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ULLA KORHONEN

*Maternal pelvis,
feto-pelvic index and
labor dystocia*

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ABSTRACT

Cephalopelvic disproportion (CPD) occurs when there is a mismatch between the fetus and the maternal birth canal. In the previous century, a variety of methods were introduced to predict CPD, such as X-Ray and magnetic resonance (MR)-pelvimetry and fetal pelvic index (FPI), an index that combines maternal inlet and outlet size with the fetal head circumference (HC) and abdominal circumference (AC). Further studies of these methods in the prediction of successful labor have been controversial. The objective of this retrospective study was to evaluate pelvimetry and FPI by observing variation in measurements and accuracy in predicting labor dystocia.

First, the intra-observer and inter-observer variation of four MR- pelvimetric dimensions were evaluated in 100 patients. A variation within the range of 0.5 cm was considered acceptable. Ninety-five and ninety-nine% of the anteroposterior and transverse measurements of the inlet were within this range but especially the inter-observer variation of the outlet dimensions was unacceptably high as up to 15% of measurements were outside this range.

To test the association of different pelvimetric measurements and FPI with labor arrest leading to cesarean section (CS), a patient group of 274 women having a trial of labour was analysed. Thirty-two (11.7 %) of them had an emergency CS for labor arrest. The independent risk factors for CS caused by labor arrest were advanced maternal age, small maternal inlet dimensions, large fetal HC and increasing fetal pelvic index. However, both pelvimetric parameters and FPI exhibited poor sensitivity or positive predictive value in the prediction of CS for dystocia. If the fetal head circumference was more than 340 mm, the ability of pelvimetric parameters to predict labor arrest increased.

The impact of maternal pelvimetric dimensions for the need of assisted vaginal delivery was studied in a patient group of 226 women of which 42 (18,6%) delivered with vacuum extraction. No correlation between the maternal pelvic inlet or outlet circumference and the need for vacuum extraction was found.

In summary, pelvimetric measurements with MRI of pelvic inlet were proven to be accurate within the limit 0.5 cm of variation, but there was considerable observer-related variation in the measurements of pelvic outlet. In the prediction of labor arrest and operative vaginal delivery, the accuracy of pelvimetric measurements proved to be poor. The accuracy of inlet size in the prediction of CS was moderate, if the fetal HC size was taken into consideration. However, FPI did not improve the predictive power. It is concluded that neither pelvimetry nor pelvimetry- related methods should be encouraged to be used in clinical decision making.

National Library of Medicine Classification WP155, WQ310, WQ320, WQ430:

Pelvimetry; Trial of Labor; Vacuum Extraction; Obstetrical; Dystocia; Observer Variation; Dimensional Measurement Accuracy; Retrospective Studies

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TIIVISTELMÄ

Synnytyksen pysähtymisen syynä voidaan pitää sikiön koon ja äidin lantion koon välistä epäsuhtaa eli fetopelvistä disproportiota. Viime vuosisadalla kehitettiin disproportioon ennustamista varten menetelmiä, kuten röntgen pelvimetria sekä magneettiseen resonanssi-ilmiöön perustuva (MR)-pelvimetria sekä fetopelvinen indeksi (FPI), joka lasketaan äidin lantion ylä- ja keskiaukeaman ympärysmittojen sekä sikiön pään ja vartalon ympärysmittojen avulla. Alustavat tutkimukset FPI:stä synnytyksen pysähtymisen ennustamisessa olivat lupaavat, mutta myöhemmät tutkimustulokset ovat olleet ristiriitaisia. Tämän retrospektiivisen tutkimuksen tarkoituksena oli selvittää pelvimetriassa käytettyjen mittausten toistettavuutta ja pelvimetrian sekä FPI:n käyttöä synnytyksen pysähtymisestä johtuvan keisarileikkauksen tai operatiivisen alatiesynnytyksen ennustamisessa.

Pelvimetriamittausten toistettavuutta tutkittiin sadan potilaan aineistolla sekä yhden mittaajan kahden, ajallisesti eriävän mittauksen välillä että kahden eri mittaajaan samasta kuvasta tehdyn mittauksen välillä. Tutkimuksessa valittiin hyväksyttäväksi poikkeamaksi alle 0,5 cm ero kahdessa erillisessä mittauksessa. Vain yläaukeaman anteroposteriorisen ja sivumitan kahden mittauksen välinen poikkeama jäi 95 ja 99 %:ssa mittauksista sallittuun arvoon, kun taas ala-aukeaman mitat poikkesivat toisistaan 0,5 cm tai enemmän jopa 15 % mittauksista.

Pelvimetriamittausten osuvuutta synnytyksen pysähtymisestä johtuvaan keisarileikkauksen ennustamisessa tutkittiin takautuvassa 274 synnyttäjän aineistossa. Synnytyksen pysähtymisestä johtuva keisarileikkaus tehtiin 32 potilaalle. Regressioanalyysin perusteella keisarileikkaukselle altistavia riskitekijöitä olivat äidin ikä, sikiön päänympärysmitta ja äidin lantion yläaukeaman ympärysmitta. Pelvimetriasta saatujen lantion mittojen osuvuus sekä FPI osoittautuivat ainoastaan kohtalaiseksi ennustettaessa synnytyksen pysähtymistä. Jos sikiön päänympäryys oli suurempi kuin 340mm, osuvuus parani. Lantion koko ei vaikuttanut alatiesynnytyksessä loppuvaiheen interventioiden tarpeeseen 226 synnyttäjän aineistossa, jossa 42 naista (18,6 %) synnytti imukuppiavusteisesti.

Tutkimusten perusteella voidaan todeta, että pelvimetriassa käytetyt mittaukset olivat oikeita, kun poikkeamana hyväksyttiin 0,5 cm, mutta mittaukset ovat alttiita merkittävälle mittaajien välisille vaihteluille erityisesti lantion ala-aukeaman mittauksissa. Pelvimetriamittaukset ennustivat huonosti synnytyksen pysähtymistä tai intervention tarvetta alatiesynnytyksen loppuvaiheessa. Jos sikiön päänympäryys huomioitiin, yläaukeaman ympärysmitta ennusti kohtalaisesti synnytyksen pysähtymistä. FPI ei kuitenkaan osoittautunut ennustuskyvyllään pelvimetriaa paremmaksi. Johtopäätöksenä voidaan todeta, että pelvimetrian tai FPI:n diagnostinen tarkkuus ei ole riittävä, jotta niitä voitaisiin käyttää sellaisenaan synnytystavan valintaan.

