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« HEAD CIRCUMFERENCE MEASUREMENTS IN FETUS AND NEWBORN CHILDREN: HOW ACCURATE ARE WE? »

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1   Preface

As part of the medical studies at the University of Lausanne, students are asked to achieve a personal research project and write a master thesis in addition to other exams in order to achieve a medical degree. As I have always been attracted to obstetrics, it became obvious that I would ask to perform this research project in this field.

This master thesis has taken place at the Klinik für Geburtshilfe, at the Universitätsspital in Zürich (USZ) from March 2017 to April 2018 and aims at assessing the accuracy of fetal and newborn HCs measurements, combined with it's relation to delivery.

It has always been considered obvious that the larger the head of the fetus, the higher risk of delivery difficulties. This relationship seems, however, nowadays still quite imprecise. The objective of the current Master thesis is therefore to provide, in a first part, an overview of the history up to today's aspects of childbirth and the methods used over time to assess the fetal head circumference (HC). This first part aims for a better understanding of the second part and does not provide a complete overview of the obstetric history. In the second part, the design and initial results of a prospective study are presented. In this study, the accuracy of the post-birth HC measurement will be verified by measuring inter-observer variability, the accuracy of the pre-birth HC's ultrasonographic assessment will be verified by comparing the data with those obtained immediately, as well as two days after birth.

2   Part 1: Relation between fetal head circumference and delivery mode: past and present situation

2.1   Childbirth in History

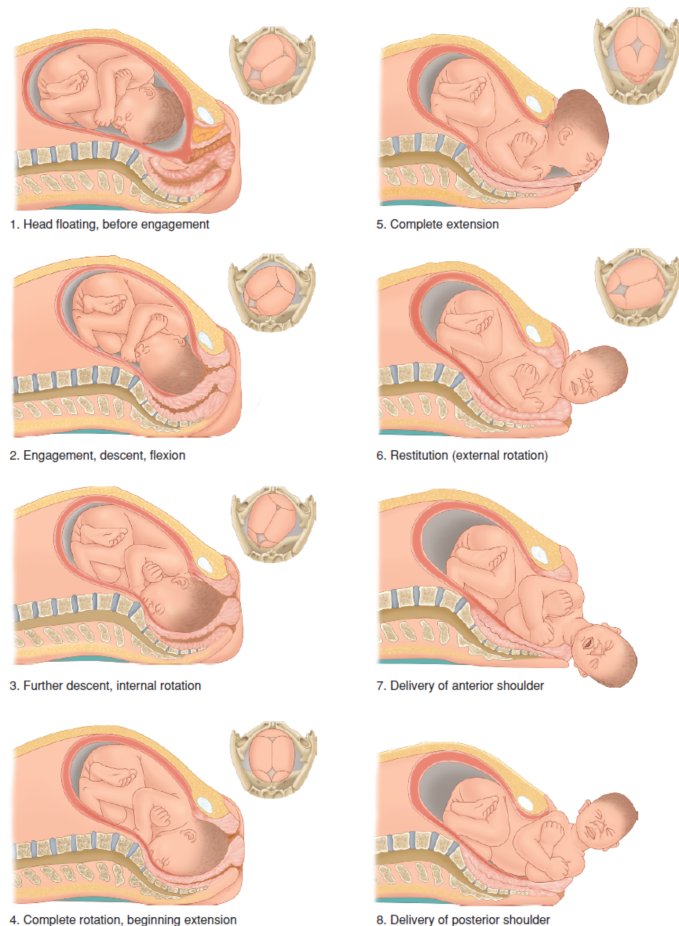### 2.1.1   Childbirth between then and now

Throughout the ages, childbirth has evolved in many ways before it eventually became birth as we presently know it in developed countries. Although many changes have occurred, the main principles and intentions have always been the same: the fetus must come out of its mother's uterus, both mother and child being alive. Hippocrates had also already described the basic mechanisms of birth in the 5th century BC (1). Today, mechanisms of normal labor with occiput performance (most common presentation) can be described this way:

Childbirth, as described in the Williams Obstetrics 22nd edition, begins from the onset of regular uterine contractions to the expulsion of the placenta (2). When the fetus is said to be 'at term', from 37-42 weeks of gestation, inhibitors are removed, allowing the myometrium to activate and cause the well-known contractions. These are helpful to both dilate the cervix and help push the fetus through the birth canal. In common practice, labor is divided into three stages. The first stage is described as the interval between onset of labor and full cervical dilatation and is usually divided into three phases: latent, active and descent. As the latent and active phases both refer to the opening of the cervix, the descent refers to the fetus's descent through the birth canal and usually overlaps the second stage. This second stage is described as the interval between full cervical dilatation (10 cm) and delivery of the baby. During this stage and to make its descent, the fetus experiences cardinal movements allowing it to pass in the best way possible through the birth canal. To understand these

mechanisms, basic knowledge of the mother's pelvic bone anatomy is probably useful (Figure 1)[1]. In most cases, the fetus at term lays longitudinally, in an occiput anterior position. Normal labor will in such cases usually occur through seven cardinal movements known as:

1. Engagement: the fetal head enters the pelvic inlet, usually transversely or obliquely (see the anatomy of the mother's pelvis), according to the mother's pelvic axis.
2. Descent: this is the fetus's descent through the birth canal. This movement is continuous during the whole second phase.
3. Flexion: the fetus's head flexes passively as it continues its way through the birth canal, leading its chin to come closer and closer to its chest and therefore allowing a smaller diameter to be presented.
4. Internal rotation: as the fetus's head was until now in a transverse position, it will now rotate to the anteroposterior position allowing it to match the mother's pelvic axis.

Figure 1 Cardinal movements of labor and delivery

5. Extension: it is the baby's head that is delivered by extending and rotating around the symphysis pubis. This is due to the anatomy of the birth canal that is at that point curving upwards.
6. External rotation: it is now time for the shoulders and the rest of the baby's body to be delivered. As the shoulders' axis is perpendicular to the head's longest axis (occipitofrontal axis), the baby's head will return to its original transverse or oblique position, meaning the same rotation for its body.
7. Expulsion: with the external rotation, shoulders can be delivered, followed quickly by the rest of the baby's body.

Finally, the third and last stage is described as the interval between delivery of the baby and delivery of the placenta, with separation between the baby and the placenta (2, 3).

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[1] Cunningham, F. Gary,, et al. *Williams Obstetrics*. 24th edition. New York: McGraw-Hill Education, 2014

Although Hippocrates basic description of birth might differ at some points, the main principles of normal birth have not changed throughout the ages. However, birth conditions, place of birth and people present during the birth process are notions that have evolved and changed through time.

All through antiquity, the Middle Ages and Modern Times, regular deliveries would always be in the hands of the midwives (4). Doctors, nearly all of the male gender, would only be requested in cases of complications. Until 1900 giving birth would almost always be done at home (5), with some examples registered in hospitals during the 19th century. The mother would sit on a chair designed for that effect in a closed overheated room and would usually be assisted by midwives and female relatives (4), (5). It is not until 1513, during the Renaissance, that the first successful obstetric textbook -The Rossgarten (6, 7) - made its appearance in Europe. Originally written in German by Rösslin, it was later translated into multiple languages (1, 4). This illustrated textbook described procedures and the management of normal and abnormal birth, namely the obstetrical chair, with its curved back and two handles on either sides designed for the mother to grab during labor. The book also described various fetal presentations in utero, maternal positions for delivery and causes of difficult labor (6, 7). This was therefore helpful for midwives at that time, but also gave access to midwifery knowledge for the male gender.
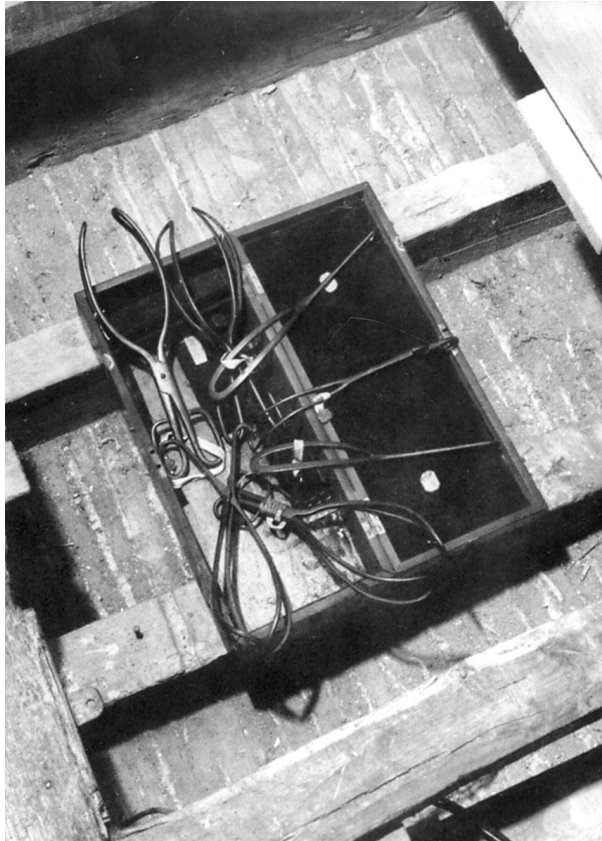
Figure 2 Peter Chamberlen (1601-1683)

