPD were performed between contractions online in two dimensions in the labor room, and women with fetuses in all fetal head positions were included. The first ultrasound examiner performed three acquisitions with one ultrasound device and the transducer was removed from the woman between the acquisitions. Thereafter another examiner followed the same procedure with another ultrasound device. In all, six ultrasound acquisitions were recorded in each woman. In addition, the midwife in charge of the delivery performed a clinical palpation. The investigators were not present during each other's examinations and were blinded to each other's results. The women reported pain perceived during ultrasound examinations and clinical examinations through a visual analog scale (VAS) score with zero as lowest possible pain and 10 as the highest possible pain (16,17).

Statistical analyses

Intra-observer repeatability was expressed as the difference between the highest and lowest measurement value obtained. The pooled calculations were based on both ultrasound devices and all examiners. Intra-observer repeatability was expressed as the intraclass correlation coefficient (ICC). In addition, the repeatability coefficient

Key Message

The reproducibility of measuring head–perineum distance during active labor was good and the women tolerated the ultrasound examination well.

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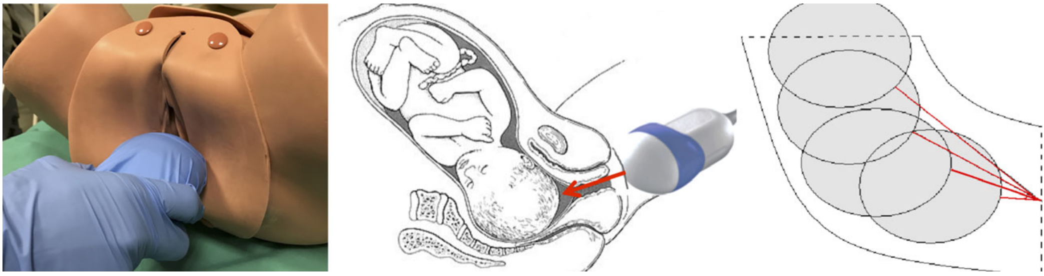

Figure 1. Illustration of how head–perineum distance is measured (left image S. Benediktsdottir, middle image E.A. Torkildsen and right image T.M.Eggebø). [Color figure can be viewed at wileyonlinelibrary.com].

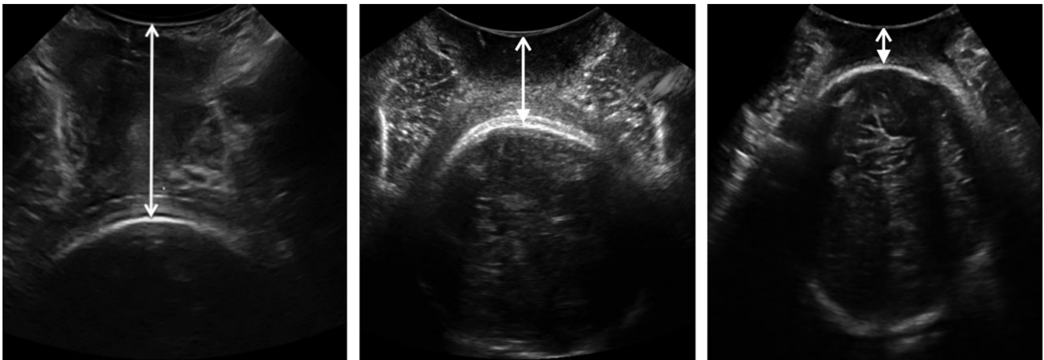

Figure 2. Head–perineum distance (HPD) at high station (HPD = 60 mm), mid station (HPD = 35 mm) and low station (HPD = 15 mm).

was calculated as the range within which two measurements by the same observer will fall for 95% of subjects. Analysis of variance for repeated measurements was used to determine whether there was any systematic difference between the first, second and third measurements of each observer.