Luokitus WP155, WQ310, WQ320, WQ430:

pelvimetria; sikiön ja lantion välinen epäsuhta; keisarileikkaus; imukuppi-synnytys; dystokia; tutkijasta riippuva vaihtelu; mittausvirheet; tarkkuus; toistettavuus; retrospektiiviset tutkimukset

To mothers and their caregivers in labor

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Joensuu, July 2014

Ulla Korhonen

List of the original publications

This dissertation is based on the following original publications:

- I Korhonen U, Solja R, Laitinen J, Heinonen S, Taipale P. MR pelvimetry measurements, analysis of inter- and intra-observer variation. *European Journal of Radiology*, 75, e56-e61. 2010.
- II Korhonen U, Taipale P and Heinonen, S. The Diagnostic Accuracy of Pelvic Measurements—Threshold Values and Fetal Size. *Archives in Obstetrics and Gynecology*. [Epub ahead of print]. 2014.
- III Korhonen U, Taipale P and Heinonen, S. Fetal Pelvic Index to Predict Cephalopelvic Disproportion- A Retrospective Clinical Cohort Study. *Submitted*.
- IV Korhonen U, Taipale P and Heinonen S. Assessment of Bony Pelvis and vaginally assisted Deliveries. *ISRN Obstetrics and Gynecology*, Article ID 763782 doi:10.1155/2013/763782. 2013.

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Abbreviations

95%CI	95% Confidence Interval	LGA	Large for Gestational Age
AC	Abdominal Circumference	MC	Midpelvic Circumference
ACOG	American College of Obstetrics and Gynecology	MD	Mean Duration
AEC	Automatic Exposure Control	NPV	Negative Predictive Value
AP	Antero-Posterior	NSA	Number of Signal Averages
AUC	Area Under the Curve	OR	Odds Ratio
BPD	Biparietal Distance	PPV	Positive Predictive Value
BW	Birth Weight	PROM	Premature Rupture of Membranes
CPD	Cephalopelvic Disproportion	RFOV	Rectangular Field of View
CS	Cesarean Section	ROC	Receiver Operating Characteristic curve
CV	Conjugata Vera, anteroposterior conjugate	RR	Risk Ratio
DT	Transverse Diameter	SD	Standard Deviation
EFW	Estimated Fetal Weight	SFH	Symphysis Fundus Height
FFE	Fast Field Echo	SGA	Small for Gestational Age
FL	Femur Length	SID	Source Image Distance
FOV	Field of View	TSE	Turbo Spin Echo
FPI	Fetal Pelvic Index	US	Ultrasonography
FTP	Failure to Progress	VBAC	Vaginal Birth After Cesarean Section
HC	Head Circumference		
IC	Inlet Circumference		
ICC	Intraclass Correlation Coefficient		

1 Introduction

Cephalopelvic disproportion (CPD) or fetal pelvic disproportion in labor occurs, when there is a mismatch between the fetus and the maternal birth canal (Maharaj 2010). The first description of a severe birth injury was found in the mummy of Queen Henhenit 2000 B.C. who had a small, android shape pelvis (Derry 1935). Until the 15th century, operative delivery was performed only postmortem (Lurie 2005). Already in the 19th century, the idea of disproportion was raised by Litzmann in Germany in 1861. In modern obstetrics, the concept of the inadequate maternal pelvic size along with the uterine driving forces was introduced by Mengert in 1948. CPD is considered to cause protraction and even arrest of labor and as a consequence, it increases both maternal and fetal morbidity (Wax 2006). In term non-complicated pregnancies, the benefits of the trial of labor are well known especially among nulliparous women (de Jong 1987; Rosen et al. 1990; Rozen, et al. 2011) and the mode of delivery requires no routine prenatal consultation.

The factors that affect the success of vaginal delivery can be considered as the three “P”s of labor, the “passenger”, the “passageway” and the “power” (Maharaj 2010). In modern obstetrics, the evaluation of size of the “passenger” – is done via ultrasonographical measurements, but the accuracy of fetal weight estimation in term pregnancy has proven to be low even with access to modern technology (Dudley 2005). Magnetic resonance imaging (MRI) has been utilized in fetal volumetric measurements to increase the accuracy (Zaretsky et al. 2003). In the evaluation of the passageway, modern pelvimetric measuring was introduced by Colcher and Sussman (Colcher and Sussman 1949). In order to decrease the risks of radiation to the fetus, MR pelvimetry was recommended for clinical practice (Sporri et al. 2002). However, already two decades ago, the usefulness of pelvimetry in the diagnosis of CPD was proven to be low and it was proposed that the practice should be abandoned (Pattinson 2000). A number of fetal and maternal parameters have been investigated in order to find a diagnostic tool to evaluate CPD, but none of these has proven to be reliable for clinical use (Mahmood 1989; Mahmood et al 1988; Dahan et al.2005).

When the poor predictive value of pelvimetry was appreciated, the concept of combining the fetal dimensions with the size of the maternal birth canal was introduced by Jagani et al (1981). Fetal pelvic index (FPI), originally introduced by Morgan and Thurnay (1986), combines the fetal head and abdominal circumferences with the maternal pelvic inlet and outlet circumferences. In the preliminary reports, the results for FPI as a predictive method for CPD seemed promising (Thurnau et al.1988; Morgan et al 1988a; Morgan et al. 1992). However, with larger cohorts, the results were not reproducible (Ferguson et al. 1998) raising questions about the role of FPI. The aim of this study was to investigate the reproducibility of pelvimetric measurements in term singleton pregnancies with vertex cephalic presentation and to test the predictive value of pelvimetry combined with fetal dimensions and the accuracy of FPI in a cohort of women undergoing labor.