In fact, in the 17th century, man-midwives, surgeons, and doctors became more and more present and involved in the obstetric field (4). This intrusion of the male gender into a female world generated conflicts between the two genders, leading to significant changes in the practice of childbirth. It is during the transition from the 17th century to the 18th century that well-known maneuvers, as well as instrumental deliveries, first made their appearance in the obstetric field. The so-called 'Mauriceau-Smellie-Veit maneuver' for instance was first described by a French accoucheur (man-midwife) Guillemeau and later reproduced by another French accoucheur Francois Mauriceau in the 17th century. This maneuver describes how to deliver a baby in a breech position. At the time, it was taught mainly to help in cases of breech position for vaginal deliveries, allowing the avoidance of cesarean sections (CS) (1), a procedure which meant great danger for both mother and child at that time. Nowadays, this method is still used for breech presentations, but mostly for cases of a breech presentation delivered by CS. In fact, although the breech presentation is not an absolute indication for CS, doctors tend to prefer performing a CS to avoid any complications. Another big change of the time is the emergence of forceps in

Europe. It is, in fact, the surgeon Peter Chamberlen (Figure 2)[2] in England who probably introduced the forceps. This French Huguenot refugee had moved to England a few years earlier and started using his forceps at the beginning of the 17th century. This instrument was meant to help extract the baby from its mother's genital tract during delivery by grabbing it by the head (Figure 3)[3]. However, although forceps where known, the Chamberlen family first kept it a secret for over a century, continuing with the invented instrument and passing it on from generation to generation. Later on, forceps have been modified and improved by several other doctors until it eventually became the instrument, as we now know it. As medical technology was still inferior at the time, forceps have thus contributed in helping save a lot of lives. Today, however, as medical technology has known significant improvements, forceps are less used.

Figure 3 Chamberlen's forceps

Nowadays in developed countries, although CS rates tend to increase, vaginal deliveries still are the primary mode of births. A WHO report of 2011 indicates that worldwide, 10-20% of all vaginal deliveries require a form of intervention and that 2-23% are instrumental deliveries (with forceps or vacuum).

2.1.2 Cesarean sections over the ages

The practice of CS has long been known and done, but it was initially only indicated in postmortem situations (8). Its existence and its practice are often referred to in mythology (4, 9). One of the first legal texts regarding CS, 'Lex Regia' (the Law of the Kings), proclaimed in the 8th century BC by an ancient Roman King, established that a baby should be extracted from its mother's womb if the latter had died before giving birth. This would give the possibility to bury them separately (8-10).

The origin of the word *Cesarean section* remains debatable. Although it is more likely that the *Cesarean* takes it's origin from the Latin verb *caedere* 'to cut', many articles also mention the possible origin of the name derived from Julius Caesar, who is told to be born by CS in about 100 BC (1, 4, 9). However, as the Lex Regia suggests and as many articles have said, the Romans only performed CS postmortem, but Julius Caesar's mother is still described as very

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[2] Dunn PM. The Chamberlen family (1560–1728) and obstetric forceps. Archives of Disease in Childhood - Fetal and Neonatal Edition. 1999;81(3):F232-F4.
[3] Dunn PM. The Chamberlen family (1560–1728) and obstetric forceps. Archives of Disease in Childhood - Fetal and Neonatal Edition. 1999;81(3):F232-F4.

much alive a few years after his birth (4, 9). Hence, the first explanation for the origin of the word is thought to be more reliable. Thus, for many years, CS was performed postmortem to try and save the baby, or for religious reasons, to bury the mother and her child separately (9).

The first case of a successful CS where both mother and child survived was first recorded in Siegerhausen in the Canton of Thurgau, Switzerland, in 1500 (4, 9). '*Jacob Nufer, a pig gelder, reportedly performed the operation on his wife after a prolonged labor. She spent several days in labor and had assistance from 13 midwives but was still unable to deliver her baby. Her husband received permission from the religious authorities to perform a cesarean section. Miraculously, the mother lived and subsequently gave birth to five other children by vaginal deliveries including twins*' (9). But the case stays controversial as it was first reported 81 years after the events. In fact, it was reported by the surgeon François Rousset, who in 1581 published the first work entirely dedicated to CS (4, 10) and suggested, for the first time, the possibility for a successful outcome for both mother and child when performing CS and hence a medical indication for a CS. In his work, Rousset discusses both his, and reported observations of both successful and unsuccessful CS. However, the next cases with a successful outcome for both mother and child were only later reported in the 18th century. In fact, until the 19th century, all CS were performed without the help of anesthesia, which made it difficult for the mother to survive. Thus, CS were only indicated in specific situations such as the impossibility for vaginal delivery, even with the help of instruments like forceps (4). But mortality rates due to CS stayed very high, mostly due to 'exhaustion', peritonitis, septicemia, hemorrhage and eclampsia (10).

It is mostly during the 19th century that important changes occurred: medical technics, as well as surgical skills, improved, concerns about pain during labor played an important part in the emergence of anesthesia, and hospitals became more and more aware of the importance of asepsis. With that said and with childbirth being done more and more often by medical members, CS, as well as vaginal deliveries, would more and more often be done in hospitals and an important reduction of maternal mortality could be recorded (1, 9, 10). In Britain, at the beginning of the 19th century, maternal mortality due to CS was 65–75%, dropping to 5-10% by the end of the century (9).

Later on, cesarean technics such as abdominal incision, uterine incision or uterine closure were discussed and improved. At the beginning of the 19th century, abdominal incisions of the skin would be performed transversely, but the fascia would be incised longitudinally. In 1900, it was Pfannenstiel who introduced and recommended the current method, that is the transverse incision of both skin and fascias, suggesting this method to be more secure, to reduce postoperative pain and to provide a better cosmetic appearance (11). The uterus also used to be incised longitudinally, but as Monroe Kerr suggested in 1926, the incision is nowadays made transversally in a lower uterine segment, causing less bleeding and less risk of uterine rupture following vaginal deliveries. As for uterine closure, as resolvable sutures did not exist at the time, it could therefore not be sutured. To control uterine hemorrhage and prevent maternal mortality, Eduardo Porro, Professor of Obstetrics in Italy, recommended in 1876 a total hysterectomy when performing CS. Although this drastically decreased maternal mortality, it also implied that the mother should sacrifice her future fertility. Thus, in 1882,

Max Sanger insisted on the importance of the uterine closure and introduced river suture (10, 11).

According to the WHO recommendations, CS rates should be 10-15%, and should be justified to reduce maternal and neonatal mortality. However, in most developed countries, CS rates tend to increase: in 2015 for instance, Xie wrote in his article that more than half of high-income industrialized countries have a CS delivery rate of >25% (12). It has been noted in Niino's review that this increase is linked to economic motivations: women of higher socio-economic classes or better insured appear to present higher rates of CS deliveries. Other explanations or correlations for this increase include in higher medical technology, surgical technics, the changing perception that people have of the safety of this procedure, and the supposed benefits of protection against urinary incontinence, prolapse and sexual dissatisfaction. Moreover, according to the review, four of the significant CS indications in the US are actually 'gray areas': uterine scar, obstructed labor, fetal distress and breech presentation. These indications seem to have increased over the years but appear for some to be ambiguous, which means that CS might not offer a real benefit (13). With increasing rates of CS, studies have questioned the indications for this procedure (14). As many articles have shown, CS are more often associated with maternal death than are vaginal deliveries (15). As Clark mentioned in his article, a significant positive association between CS and maternal death has been shown, but the death is in almost all cases due to the indication for CS rather than the operation itself (15).

2.1.3 Maternal and fetal complications of deliveries

All through the ages, the obstetric field has known significant progress. As pregnancy, vaginal delivery and CS where usually and sometimes still are synonym with great pain, traumas and in some cases even death (5), medical improvements have made it nowadays possible to control and decrease most of the suffering, complications and deaths.