In all calculations used for determining inter-device agreement, the mean of the three measurements from each device was used. To assess systematic bias between the two devices, and to assess the relation between the difference and magnitude between the measured values, the differences between the measurements were plotted against the means of the measurements in a Bland–Altman plot. A possible systematic difference between the two devices was assessed by evaluating the 95% CI for the mean difference. If zero was inside this interval, no bias was assumed to exist. Limits of agreement with 95% CI were calculated as described by Bland and Altman (18). Inter-device agreement was also expressed as the ICC. The correlation between ultrasound measurements and clinical assessments was analyzed using linear regression. The comparison of VAS scores was analyzed using paired *t*-test. All data were analyzed with the statistical software package IBM SPSS statistics version 24.0 (IMB Corp, Armonk, NY, USA).

Ethical approval

The local ethics committees approved the study with reference numbers 2014/180 in Sweden and VSN-15-216 in Iceland. All women signed written informed consent.

Results

Four sets of examinations were excluded because the time interval between examinations exceeded 30 min. The final study population comprised 40 women with mean maternal age 30 years and mean body mass index 26 kg/m^2. In all, 28 (70%) nulliparous women and 19 (48%) women had epidural analgesia. The Voluson *i* device was used first in 23 women and Philips VISIQ was used first in 17 women. The median time interval between the start of examinations was 10 min (range from 1 to 26 min). Cervical dilatation was <4 cm in 10 women, 4–6 cm in 15

women, 7–9 cm in nine women and the cervix was fully dilated in six women.

Intra-observer variance did not vary in any systematic way over the range of values measured. Intra-observer repeatability of HPD is shown in Table 1. The mean measurements were 40.6 mm, 40.1 mm and 39.5 mm for the first, second and third measurements, respectively, with a small, but significant tendency to shorter values in the second and third measurements ($p < 0.01$). The pooled repeatability coefficient for all five examiners was 4.3 mm and ICC was 0.97 (95% CI 0.95–0.98). ICC for examiner one (40 examinations) was 0.98 (95% CI 0.96–0.99), for examiner two (18 examinations) was 0.87 (95% CI 0.75–0.95) and for examiner three (16 examinations) was 0.99 (95% CI 0.97–0.995). Individual ICC could not be calculated for two examiners because of too few examinations (five and one examination).

Combined inter-device and inter-observer agreement of HPD measurements is shown in Table 2 and the correlation is illustrated in Figures 3 and 4. The ICC between the two devices was 0.86 (95% CI 0.74–0.93) and limits of agreement were −9.6 mm to 16.6 mm. However, we observed a significant mean HPD difference between devices (3.5 mm; 95% CI 1.4–5.6 mm). The differences between the two devices did not vary in any systematic way over the range of values measured (Figure 4). The correlation between clinical assessments and the mean measurements of HPD is shown in Figure 5 ($r = 0.64$; $p < 0.01$).

The mean discomfort related to the examinations using the Voluson *i* device, Philips VISIQ device or clinical examinations were 1.6 (median 1.0), 2.4 (median 1.5) and 4.1 (median 4.0), respectively. We compared the mean VAS score from both ultrasound devices with VAS score from clinical palpation and found a significant difference in favor of ultrasound ($p < 0.01$).

Discussion

The intra-observer repeatability of HPD measurements was excellent (ICC = 0.97), the inter-device correlation was good (ICC = 0.86), with acceptable limits of agreement, but significant difference between devices was observed. The correlation between HPD measurements and clinical examinations was moderate ($r = 0.64$). Women reported less discomfort related to ultrasound examinations compared with clinical palpation.

Investigating measurement error, observer variation and agreement between different methods are important topics before new modalities are introduced into clinical practice (19). ICC values >0.75 are considered acceptable (20,21), but ICCs depend on the variation in the population and are insufficient variables when investigating repeatability and agreement (21). Bland and Altman have described methods for reproducibility studies (18), and Valentin and Bergelin have investigated measurements of cervical length and width in accordance with the recommended principles (21). Measurements of cervical length were introduced for surveillance of women with a high risk of preterm delivery; however, a substantial intra- and inter-observer variability has been observed even with experienced examiners under standardized conditions (21). Clinicians should be aware of such variations, which probably exist in all imaging techniques.