2 Review of the literature

2.1 LABOR

Labor can be defined as the period that ends the pregnancy and culminates in the birth of the child. The process is initiated with the onset of regular uterine contractions that cause the dilatation of the cervix and expulsion of the fetus and placenta. There is extensive biological variation that characterizes normal labor. According to the 2010-2011 Perinatal Statistic Report from the Finnish National Institute for Health and Welfare (2012), three out of every four mothers delivered via spontaneous labor. Among the nulliparous women, 63% had spontaneous labor. In this review, labor is discussed in term singleton pregnancies with vertex cephalic presentation, if not otherwise mentioned.

2.1.1 Normal labor

The onset of labor is defined as the period when the uterine contraction activity is regular and cervical dilatation is present. However, determining the actual onset of labor can be done only retrospectively, since the painfulness of the uterine contractions does not correlate with the power of uterine activity and the dilatation of the cervix. In clinical obstetrics, the onset is commonly determined as the time when the painful uterine contractions lead to cervical shortening and dilatation. Friedman (1972) stated that the labor can be considered as ongoing when there are painful contractions recorded and the cervix is dilated to 3-5cm. According to Kilpatrick et al. (1989), the labor onset is defined with cervical change along with regular contractions with every 3-5minutes, whereas Pates et al. (1997) suggested that a contraction activity of 12 contractions/hour and the cervix dilatation of > 4cm is required for labor onset. Recently, the limit of cervix dilatation of >5 cm has been suggested for a limit of labor onset (Zhang et al. 2010). In Finland, the onset of labor is defined with cervical dilatation of 2-4cm along with regular uterine contraction activity (Ekblad 2013).

The progress of labor can be divided into three stages which are preceded by the latent phase. The first stage starts with the onset of labor and leads to the complete effacement of the cervix. This is followed by the second stage of labor, which ends with the delivery of the fetus. The third stage, the "final stage" involves the delivery of the placenta and amniotic membranes. The normal duration of the labor was initially quantified by Friedman (Friedman 1954). By monitoring the cervical dilatation against the time, he was able to develop the modern partogram model (figure 1). For the next 50 years, the observations about the normal duration of the labor made by Friedman have been taken as the thresholds to be used in clinical practice (Tita 2012).

Since the population now undergoing labor differs from those that were investigated by Friedman, the limits for normal duration of the labor have proved to require adjustment (El-Sayed 2012). Zhang et al (Zhang et al. 2010a) used a large contemporary database to determine the normal patterns of spontaneous labor with normal neonatal outcomes. According to their study, normal labor can take more than six hours for cervical dilatation to progress to 4 to 5 cm and more than three hours to progress from 5cm to 6 cm. After 6 cm of cervical dilatation, the labor progresses much faster in multiparous women compared with nulliparous women. The 95th percentile for normal duration of the second stage of the labor was up to 3.6 hours in the nulliparous but about 2 hours in multiparous women (Zhang et al. 2010a).

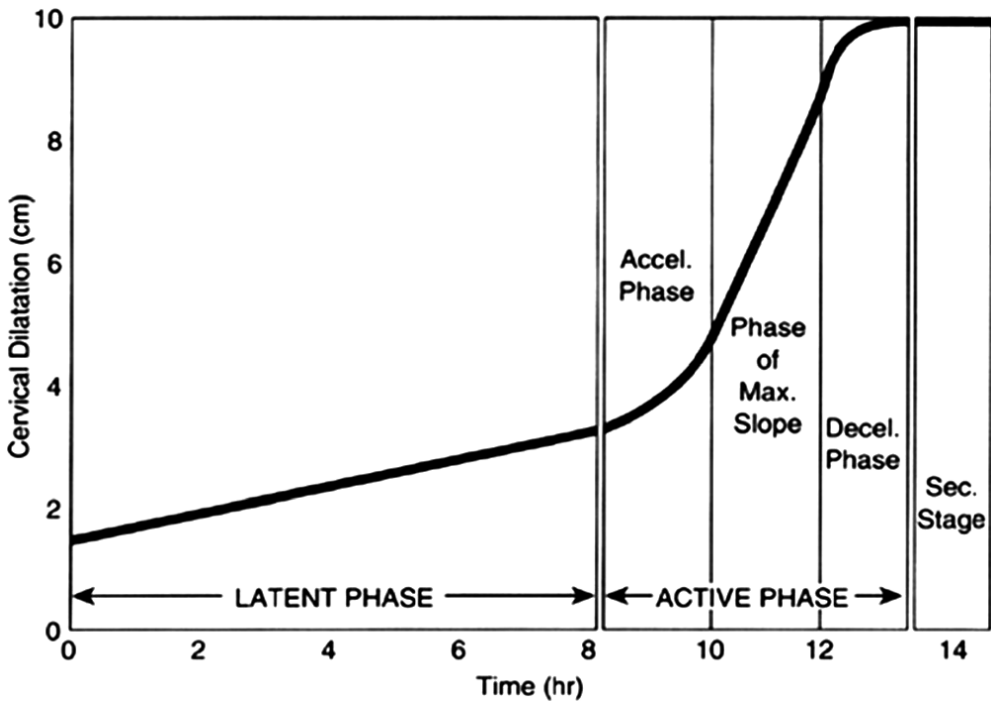


Figure 1. The Friedman curve for normal labour.(With permission of Wolters Kluwer Health.)