Maternal death due to pregnancy has decreased drastically during the 20th century in both developed and developing countries (16). For developing countries, access to medical health care during pregnancy has shown to help the most in decreasing maternal deaths. According to Main's study in 2015, major causes of pregnancy-related deaths in California are (from most frequent to less frequent) cardiovascular diseases, preeclampsia or eclampsia, obstetric hemorrhage, venous thromboembolism or amniotic fluid embolism (17). However, in this article, Main also points out the possibility of decreasing maternal death rates due to one of the five causes mentioned above by improving clinical recognition and response. Therefore, even though maternal mortality and morbidity rates have considerably been reduced, a further reduction of those rates could be expected for the future.

According to Rossi's systematic review regarding the etiology of maternal mortality in developed countries, the main events that cause maternal death are hemorrhage, hypertension and cardiovascular diseases (18).

As for perinatal mortality, including stillbirths and neonatal deaths, there are only a few data dating from earlier than the 20th century. In fact, it is only with the beginning of imaging that the fetus could first be observed and became an individual patient. The latest edition of the Williams Obstetrics (19) describes a decrease in fetal mortality rates from 1990 to 2005 of

the fetus at 28 weeks of gestation or more. However, fetal mortality rates of the fetus between 20-27 weeks of gestation stayed static. Almost half of all infant deaths can be attributed to the three leading causes of infant death: congenital malformations, low birth weight and sudden infant death (19).

Dystocia is the medical term to express abnormal or difficult labor. The main mechanisms or causes leading to such difficult labors can be simplified into four categories (4 P) (19):

- Powers: uterine contractility and maternal expulsive efforts
- Passenger: the fetus
- Passage: the pelvis
- Psychology

A commonly used term when talking about dystocia is 'fetopelvic disproportion'. It is nowadays rare to have an absolute cephalopelvic disproportion, and most cases result from fetal malposition of the head within the pelvis or from ineffective uterine contractions. An estimation of the pelvic capacity can be and is nowadays done, more often. Manual assessment of the pelvic bone has been described but is no longer performed in the usual practice. Radiology and CT-scans have also been performed to assess pelvic capacity but are no longer done due to ionizing radiation. MRIs seem to present many advantages compared to the previous two mentioned methods. It gives the possibility of measuring pelvic capacity without ionizing radiation, it provides accurate measurements, complete fetal imaging and the potential for evaluation of the soft tissues. However, it is not of standard use in the obstetric field, and it is only sometimes performed in case of doubt.

In cases of dystocia, several instruments can be used to remedy the problem such as forceps, vacuum, manual maneuvers and emergency CS. Although the use of these instruments, maneuvers or procedures doesn't usually cause irreversible trouble or death, the risks are much higher, not to mention the psychological trauma and stress experienced by the family and the medical staff.

2.1.4 Situation at the USZ today

In 2017, 2796 women gave birth at the USZ, 2623 being singleton pregnancies.

Of these singleton pregnancies, 1330 (50.71%) were vaginal deliveries, 1041 (39.69%) were CS, 240 (9.15%) were vacuum deliveries, 4 (0.15%) were forceps deliveries and 8 (0.3%) were manual, extraction or breech deliveries (Table 1).

Of all CS in singleton pregnancies, 594 (57%) were primary CS, and 447 (43%) were emergency CS. As previously mentioned, indications for performing a CS vary in different countries and hospitals, depending on the medical access and technologies available. At the USZ, the primary indications for CS in singleton pregnancies are a breech presentation, a previous CS, abnormal placenta presentation, and the patient's choice.

In 2017, maternal mortality represented 1/2796 (0.04%).

Table 1 Delivery mode of singleton pregnancies at the USZ in 2017
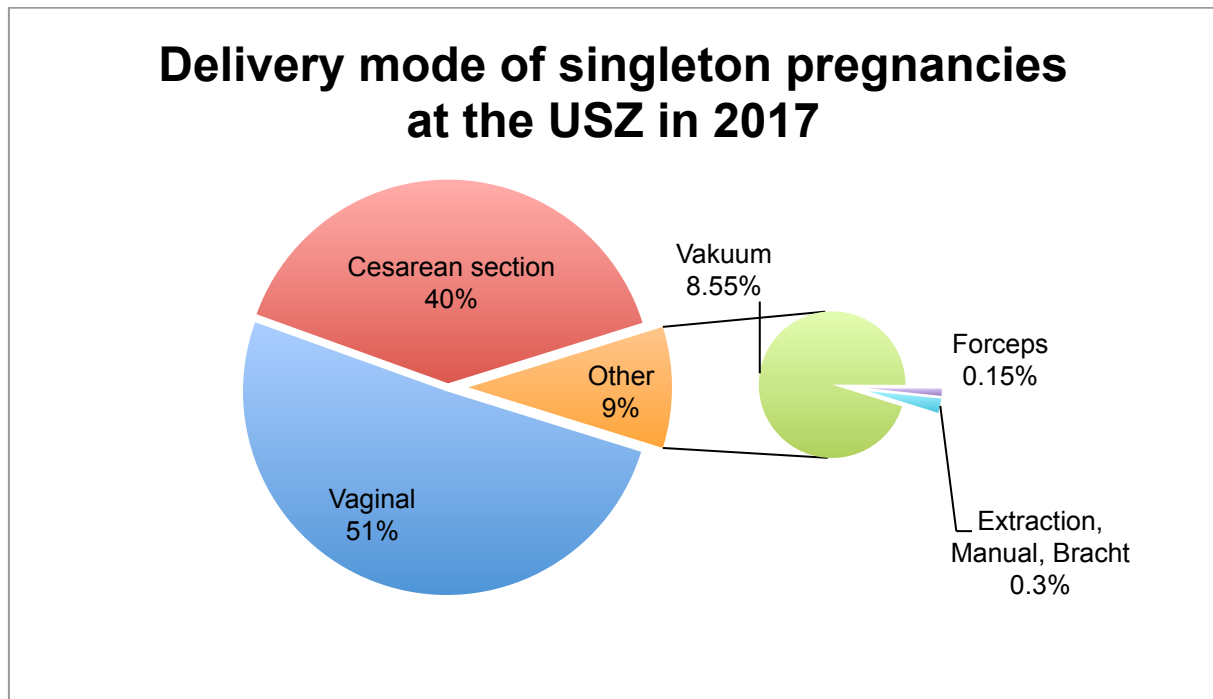
2.2 Brief history of prenatal fetal morphologic assessment

2.2.1 Fetal assessment

Fetal assessment or fetal monitoring during pregnancy, regroups all available methods and techniques that are used to assess fetal well-being and therefore prevent fetal complications including death (19), (20).

2.2.2 Methods 1: Manual assessment

Abdominal palpation (Leopold Handgriff) and vaginal examination:

Fetal presentation and position can be diagnosed using the Leopold maneuvers described in 1894 by Leopold. The mother lies on her back while the doctor in charge performs four maneuvers successively (Figure 4)[4].

The first maneuver assesses the uterus fundus and identifies by what fetal pole it is occupied (breech or head). The second maneuver determines on which side the fetal back is (I. if the back lies on the right side, II. if it lies on the left side). The third

Figure 4 Leopold maneuvers

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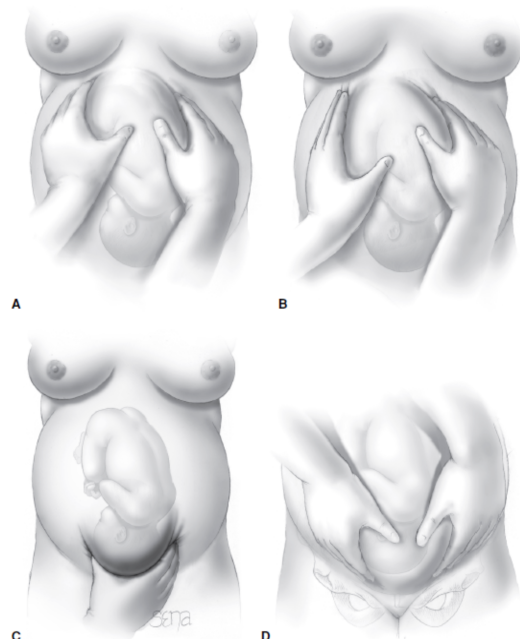
[4] Cunningham, F. Gary,, et al. *Williams Obstetrics*. 24th edition. New York: McGraw-Hill Education, 2014

maneuver concentrates on the lower portion of the maternal abdomen. The doctor determines which fetal pole is lying in the mother's lower abdomen as well as if this pole is already engaged in the mother's pelvis. The fourth maneuver is usually only performed in late pregnancy to evaluate engagement of the fetus through the mother's pelvis (19).