Ultrasound has been introduced as a diagnostic tool in active labor and cervical dilatation (22,23), fetal lie, presentation (24), position (25), and station and attitude (26) can be assessed. The reproducibility of head direction, midline angle, progression distance and angle of progression were investigated offline on stored three-dimensional acquisitions by Ghi et al. Progression distance and angle of progression were the most reproducible methods with intra-observer ICCs of 0.84 and 0.93 and inter-observer ICCs of 0.89 and 0.90, respectively. Limits of agreement using progression distance was −17.5 mm to 6.9 mm and using progression angle −24.4 to 11.3 degrees (15). We have studied the reproducibility of HPD measurements using a study design simulating daily clinical practice including several examiners and two different ultrasound devices. The intra-observer ICC was excellent (0.97) and better than results in the offline study by Ghi et al. The limits of agreement in our study were similar to the variation in progression distance measurements. Valentin and Bergelin found inter-observer ICC measuring cervical length to be 0.76 (21). The inter-device ICC measuring HPD in our study cannot be directly

Table 1. Pooled intra-observer repeatability of head–perineum distance measurements ($n = 80$).

Measurement			ICC (95% CI)	Repeatability coefficient	Difference between highest and lowest values				
Mean	Median	Range			Mean	Median	10th centile	90th centile	Range
40.1	40	13–59	0.97 (0.95–0.98)	4.3	2.9	2.0	1.0	6.0	0–11

ICC, intraclass correlation coefficient.
Two ultrasound devices used and five examiners participated.
Mean, median and range of measurements (in millimeters) are calculated from the mean of three measurements.

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Table 2. Combined inter-device and inter-observer agreement of head–perineum distance measurements (n = 40) comparing Voluson *i* and Philips VISIQ.

Measurement				Difference between the two devices				
Mean	Median	Range	ICC (95% CI)	Mean (95% CI)	1.96 SD	Lower limit (95% CI)	Upper limit (95% CI)	Range
40.1	39.3	16–57	0.86 (0.74–0.93)	3.5 (1.4–5.7)	13.1	−9.6 (−12.3 to −6.9)	16.6 (13.9–19.3)	−7 to 21

ICC, intraclass correlation coefficient; SD, standard deviation.
Five examiners participated.
Mean, median and range (in millimeters) for head–perineum distance are calculated from the mean results from both devices.

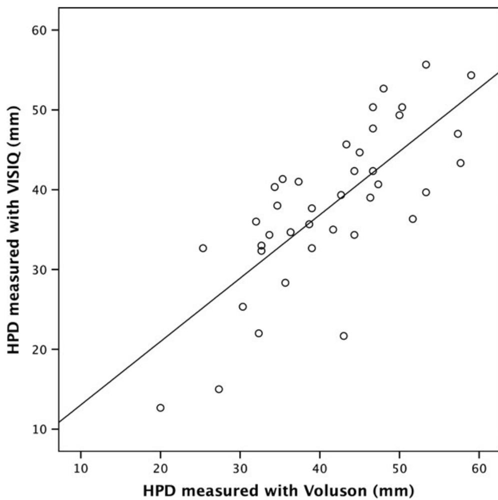

Figure 3. Scatterplot with regression line showing correlation between head–perineum distance (HPD) ultrasound measurements using Voluson *i* and Philips VISIQ.

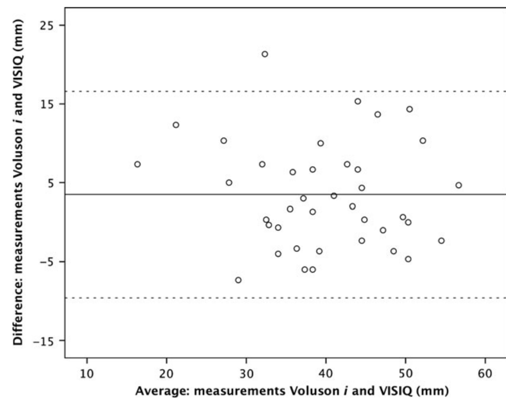

Figure 4. Bland–Altman plots of combined inter-device and inter-observer agreement between Voluson *i* and Philips VISIQ measuring head–perineum distance. Mean difference (solid line) and 95% limits of agreement (broken lines) are shown.