In the management of the normal labor, it is important to understand that childbirth is a normal physiological process but simultaneously be aware of the complications, which may occur rather abruptly. The role of active management of labor (O'Driscoll et al. 1984), including the strict diagnosis, the use of augmentation, routine amniotomy and so-called one to one support during labor have been postulated to reduce the need for operative interventions. In a recent meta-analysis of over 5000 labors, active management was associated with only a small reduction in the CS rates (Brown et al. 2008). Wei et al(2012) concluded in their large cohort meta-analysis that early intervention with amniotomy and augmentation with oxytocin were associated with a modest reduce of CS rates and shortened duration of the labor in comparison with standard care. In conclusion, the studies reveal that early interventions and active management in normal labor achieve no significant reduction in the CS rate (RR 0.88, 95%CI 0.77-1.01) but do shorten the duration of labor (MD 1.28 hours, 95%CI-1.97–0,59) and decrease the discomfort for the mother. It has also been speculated, that sufficient pain relief as a part of active management can decrease the risk for post partum depression (OR 0.25, 95%CI:0.09-0.72)(Hiltunen et al. 2004)

2.1.2 Abnormal labor

Labor can be considered to be abnormal if an operative intervention is required due to maternal or fetal distress or failure to progress, as defined by the criteria shown in Table 1. Interventions that are done to monitor the fetal or maternal well-being do not mean that the labor should be considered as abnormal. Fetal distress is a non-repeatable reason for abnormal labor and can occur for multiple reasons, such as fetal growth restriction, maternal illness, umbilical cord prolapse or placental abruption.

Table 1. Different criteria that justify the diagnosis of labor arrest.

	Uterine activity	Cervical dilatation
Impley.L 1998	Unresponsiveness to Oxytocin	>6 cm, progression < 2cm/ 2 hours
ACOG 2003	Contractile strength at least 200 Montevideo units,	>4 cm no progress in 2 hours
Morgan 1986, Ferguson 1998	Contractile strength at least 150 Montevideo units	>5cm
O'Brien 2002		(>2 hours)No change in cervical dilatation.
Kjaergaarg 2009	-	>3 cm,(< 2cm / 4hours)

If the labor is characterized by slow progress, the condition is termed as dystocia. The reasons and the clinical findings for dystocia include impaired uterine activity, narrow bony pelvis, fetal macrosomia and malposition of the fetus (Williams 2010). To simplify the abnormalities, they can be summarized as the three "P"s of the labor, "passenger-passageway-power"(ACOG 1995). Abnormal labor is usually a combination of several abnormalities which may form a vicious circle, as shown in figure 2 .When dystocia in labor is present, the need for some intervention such as acute CS increases.

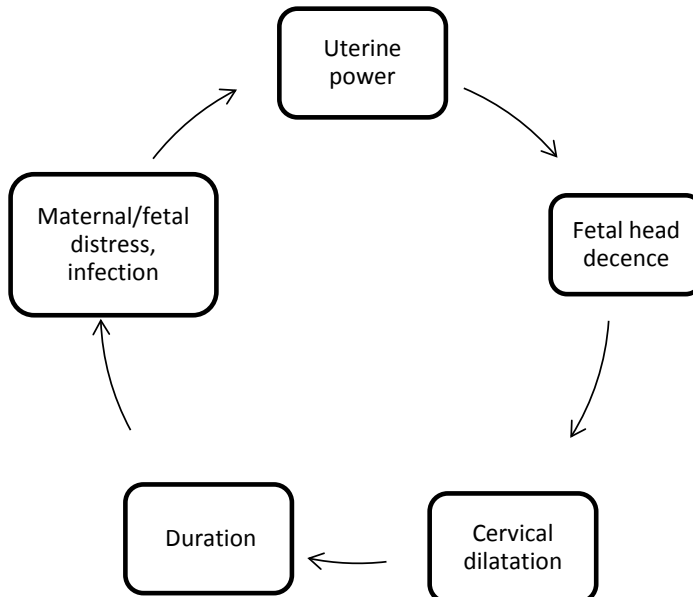


Figure 2. Vicious Circle of abnormal labor. With insufficient uterine activity, the decence of the fetal head may decelerate. These factors can also have an effect on the cervical dilatation and increase the duration of the labor. The prolonged duration may cause both maternal and fetal distress and increases the risk of infection and further, it may lead to uterine activity disorders (Modified from ACOG 2003).

2.1.2.1 Cephalopelvic disproportion

If there is a mismatch between the size of the fetus and maternal pelvic capacity, an abnormality in labor occurs as a protracted or arrested labor, as defined in table 1. Along with the original investigations of the pelvic capacity conducted by Mengert in 1948, the term cephalopelvic disproportion (CPD) was taken into practice (Mengert 1948). The invention of simple x-ray pelvimetric measurements by Colcher and Sussmann (1949) increased the use of pelvimetry and during the subsequent decades, CPD became a common reason for pre-selected CS. Since the CS rate increased rapidly, there were calls for a more critical approach to the use of pelvimetry and it was proven to have a poor association with the diagnosis of CPD (Pattinson 2000). Over the past decade, the American College for Obstetricians and Gynecologists (ACOG) recommend that labor arrest can not be diagnosed until the labor is in active phase, the cervix is dilated ≥ 4 cm and the sufficient uterine contraction activity (monitored ≥ 200 Montevideo units/10min) has been present over two hours (ACOG 2003). However, recent studies have challenged this “two-hour –rule” (Zhang et al. 2010a). According to the latest recommendation of ACOG, CS for active phase arrest can be performed for those women that have achieved cervical dilatation of ≥ 6 cm (threshold for the active phase of labor) and despite of four hours of adequate uterine activity or at least six hours of oxytocin administration no cervical change occurs (ACOG 2014).

When CPD is present, cesarean section is required as the treatment. In subsequent pregnancies, the mode of delivery requires consultation, since CPD is not an obvious non-repeatable reason for CS. In the large cohort study conducted by Peaceman et al the success rate for vaginal birth after CS (VBAC) was 54%. The success rate correlated with the fetal weight *i.e.* it decreased to 38%, if the fetus was >500 g larger than that of the previous delivery (Peaceman et al. 2006). In addition, if the labour arrest had been diagnosed in the late stage of the labor, the success of the subsequent vaginal delivery increased as compared with the early stage arrest (59% vs 39%, $p < 0.001$) (Abildgaard et al. 2013).