Vaginal palpation:

Vaginal palpation can be used to help estimate and eventually predict cephalopelvic disproportion. The diagonal conjugate can be measured first by placing index and middle finger in the patient's vagina, until touching the sacral promontory, then by placing index from the other hand against the symphysis as shown in Figure 5[4]. The distance between the middle finger and contralateral index, represents the diagonal conjugate, which is the first bony path through which the fetus will have to pass to begin its descent (19).

Figure 5 Determination of diagonal conjugate
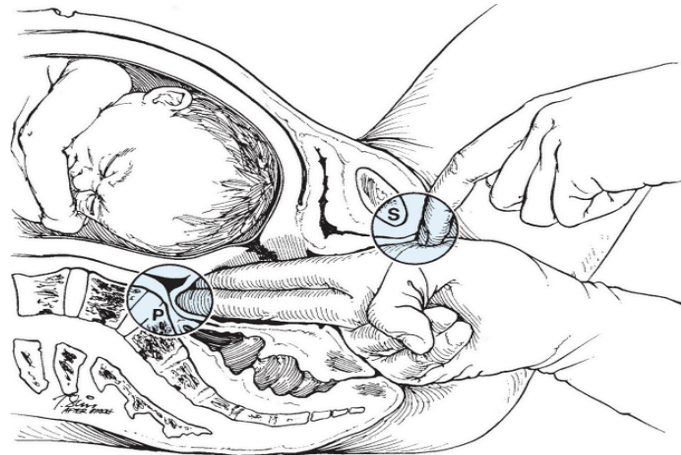
A fetal presentation can also be determined during a vaginal examination. Depending on the fetal lie, head, breech or shoulder can be felt. This is, however, only possible after the onset of labor and when the cervix is dilated, and is therefore not usually used for this purpose.

During the first stage, however, a vaginal examination is useful to estimate the cervix dilatation.

2.2.3   Methods 2: radiological assessment

With the rise of new technologies, radiology has had a major impact on fetal assessment. The most revolutionary radiological method in the obstetric field is by far the US, and it is discussed in section 2.2.4. As ionizing radiation is harmful to the fetus, CT and X-rays are no longer used to assess fetal growth and its well-being. It is also mentioned in the 24th edition of the Wiliams Obstetrics, that plain radiographic technics are not used to measure fetal head diameter because of parallax distortions. MRIs, however, seem to have a beneficial effect, as an additional detection of fetal anomalies after US suspicions leading to a change in diagnosis and prognosis, in 19% of all cases as mentioned in Verburg's article (21). However, MRIs are expensive and are therefore only used in specific conditions.

2.2.4   Ultrasonographic assessment

Although it is now of very common use in the obstetric field, it is only recently that the US has developed this and is used for medical interest. In fact, it is a method dating from the late 1940s that was developed for material testing and sonar during world war one. After its first application to medicine in 1958, it quickly became of significant interest for the obstetric field,

and after 1970, general interest for its diagnostic use grew more prominent, leading to its eventual commercialization in hospitals *(2)* (22).

Nowadays, Swiss obstetric guidelines recommend a first scan between 11 and 14 weeks of gestation and a second scan between 20 and 23 weeks, both of which are covered by the patient's health insurance. In case of doubt, complicated or high-risk pregnancies, additional scans can be performed. As mentioned in the 'Swiss Obstetric Ultrasound Guideline' 3rd edition (23), the aim of this US scanning in cases of normal pregnancies are mainly to:

- Identify the site of implantation
- Confirm the presence of a live fetus
- Diagnose a multiple pregnancy
- Determine gestational age
- Plot growth using fetal growth charts
- Assess fetal lie
- Review fetal morphology
- Determine the position and morphology of placenta and umbilical cord
- Estimate amniotic fluid volume
- Assess uterus and adnexa

At the end of the first trimester, external morphology can be best visualized. Anomalies such as fetal anencephaly should be recognized at this stage, as well as the three segments of all four fetal extremities (legs and arms).

The second scan occurs once the fetal organs have reached their final position and size, allowing the scan to focus mainly on the fetal anatomy and therefore recognize eventual developmental disorders and malformations. It is during this second scan also, that the doctor in charge will, among others, focus on the fetal biometry and measure head diameter in this way:

The head should be measured using an axial section, and the skull should be symmetrically oval. If the plane of section is correct, cerebellum and orbits should not be visible. A midline echo with hyperechoic thalamic nuclei on both sides and broken at the anterior third by the cavum septi pellucidi should be visible. HC can either be measured with an ellipse formula or with the help of an inbuilt US program which will measure HC using biparietal diameter (BPD) and occipitofrontal diameter (OFD). BPD is the line perpendicular to the midline echo from one parietal bone to the other, standard curves assuming outer to outer measurements. The same applies to the OFD, which is the line measured from outer frontal to outer occipital margins of the head (Figure 6)[5], (Figure 7)[6].

An association with other fetal biometry measurements such as the fetal abdominal circumference of femur length, and several differential diagnoses can be made, as listed in 'Swiss Obstetric Ultrasound Guideline' 3rd edition (Table 1) (23). All fetal biometry measurements are plotted on percentile fetal growth charts and hence allow a continuous follow-up of the fetal growth.

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[5] Cunningham, F. Gary,, et al. *Williams Obstetrics*. 24th edition. New York: McGraw-Hill Education, 2014
[6] Swiss Society for Ultrasound in Medicine GaOS. Swiss Obstetric Ultrasound Guideline. 2011.

In cases of planned CS, a US is usually performed on the day before planned CS. This US aims to mainly measure weight and HC estimation as well as to determine fetal presentation.

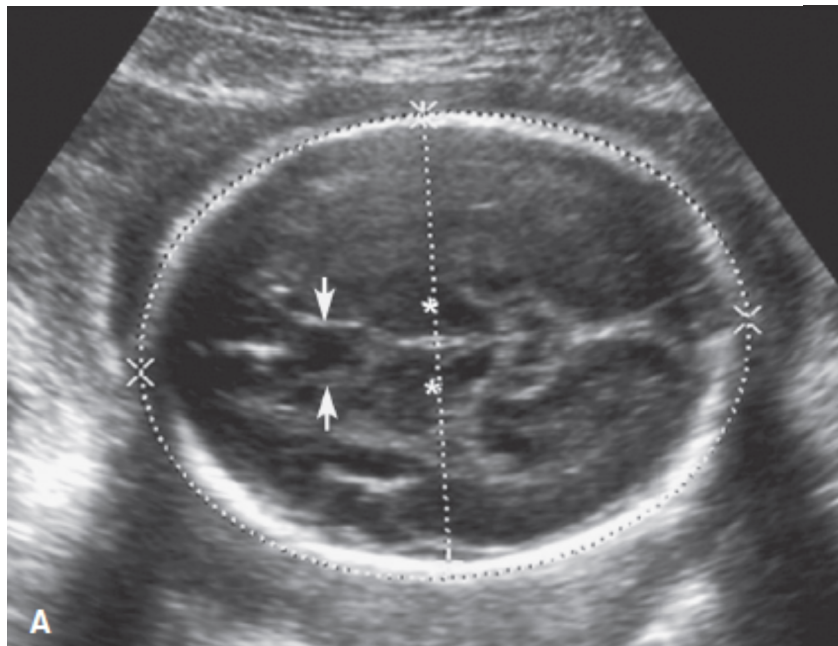**Figure 6 Reference plane for BPD and HC measurement**

Figure 7 Incorrect measurement plane (the cerebellum should not be visible)

Table 2 Differential diagnoses according to fetal biomery measurements between 20 and 23 weeks of gestation

Head circumference	Abdominal circumference	Femur	Increased in
↑	Normal	Normal	Hydrocephalus
↓	Normal	Normal	Cytomegaly, Chromosome abnormality, Toxoplasmosis, Spina bifida, Microcephaly
Normal	↑	Normal	Macrosomia, Infection (hepatomegaly)
Normal - (↓)	↓	Normal - (↓)	Growth retardation, Chromosome abnormality
Normal	Normal	↓	Skeletal dysplasia, Aneuploidy

2.2.5 Remaining problems of assessment

Although developed countries nowadays have access to high-quality technology, training, and education, there are no data regarding the accuracy of the assessment. As imaging technology seems to evolve rapidly, manual maneuvers seem to disappear. Some studies show that although US has brought important changes into the obstetric field, it still presents some problems of accuracy (24). As seen in the previous paragraph, US measurements of the fetus's HC imply certain standards and small imprecisions can lead to significant changes of HC measurements (Figure 13). However, in practice, it can be difficult to obtain perfect HC by the standards. Typical situations leading to difficulties when measuring are the low positioning of the fetal head, maternal obesity or even myomas. In these situations, other structures interfere between the fetal head and the US, leading to a decrease in the accuracy.