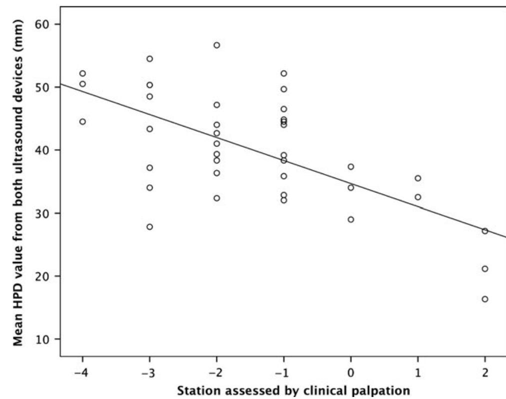

Figure 5. Scatterplot with regression line showing association between mean head–perineum distance (HPD) of ultrasound measurements and clinical assessments (r = 0.64).

compared with cervical length measurements, but it is interesting that our inter-device ICC is slightly better (0.86) even though both inter-device variation and inter-observer variation influenced our results. The reproducibility of HPD in our new study is in accordance with previous studies (7,27), and we find the variation acceptable. In a recently published study, Kasbaoui et al. reported the inter-observer ICC measuring HPD (called perineum to skull ultrasound distance in their study) to be 0.96 with similar repeatability also in obese women (28).

The Philips VISIQ device has a transducer directly plugged into a tablet and is well suited for ultrasound use in labor rooms. We believe that small hand-held devices will be the future for obstetricians and midwives looking after women in both normal and obstructed labor. One major concern was that we observed a significantly shorter HPD using the VISIQ device compared with the Voluson *i*. The difference might be due to the different size of the transducers or to calibration of the devices. The VISIQ transducer was thinner than the Voluson

transducer and may come closer to the fetal head when the soft tissue was compressed. The variation might also be influenced by the time interval between the measurements and the fact that Voluson *i* was used first in 23 of the 40 examinations. The examinations were performed during labor, and labor progression is expected between measurements. We observed a small tendency to shorter HPD from the first to the third measurement, but the difference was only 1 mm and was without clinical importance.

In one old study the reproducibility of clinical examination was found to be acceptable (29), but the centimeter steps used in assessing fetal station from −5 to +5 are imprecise and should be replaced with more exact measurements. Low to moderate correlation between ultrasound measurements and clinical assessments of station are documented in previous studies (30,31). Dupuis et al. found that undiagnosed high station occurred in around 20% of cases (3), and this mistake could be associated with high risk when considering an operative vaginal delivery. Unexperienced ultrasound users will probably overestimate high stations using HPD, because they may not compress the soft tissue completely or might not angle the transducer correctly. The ultrasound beam should be perpendicular to the fetal skull; that means that the skull contour should be visualized as clearly as possible (Figure 2) and this will represent the shortest distance. Important benefits using ultrasound are that results can be recorded and stored.

Women tolerated transperineal ultrasound well in previous studies (11,31,32). Chan et al. used a VAS score investigating Chinese women's preference of examination method and found the median pain score was zero after transperineal ultrasound and 4.5 after clinical examinations (33), and our results correspond well to these findings even though none of the women in the Chinese study had epidural analgesia vs. 48% in our study.

A major strength of our study is that the design reflects clinical practice. Limitations are related to unequal distribution of which device was used first and to a small study population. The size of the study population is, however, in accordance with other reproducibility studies. In our study, two examiners using two different devices examined each woman. Hence, we do not know whether the observed variation is due to inter-device or inter-observer variation. We think both factors can influence variation. The fetal head is moving in active labor, and the time interval between measurements can partly explain the observed variation. In a previous online study investigating inter-observer agreement of HPD we found slightly closer limits of agreement; −8.5 to 12.3 mm vs. −9.6 to 16.6 mm (7). In that study, agreement was investigated before start of labor and with shortest possible time interval between examinations. Results might also be influenced by the fact that three of the examiners had limited ultrasound experience and two of them performed few examinations.

In conclusion, we found excellent intra-observer repeatability. Good correlation, acceptable limits of agreement, but a significant difference between devices were found. The correlation between HPD and clinical assessments was moderate. Women reported less discomfort related to ultrasound examinations compared with clinical palpation. Ultrasound-measured HPD has the potential to improve the precision of fetal station assessment.

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