2.1.2.2 Operative vaginal delivery

In modern obstetrics, the operative maneuvers to deliver the fetus consist of vacuum extraction and forceps. These methods are used to expedite the delivery of the fetus for the benefit of the mother or the fetus or both (O’Mahony et al. 2010). The rates of operative vaginal deliveries with vacuum extraction in Finland between 1993-2011 according to Perinatal Statistics (2012) are seen in figure 3. The indications for operative vaginal delivery are prolonged second stage of the labor or exhaustion of the mother, signs of fetal distress or rarely, maternal chronic illness (ACOG 2000). If fetal pelvic disproportion is suspected, attempts of operative vaginal delivery should be avoided (ACOG 2000).

The risks and benefits of the use of forceps and vacuum extraction have been investigated in several studies (Yeomans 2010). In their meta-analysis, Vayssiere et al. concluded, that vacuum extraction could reduce the risks for maternal injury but the duration of the delivery was longer than with forceps (2011). There is a report that the success of vaginal delivery appears to be better with forceps (O’Mahony et al. 2010). If the criteria for the use of operative maneuver are met, the benefits of operative vaginal delivery are clear in comparison with the risks associated with acute CS (Goetzinger et al. 2008). As a delivery experience, operative delivery can be traumatic to mother. Insufficient support immediately after delivery, the experience of being poorly listened to during labor, insufficient physician support during the first stage of labor, and pre-labor training classes considered as being insufficient were all independent factors that increase the risk for a traumatic experience (Uotila et al. 2005).

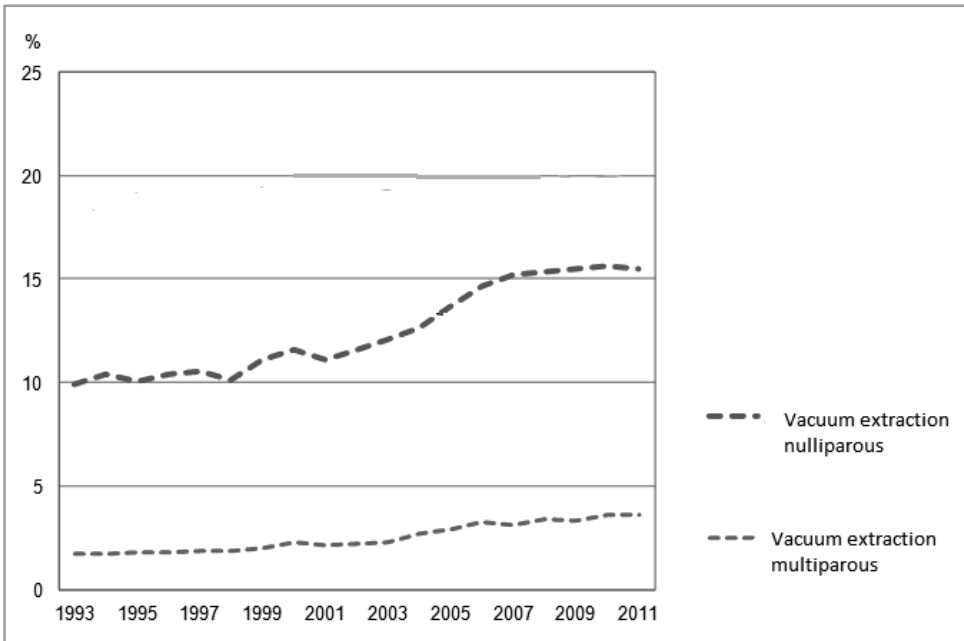
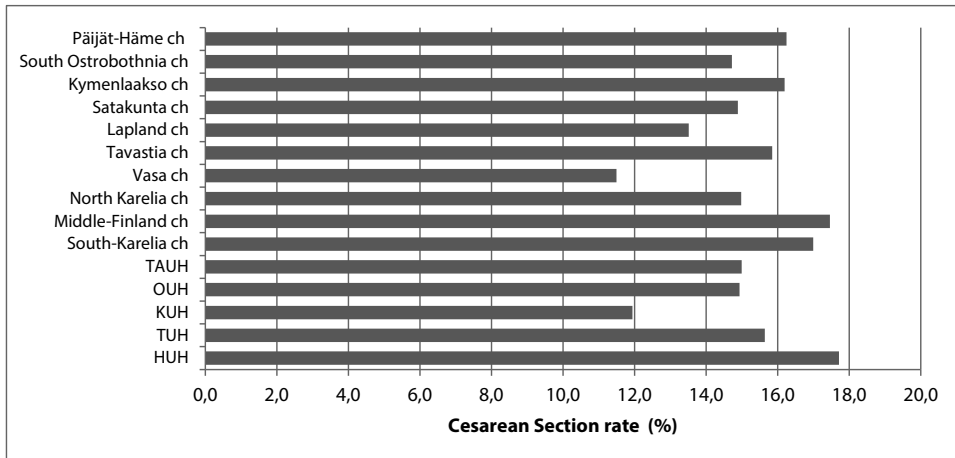


Figure 3. The rates of the operative vaginal deliveries with vacuum extraction in Finland between 1993-2011 in nulliparous and multiparous women according to Perinatal Statistics (2012).