2.3 Prediction of the delivery mode

Many factors are implicated and can have an influence on the delivery mode. One major factor that I would like to discuss in this Master thesis is dystocia and more precisely, cephalo-pelvic disproportion. As mentioned in section 2.1.3., such disproportions exist when pelvis capacity does not allow fetal passage. Unfortunately, fetal disproportion is a delicate measure. It is mostly predicted with the help of clinical maneuvers and radiology, by predicting fetal HC, but as recorded in the Williams Obstetrics, 24th edition, these methods do not seem to have proven to have satisfying results.

A manual maneuver has been described by Mueller and Hillis to predict cephalo-pelvic disproportion ('*the fetal brow and the suboccipital region are grasped through the abdominal wall with the fingers, and firm pressure is directed downwards in the axis of the inlet. If no disproportion exists, the head readily enters the pelvis, and vaginal delivery can be predicted*'), but in 1993, Thorp and coworkers (25) concluded by saying that they have found

no correlation between dystocia and fetal descent and that this method should not be used to predict dystocia. Thurnau and his colleagues describe the *fetal-pelvic index*, which should help to identify complicated labors, but its use is controversial. Some studies reject it (26) and some approve its benefits for specific situations, such as for women with high risks for cephalo-pelvic disproportion, nulliparous women or women undergoing vaginal delivery after previous CS (27, 28).

Measuring HC and pelvic diameters separately can also be done to predict cephalo-pelvic disproportions. As seen earlier, fetal HC is mostly assessed with the US, but the mother's pelvis can be measured in different ways. In most situations and when no complication is suspected, the obstetrician can perform a clinical examination with digital measurements. The anteroposterior diameter can be estimated directly with manual palpation. As the shortest distance between the symphysis pubis and the sacral promontory cannot directly be measured manually with the fingers, obstetricians can measure the distance between the lowest margin of the symphysis and the sacral promontory. 1.5-2 cm is then subtracted, giving an estimated value of the smallest anteroposterior value (19). When in doubt, an MRI can be used to determine the pelvis size (29). This last method, however, often presents false positive, leading to unnecessary CS. Other disadvantages include elevated costs.

These tools might help in specific cases, but the benefits and the efficacy do not appear to be sufficient enough to be used as standards.

Other important factors to predict the delivery mode include previous CS, co-morbidities and fetal particularities, but will not be further discussed in this Master thesis. Prediction of the delivery mode should thus be evaluated on a case-by-case basis.

In Zurich, there is no precise cut-off for predicting the delivery mode. Vaginal delivery is preferred if there are no absolute contra-indications. When in doubt, the decision is considered on a case-by-case basis and usually depends on the US measurement estimations, previous CS, abnormal placenta presentation or on patient's demand.

2.4   Relation between HC and mode of delivery

Multiple studies have already established the link between birth weight and mode of delivery. However, there is no link between HC of newborns and mode of delivery. It is a well-known fact that a higher risk for a prolonged first stage, second stage as well as an unplanned CS or instrumental delivery, occurs with cases of macrosomia (30, 31), but only a few studies report on the influence of HC on delivery mode. For instance, Elvander has shown that a HC of 39 to 41 cm at birth is associated with a higher risk of a prolonged first stage, pathological CTG, vacuum extraction and CS (32). But only one study has compared the relationship between birth weight and mode of delivery, HC and mode of delivery, as well as birth weight, HC, and mode of delivery. Its results showed that a high HC has a larger impact on an unplanned CS and instrumental delivery than a high birth weight (33). This is why it is important to be as accurate as possible when measuring fetal HCs with an US. However, the results from Melamed's study show a significant underestimation of sonographic HCs

estimations in comparison to postnatal measurements (24). Reasons for this considerable underestimation remain unclear, but it has been observed that a reduction of newborns' HCs occur during the first week after birth (34). In addition, Simič Klarić's study has pointed out statistically significant differences between HCs measured at birth versus three days post delivery, this latter information appearing more valuable (35). Thus, this suggests a possible over estimation of the newborns' HCs when routinely made on the day of delivery. Hence, to have a better estimation of the newborns' HCs, these measurements should be made a few days after birth instead of directly on the day of delivery. It is also important to analyze the inter-observer variability when measuring HCs, as these measurements are usually made by different medical members.

The current Master Thesis discusses problems related to the accuracy of fetal and newborn HC measurements. It will also include prospectively collected clinical data, which will be part of a larger clinical study. The aim of this work is thus to improve the relevance of pre-delivery HC measurements and as such, the planning of the delivery mode, and subsequently to reduce the rate of prolonged and complicated births.

3 Part 2: Current Master Thesis, prospective evaluation of fetal head circumference measurements

3.1 Introduction

3.1.1 Current problematic

The current master Thesis has initially been established as part of a larger study. This larger study focuses on the relation between HC and delivery mode as well as complications that could be caused by a big HC. In order to do so, a retrospective part has taken place. The current master Thesis, however, will focus on assessing accuracy in fetal HC measurements of fetus and newborn children born by planned CS. We have chosen to include only planned CS as these present us with less head configuration changes. Measurements made after delivery should, therefore, be similar to US measurements. This part has taken place as a prospective part.

3.1.2 USZ

This master Thesis has taken place in the obstetric department of the University Hospital in Zurich (USZ).

3.1.3 Objectives

3.1.3.1 Main objectives

The main objectives of the retrospective part include:

- Analyzing the correlation between HC, birth weight (BW) after birth, together with the delivery mode,
- An analysis to determine at which point HC measurement and risks for complications increase and what a big head actually is,
- Develop methods to improve prepartal sonographic HC measurements.

3.1.3.2 Objectives of the current master thesis

The primary objective of the current Master Thesis is to assess the accuracy of fetal and newborn HCs measurements. Newborns' HCs measurements will be assessed on the day of delivery by two observers, in order to check for inter-observer variability, as well as by one observer two days after delivery, and compared with sonographic measurements obtained on the day before birth. Also, and as previously mentioned, the results of this analysis will be part of a larger study, whose aim is to assess the influence of fetal HC and weight on the outcome of delivery, with the intention of predicting and preventing prolonged and complicated deliveries.

3.2 Methods

3.2.1 Design of the study

This is a prospective monocentric observational study including 51 female patients, who have given birth by planned CS at the «Klinik für Geburtshilfe des Universitätsspitals Zürich» USZ between 03/2017 and 09/2017.

3.2.2 Description of the study

On the day before delivery, the doctor in charge of admitting the concerned patient has already performed a routine US examination, which includes the fetal HC estimation. On the day of delivery (+/- 12h), and after receiving the parental consent, I (Fanny Tevaearai, Master Student) measured the HC of the newborn (D0_F), in addition to the one done routinely by the midwives (D0_H). The baby's second HC measurement was then taken two days after the delivery by myself (D2), in the patient's hospital room. All the post-natal HC measurements were made with disposable paper meters from Nestlé Nutrition (Figure 8).

Each measurement has been recorded on an excel table and encoded through the patient's ID number. In addition to these measurements, the excel table also includes the mother's demographic data (maternal age, education, height, weight, BMI, previous pregnancies, previous delivery mode, gestational age), the data of the fetuses latest US measurements (Estimated fetal weight (EFW), Fetal head circumference (FHC), BPD, OFD) as well as the newborn's sex, weight and height (**Erreur ! Source du renvoi introuvable.**), (**Erreur !**

Figure 8 HC measurement

Source du renvoi introuvable.).

3.2.3 Inclusion/Exclusion criteria

Both of my HCs measurements (on the day of delivery and two days later) have been compared to those made by the midwives as well as to the one predicted by the US. These measurements have then been compared with the other data from the excel table to see if a correlation could be made. All data have been compiled in tables and figures and have then been analyzed and discussed (see results and discussion).

Only patients meeting the following criteria have been included in the study:

- A planned CS between 03/2017 and 09/2017 at the USZ
- ≥ 37+0 weeks of pregnancy
- Cephalic presentation

Patients with the following criteria have been excluded from this study:

- Breech presentation
- Emergency CS
- Fetal anomaly
- IUGR (weight under 5th percentile)
- Multiple pregnancy
- Stillbirth
- False/incomplete data

3.2.4 Statistical methods

Analyze: descriptive statistic to compare HC before, on the day and two days after delivery. Group: Fisher-Exact test, t-Test, Bland-Altman Method, ANOVA. The systemic error of the sonographic measurement of the HC has been determined by percent error: (fetal HC – newborn HC)/ newborn HC * 100%. Systemic error of the sonographic measurement of the HC has been determined once using newborn HC value on the day 0 (mean value of the measurements made by the midwives and myself on the day 0) and once using newborn HC value on the day 2.

Bland Altman method (difference plot): Plot used for descriptive statistics to compare two methods used for the same purpose. For this study, the Bland Altman method was used to compare inter-observer variability (D0_H vs. D0_F) and to compare variability between different methods used to measure fetal and newborn HC (D0_H vs. US, D0_F vs. US, D0 vs. US, D2 vs. US, D0_F vs. D2).

3.3 Results

3.3.1 Characteristics of the study group

51 pregnant women met the inclusion criteria and took part in the study. Mother's and babies' demographic and obstetric data are represented respectively in **Table 3** and **Table 4**.

Table 3 Mother's data (n=51)

		Number (n)	(%)
Age		35y	
Education n (%)	University	16	31
	Other	29	57
	Unknown	5	10
Ethnicity n (%)	Caucasian	40	78
	Afro-Caribbean	3	6
	Mixed	3	6
	Mediterranean	2	4
	Asian	2	4
	Oriental	1	2
Parity n (%)	1	9	18
	2	32	63
	3	5	10
	4	4	8
	5	1	2
BMI		24.25	

Table 4 Newborn's data (n=51)

			Number	%
Birth week	38+3			
Personal data	Gender	Female	33	65
		Male	16	35
Before birth (US)	EFW (g)		3256	
	FHC (cm)		33.7	
Day of birth	BW (g)		3220	
	Birth length (cm)		49.2	
	HC, Midwife (cm)		34.9	
	HC, Fanny (cm)		35.1	
2 days after birth	HC, Fanny (cm)		34.4	
	Weight (g)		2996	

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3.3.2 Accuracy and variability of assessments

Inter-observer variability: D0_M vs. D0_F:

All 51 babies had their head measured on the day of delivery, first by the midwife then by myself. Inter-observer variability could thus be evaluated and showed small differences, as my measurements were on average a little higher than the ones made by the midwives. However, t-test shows that this difference is not significant ($p > 0.05$) (Figure 9).

Figure 9 D0_F vs. D0_M

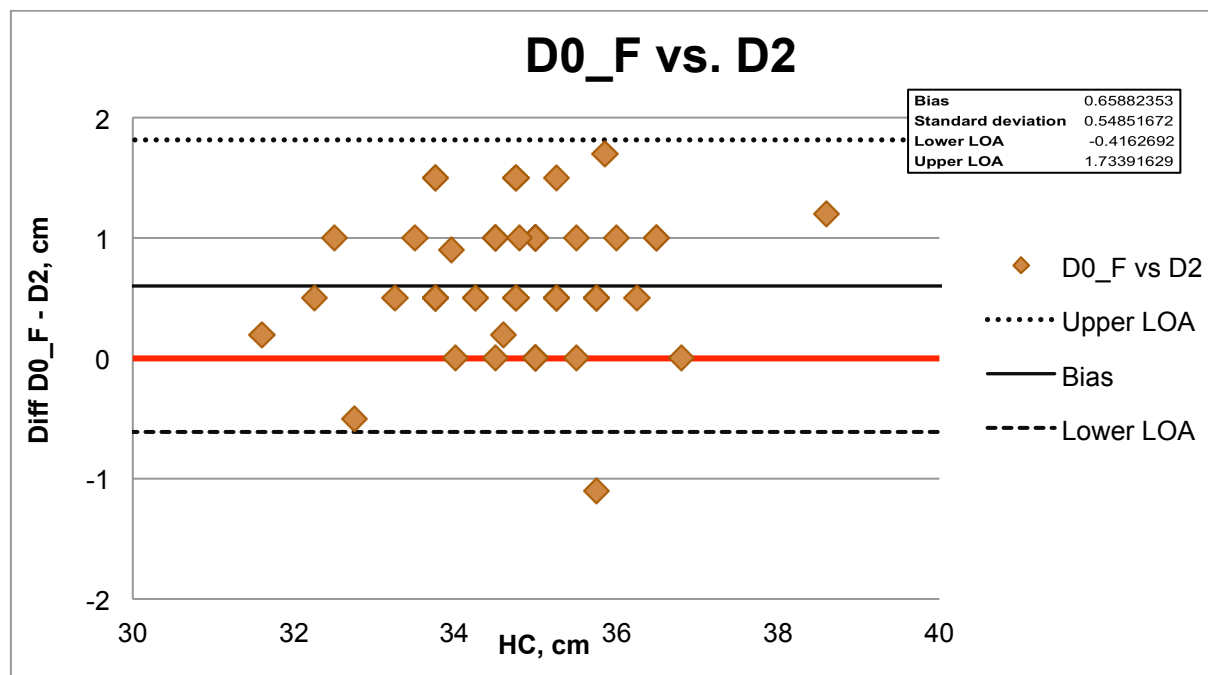|	
Bias	0.15294118
Standard deviation	0.47216647
Lower LOA	-0.7725051
Upper LOA	1.07838746
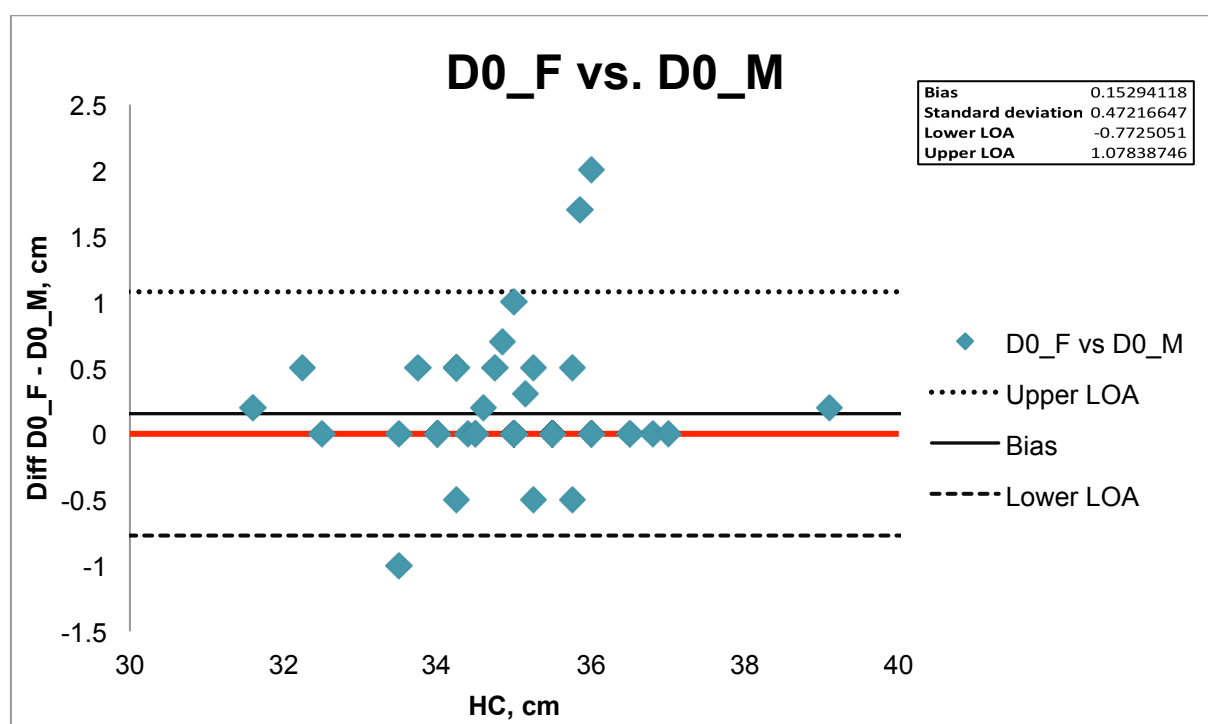
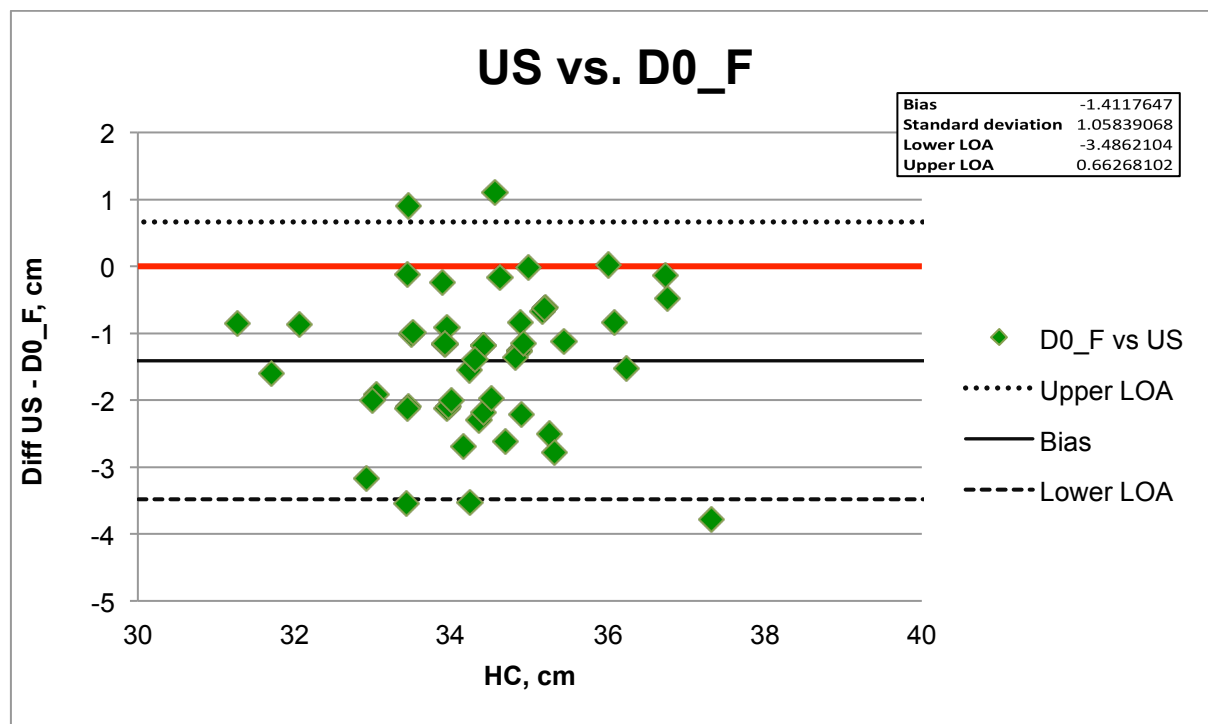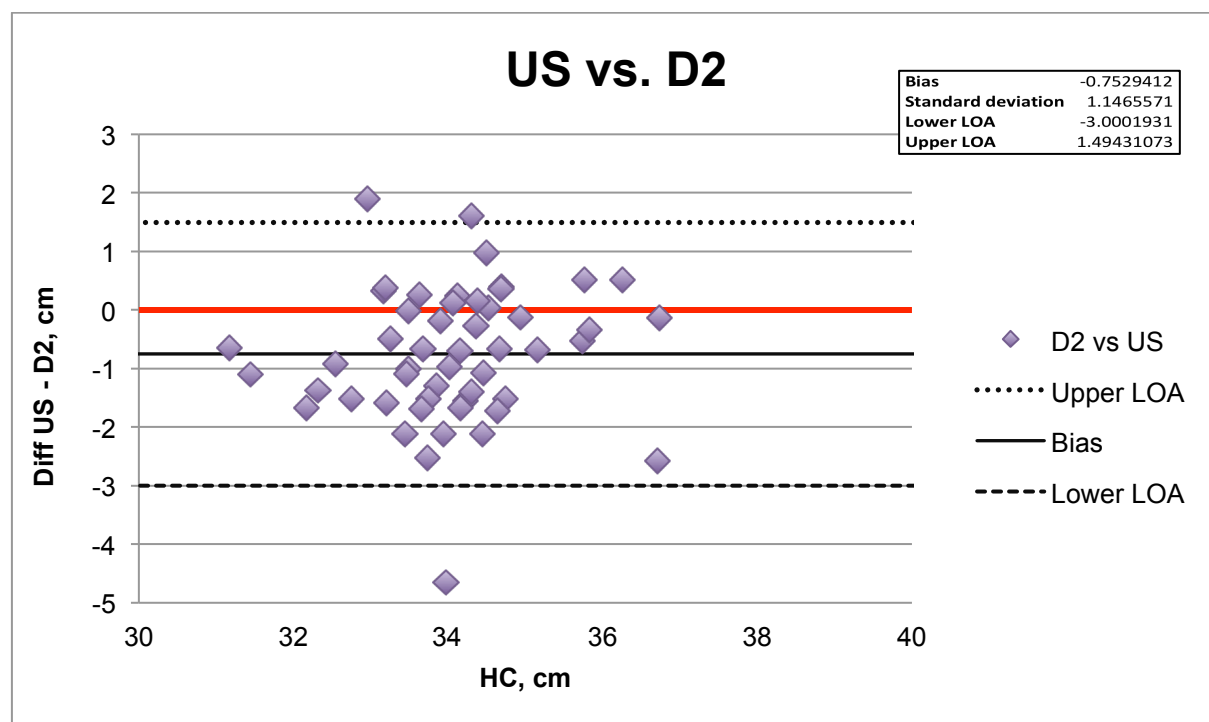**Figure 10 D0_F vs. D2**