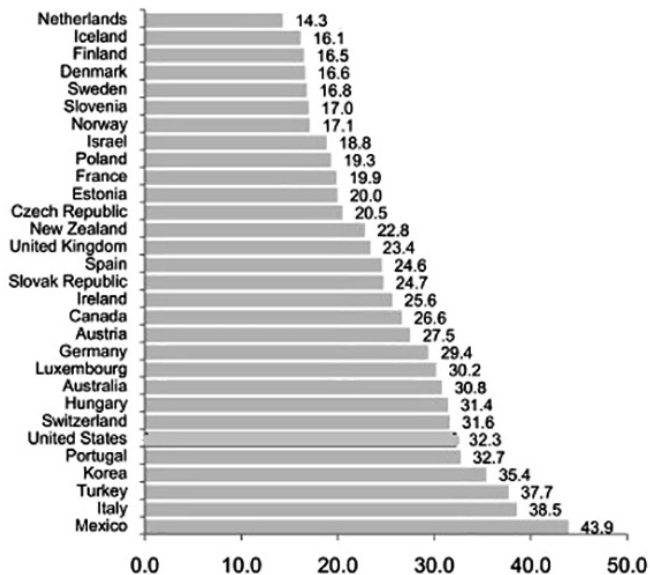
2.1.2.3 Cesarean section

The definition for cesarean section (CS) refers to the operative labor through the abdominal wall and uterine muscle. In Finland, during the years 2010-2011, the CS rate was 16% and this rate has remained stable over the past decade (Perinatal Statistics 2012). The CS rates 2011 according to different hospitals are shown in figure 4a. A Finnish multicenter study concluded that although there was a significant variation in CS rates between the units, this had no effect on morbidity or mortality, indicating that there is no “golden standard” CS rate (Pallasmaa et al. 2013). There is a significant variation in CS rates in different countries (Einarsdottir et al. 2013). As seen in figure 4b, in Europe, especially in Scandinavia, the CS rates are low whereas in the United States and in Latin America, the CS rates are almost threefold higher than in some other countries *i.e.* The Netherlands (Boyle et al.2012). In the high CS rate nations, the increase of the rate has been remarkable and in United States, the CS rate has risen from 4.5% to more than 30% during the last 40 years (Martin et al. 2011).



Ch, central hospital; TAUH, Tampere University Hospital; OUH, Oulu University Hospital; KUH, Kuopio University Hospital; TUH, Turku University Hospital; HUH, Helsinki University Hospital.

Figure 4a-b. Cesarean section rates rates 2011.4a) CS rates in Finnish hospitals with >1000 deliveries.



Source: Organisation for Economic Co-operation and Development. OECD Health Data 2011- Frequently Requested Data. http://www.oecd.org/document/16/0,3746,en_2649_33929_2085200_1_1_1_1,00.html

Figure 4a-b. Cesarean section rates rates 2011. 4b) CS rates in different nations (with permission Elsevier Limited).

Cesarean section is further defined by the time from decision to delivery (MacKenzie et al. 2002). In the English-speaking research society, the term emergency CS refers to all the cesareans that are performed during the labor, whereas in Finland, the term “crash-cesarean” is also used for immediate delivery (Pallasmaa et al. 2010). In addition, the definitions of primary and repeated CS are also used in practice.

In a large retrospective study, the leading indication was failure to progress (Boyle et al. 2013) but the investigators stated that cervical dilatation was less than 5 cm in most of the deliveries implying that dystocia could have been overdiagnosed. It has been speculated, that the impact of dystocia has been a crucial factor in the increase of the CS rate (Tita 2012). The benefits for vaginal delivery compared with the risks of the cesarean section are well recognized (Hankins et al. 2006; Liu et al. 2007; Clark et al. 2008). The risks can be categorized as short term risks, such as infections and thromboembolism (Burrows et al. 2004; Allen et al. 2003) and long term risks, such as abnormal placentation and abruption (Gurol-Urganci et al. 2011; Lydon-Rochelle et al. 2001a; Getahun et al. 2006; Yang et al. 2007, Silver 2012) and in addition, they involve also the fetus (Morrison et al. 1995; Kennare et al. 2007; Hemminki et al. 2005; Silver 2012). The risks of severe morbidity and mortality increase along with the number of repeated cesareans (Silver et al. 2006). In a Finnish multicenter study, about 27% of women delivering by CS suffered a complication and 10% of these were considered a severe. Emergency and crash-emergency CS increased the risk for complications significantly (Pallasmaa et al. 2010). It is clearly important to be sure that the mother is aware of the risks of CS (Horey et al. 2004).

2.2 ASSESSMENT OF THE PASSENGER

2.2.1 Fetal Growth and macrosomia

In current practice fetal growth is monitored by estimating the fetal weight which can be done with variety of ways. It can be done by measuring a single fetal parameter i.e. fetal abdominal circumference or with a combination of parameters which is commonly done with sonography. In the determination of the normal fetal growth, the mean $\pm 2SD$ of population is commonly used as the reference standard (Mayer et al. 2013). There are different forms of abnormal growth *i.e.* low birth weight, small for gestational age (SGA), macrosomia and large for gestational age (LGA). The various factors (shown in table 2) can have an effect on fetal growth (Mayer et al. 2013). If the whole unselected population is used as the reference, there is a risk of misinterpretation in determining the fetal growth abnormalities (Reeves et al. 2008). Therefore, according to recent studies, it would be preferable to move away for the concept of percentile-based growth abnormality. Instead, it would be more recommendable to use criteria, where the estimated fetal size cut-off for growth restriction or excessive growth is estimated as size at and beyond which perinatal mortality and serious neonatal morbidity rates are significantly increased relative to optimal estimated size. (Mayer et al. 2013).

Table 2. Factors that can effect on the fetal growth (Mayer et al.2013)

Restriction:	Excessive growth:
Constitutionally small Mothers	Obesity
Poor Maternal Nutrition	Constitutionally large parents
Social Deprivation, smoking, drugs	Diabetes
Infections	Postterm gestation
Malformations	Multiparity
Maternal chronic illness	Advancing maternal age
Pre-eclampsia	Previous macrosomia
Placental disorders	Racial and ethnic factors
Multiple fetuses	
Infertility	

Macrosomia, excessive fetal growth, is the most common cause of CPD and labor dystocia. Unfortunately no precise agreement on the definition of macrosomia exists. If the birth weight above 2SD is used, then a birth weight of 4500g at 39 weeks of pregnancy would represent the threshold. Gestational diabetes is a well-known cause of macrosomia and shoulder dystocia. The prevalence of the macrosomic fetuses varies in different populations in a range between 5-20%, with the highest prevalence being found in the Nordic countries (Henriksen 2008). The prevalence of the large babies, however, has increased worldwide *i.e.* in the USA and Canada during 1985-1998 it ranged between 5-24% (Ananth et al. 2002). On the other hand, aggressive diagnosis and treatment of gestational diabetes can decrease the incidence of macrosomia (0.40, 95%CI 0.21-0.75) and also severe dystocia (0.38, 95%CI 0.30-0.49) according to the pooled analysis by Young et al. (2013).