Figure 11 US vs. D0_F

Figure 12 US vs. D2

As I measured newborn's HC both on the day of delivery and two days later, we where able to compare differences between those measurements. As expected from Simič Klarić's study (35), measurements made on the second day after delivery were in most cases smaller than those made on the day of delivery (Figure 10) and were thus closer to the ones measured by the US on the day before delivery. In fact, our results show significant differences between measurements made on the day of delivery when compared with those made by US (p<0.001) (

Figure 11). Although measurements made two days after delivery seem to be closer to the ones made by the US and show smaller differences than measurements made on the day of delivery compared with the US, the difference stays significant (p<0.05) (Figure 12).

3.4 Discussion of the results
Inter-observer (D0_M vs. D0_F):

- When comparing inter-observer variability on the day of delivery, statistics show insignificant values. Graphic showing correlation between the measurements also shows a good coefficient of determination (R^2 = 0.86). These differences could be due to small variations of positioning and tightening of the disposable paper meter. As seen in Figure 8, I have placed the paper meter with the purpose of having the largest HC. And this only by placing the paper meter on the newborn's head, without tightening or any pressure. When talking with some midwives, I was told that no specific guidelines or method is given for HC measurements in the USZ, but that they all simply measure the largest HC. However, it is possible, and as I have sometimes observed, that most of the midwives tighten the paper meters more than I have when measuring newborns' HCs. As I have only very little experience in newborn care, it is possible that by not wanting to hurt the newborns, I have

not tightened the paper meter enough. This may, as a result, have lead to small, insignificant differences. Due to these results, the next comparisons using D0 where made with my measurements (D0_F).

US vs. D0_F:

- As expected from Melamed's study, US measurements showed a significant underestimation of fetal HC compared with measurements made on the day of delivery. Altman plot shows that almost all measurements made with the US were smaller than the ones made on the day of delivery (difference <0 in most cases). However, two patients seem to clearly not follow that tendency and find themselves higher than upper LOA (0.66). These are the only two patients with overestimated US values compared to measurements made on the day of delivery. These two women do not seem to present particular similarities or differences compared with other patients from this sample that could explain such results. Such differences could be due to:
    - US measurement error. In fact, when looking at US pictures, they do not seem to be accurate (Figure 13).
    - D0_F measurement error. However, when these comparisons are made using D0_M, the same phenomenon is reported, suggesting that the explanation can be found elsewhere.
    - Baby moving.
- As said in Melamed's study (24), reasons for the US underestimation are unclear. It was observed in this study, that US underestimations are more frequently found in certain situations such as; increasing in the gestational age, male fetuses, vertex presentation, high cephalic index and large HC (>90th percentile). It is mentioned that the fetal scalp might not always be well distinguished from contiguous soft tissues of the uterus and that the US therefore only includes the skullcap. This could explain an US underestimation of our patients' HC as this study only included babies born at ≥37 weeks of gestation. Another explanation that could apply to our study is the fact that term pregnancies often result in fetal heads that do not fit totally into the US plane. HC measurement calculations using BPD and OFD can, therefore, be influenced. As for male fetuses, when comparing percentage error of the US HC measurements and D0_F measurements for male and female, the opposite correlation was observed (female percent error: 4.4%, male percent error: 3.2%). This could, however, be due to the small sample size of this study.

US vs. D2:

As expected, D2 measurements seem to be more accurate or at least more similar to US measurements. However, p-value still shows a significant difference (p= <0.005). When analyzing the Altman plot, two patients have significant reversed results (> upper LOA) these two being the same patients from plot US vs. D0_F. This means that D2 measurements were smaller than US measurements. Once again, US pictures could explain part of this significant difference. Figure 13 shows US pictures of these two patients. On the first US, one of the fetus's ear is visible (red circle), indicating an oblique cut. The second US shows a round shaped head, indicating a wrong plane. This lack of accuracy could thus be responsible or at least explain part of these significant reversed results. Reversed results are also reported for 12 other patients, although these patients stay between upper LOA and bias. When comparing these 14 patients, no particular similarities or differences can be noted. But this

Altman plot also shows another outlier, this time in the opposite direction (< lower LOA). It is interesting to notice that this last patient was at 40+1 weeks of gestation whereas all patients from the other group were on average at 38+1 weeks of gestation. It is possible that weeks of gestation play a role in HC measurements, however, in this study, there is not enough evidence to show significant correlations between weeks of gestation and HC measurements. Furthermore, other patients at 40 or more weeks of gestation (total n = 4) do not result in bigger US measurements than D2 measurements.

D0_F vs. D2:

Figure 13 HC US
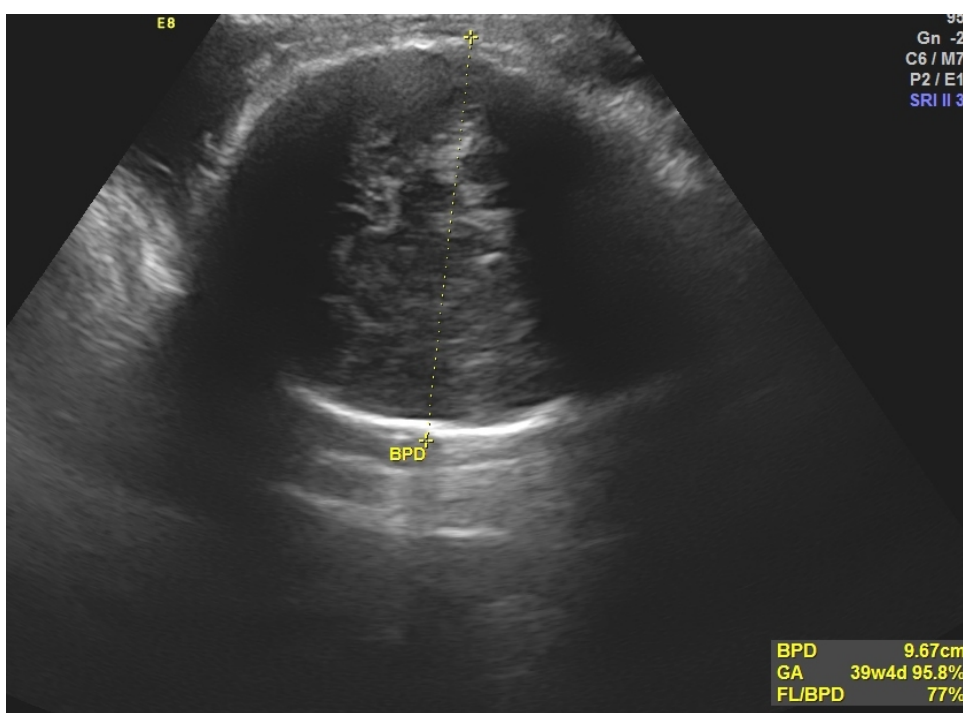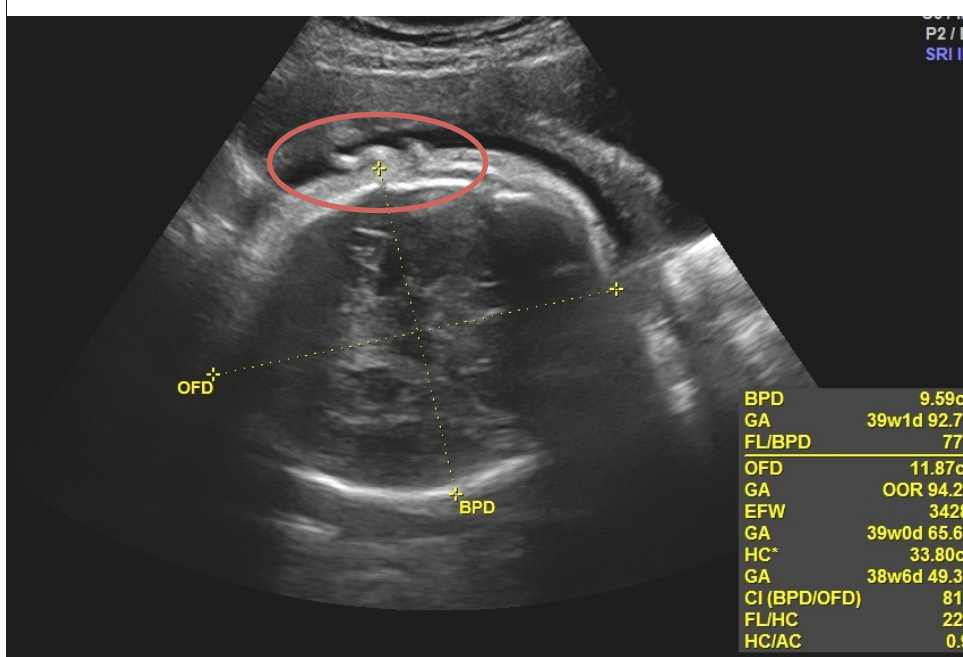
- As expected from Simic's study, D2 measurements seem to be smaller than measurements made on the day of delivery. A reduction in HC could be caused by relative physiological dehydration of newborns during the first week of life (35). This could, in fact, explain a reduction in head size and therefore, in HC. In Sankaran's study of 1983, he already reported a 'postnatal neurocranial scalp shrinkage' (36). It is suggested that a loss of water, and more specifically the loss of cerebrospinal fluid or interstitial brain water, could cause shrinkage of intracranial volume, resulting in smaller HC in the following days after delivery. According to Simic's study, HC shrinkage is mostly observed in children born by CS. These notions could thus explain our results. However, our Altman plot shows two patients who appear to have a negative difference, meaning that the D2 measurement was higher in those two cases. Aside from the fact that these two women are not Swiss natives, no specific correlation could be found between these results and the patients. Furthermore, other non-Swiss native women (total n = 35) do not result in bigger HC at D2, and therefore, this explanation is not reliable.

3.5 Limitation of the study

As previously said and as mentioned in Simic's study, shrinkage in HC is mostly observed in newborns delivered by CS, and these results might therefore not apply to all newborns. Furthermore, this study has included only elective CS; results might be different for other groups of patients.

4 Overall Discussion

Delivery has evolved over the years. As seen in part 1, although places of birth, people present to help during birth and chances of survival after vaginal delivery have changed and evolved majorly throughout the years, the event of giving birth with the purpose of keeping both mother and child alive has always stayed the same. The emergence of instrumental delivery, the CS with anesthesia, the awareness of the importance of hygiene and antibiotics as well as the emergence of imaging and prenatal diagnostic technology, have had a major contribution in decreasing morbidity and mortality of both mothers and their newborn child. With the help of new technologies, prenatal diagnosis can be done, fetal assessment can be made, and complications can be avoided. Still, some deliveries end up in emergency instrumental deliveries or CS. It is thus important to be as accurate as possible or to be aware of systematic errors that could be made when performing such actions, to prevent as many unwanted events as possible.

As we have seen in part 2, the importance of HC measurement is often underestimated as no studies regarding the relation between HC and mode of delivery has yet been made. As expected from previous studies, US measurements of the fetuses' HC was underestimated compared to measurements made on the day of delivery. Also, HC was in most cases smaller at day 2 and therefore closer to US measurements. As mentioned earlier, HC shrinkage in the first few days after birth appears to apply mostly to babies born by CS (35). It would probably be useful to repeat this study with babies born spontaneously, once with

and once without instrumentation, as well as patients with a breech position, fetal macrosomia, microcephaly, IURG and multiple pregnancies.

5   Conclusion

This study has confirmed our hypothesis, even though differences between US and D2 HC measurements stay statistically significant. As for our other results, no significant inter-observer variability was noted. Furthermore, US fetal HC measurements were significantly underestimated when compared to measurements made on the day of delivery, and HC seemed to shrink physiologically in most cases at D2, thus being more similar to measurements made with the US.

With that said, obstetricians of the USZ should be aware of this US underestimation. However, they should also be informed that these data are only valid for cases of elective CS. Therefore, further studies should thus be made if we want to apply these results to other groups of patients, and if we want to use them for a better prediction of the delivery mode.

6   Acknowledgments

7   References

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