2.2.2 Fetal Size estimation

Currently, the method of choice for fetal size estimation is sonographic imaging, a technique originally introduced by Donald et al. 1958. Before the era of sonography, the fetal size was estimated by clinical estimation. Even today, the clinical examination of the fetus has maintained its place in practice as a screening method, even though its accuracy to detect growth disorders has been shown to be inadequate (Goetzinger et al. 2013). In addition to clinical palpation, the measurement of the symphysis to the fundal part of the uterus (symfysis-fundus height SFH) is commonly used. Similar to the clinical palpation, the SFH measurement has not been proven to be accurate, especially in the diagnosis of growth restriction (Robert Peter et al. 2012). As in other clinical examinations, the experience of the examiner is crucial, but it is remarkable that in those practices where sonography is not available for socioeconomical reasons, clinical examination and SFH are often the only methods with which to evaluate the fetal growth (Bothner et al. 2000).

2.2.3 Sonography

Sonography (US) is the method of choice in fetal monitoring. In addition of the fetal size estimation, it provides the possibility to monitor fetal well-being and fetal-placental hemodynamics (Kiserud et al. 2004) with Doppler measurements (Acharya et al. 2005) and also permits screening of the fetal bio-physical profile (Fox et al. 2013). The estimation of fetal weight (EFW) with sonography is based on formulas with measurements of different fetal dimensions. Several formulas have been introduced and evaluated: most of them include the measurements of the fetal biparietal diameter (BPD), fetal head circumference (HC), fetal abdominal circumference (AC) and fetal femur length (FL). One of the most popular formulas that combines these

measurements are introduced by Hadlock et al. (1984-1985). The combination of measurements in Hadlock formulas are AC and BPD (Hadlock A), AC and HC (Hadlock B), AC, FL and BPD (Hadlock C) AC, FL, HC (Hadlock D) and finally Hadlock E include the measurements of AC, FL, BPD and HC. In the study conducted by Burd et al., the accuracy of the Hadlock formula C was proven to have the best performance, but the authors encouraged clinical units to test several formulas with their own population to determine the best opinion since it is known that there are variations in the characteristics in different populations (Burd et al. 2009).

The inaccuracy of the EFW measurements has been well publicized (Dudley 2005) even with the access to the latest modern technology. The use of 3/4D technology has not conferred any clinical advantages in EFW measurements. Even under ideal conditions, there are considerable differences between the sonographic EFW and the actual birth weight (BW), with a mean error in a range of 7% to 10% (Scioscia et al. 2008). In attempts to decrease the observer-related variation and to improve the accuracy, several quality improvement factors have been proposed, such as averaging of multiple measurements, improvements in image quality, uniform calibration of equipment, careful design and refinement of measurement methods, acknowledgment that there is a long learning curve, and regular audits of measurement quality (Dudley 2005). In addition, EFW does not reveal asymmetric macrosomia which refers to a disproportionately large body size in comparison to HC (Larson et al. 2013).

2.2.4 Magnetic resonance imaging

Fetal volumetric measurements for EFW with magnetic resonance imaging (MRI) were introduced by Baker et al. (1994). MRI based EFW achieved better accuracy (Zaretsky et al. 2003; Hassibi et al. 2004; Kacem et al. 2013) when compared with US, with the correlation and absolute error (95%CI) being 0.95 and 129g (105g-155g) for MRI and 0.85 and 225g (186g-264g) for US, MRI was significantly better with a p-value of <0.001. In addition, the use of MRI provides possibilities to measure fetal dimensions that are not available in sonographical examination, such as fetal shoulder width (Tukeva et al. 2001) and fetal density, which has an association with fetal age (Kacem et al. 2013). The problem with MRI however, is its availability and cost-related factors compared with the use of US in fetal weight estimation.

For prenatal diagnosis, fusion imaging with MRI and sonography have been introduced by Salomon et al (Salomon et al. 2013). It has been used for example for the guidance of targeted biopsy. This technique was proposed to improve the prenatal examination. It provided high tissue contrast in real time imaging capabilities with the mean duration of 10 ± 5 minutes required for the scan procedure and it is less likely to be hampered by maternal or fetal factors. This system provides the possibility to identify anatomic landmarks with sonography and the ideal plane for MRI imaging can be determined. The setup of the fusion examination is shown in figure 5. The use of fusion imaging with fetuses has been limited to cases with suspected abnormalities and data of the fetal size estimation is not yet available.

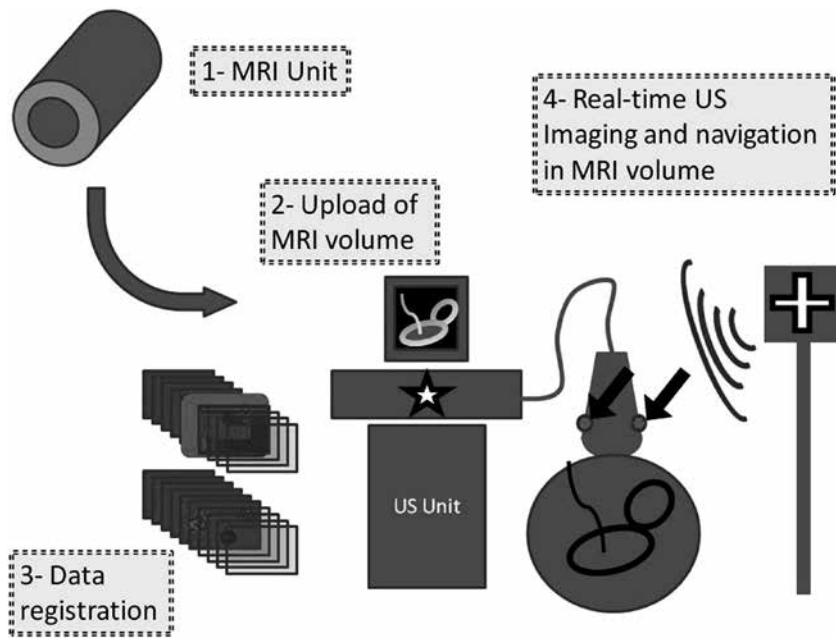


Figure 5. Fusion imaging system (With permission of Elsevier limited).

2.3 ASSESSMENT OF THE PASSAGEWAY

2.3.1 Anatomy

The bony pelvis is composed by four bones: the sacrum, coccyx and bilaterally innominate bones, that consist of the fusion between ilium, ischium and pubis. The birth canal (figure 6), also named as the “true pelvis” is divided into imaginary planes, termed as inlet, outlet and midpelvis.

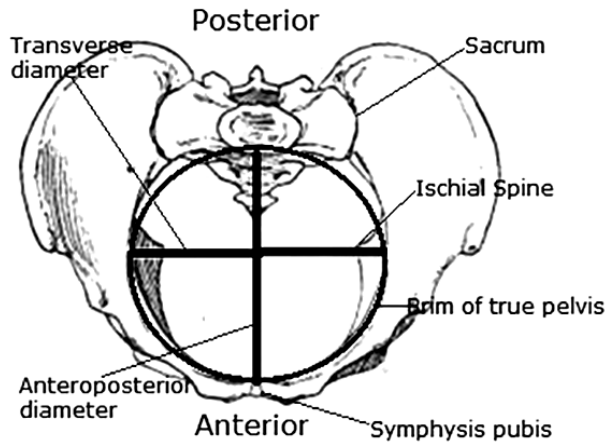


Figure 6. The bony birth canal (with permission of McGraw-Hill)

The diameters of the pelvic planes that are measured are anteroposterior (from the surface of the symphysis to the surface of the sacrum) and the transverse diameter. The transverse diameter of the inlet plane (seen in figure 6) is the largest diameter. The midpelvic transverse diameter is reflected by interspinous diameter. The classification of the female pelvis originally developed by Caldwell and Moloy in 1930's (1938) is still in clinical use. In this classification, the transverse diameters of the inlet and midpelvis determine the pelvis as being gynecoid, anthropoid, android or platypelloid, figure 7.

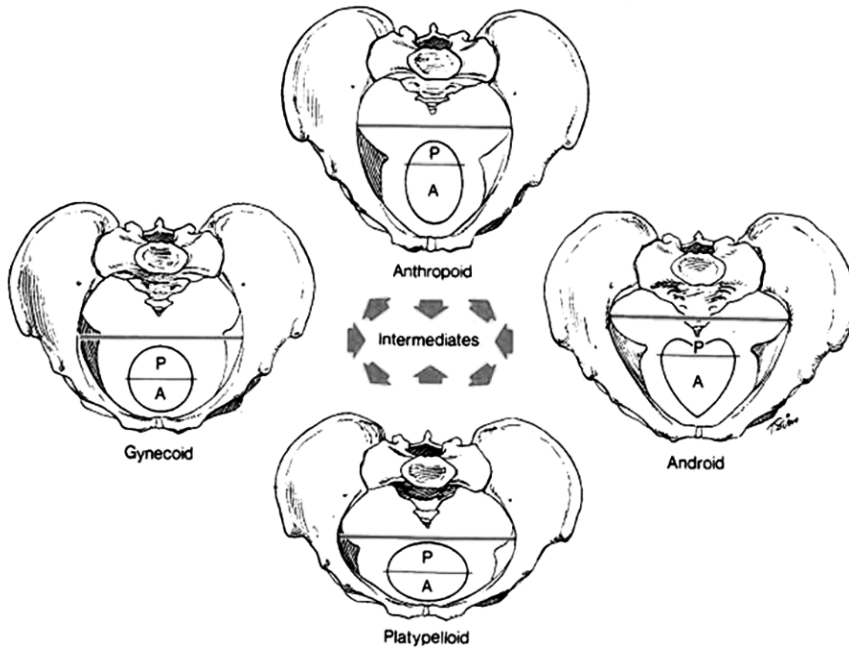


Figure 7. The classification of the female pelvis by Caldwell and Moloy (With permission of McGraw-Hill).

The support of the pelvis is formed by the pelvic diaphragm. This is formed by a muscle group, seen in figure 8a, preferably defined by the points of insertion and function (Kearney et al. 2004). The whole levator ani muscle is subjected to massive stretching during labor as seen in figure 8b. Recently, the role of levator ani stretching (Hoyte et al. 2008) and fiber elasticity (Li et al. 2010) in the success of vaginal delivery have been investigated.

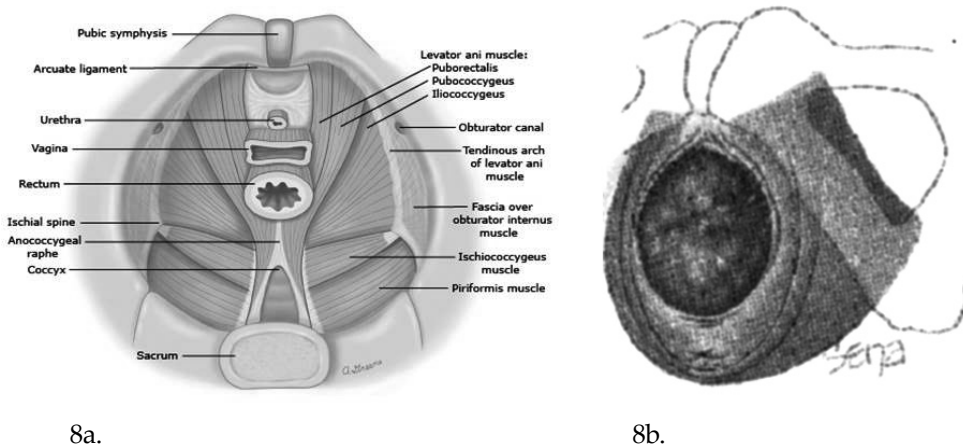


Figure 8a. The muscle group of the pelvic diaphragm. 8b. The stretch of the levator ani muscle during the labor. (With permission of McGraw-Hill)

2.3.2 Pelvic size estimation

The evaluation of the pelvic capacity can be made with clinical examination of the pelvic anteroposterior - and transverse diameters and the shape of the pelvic cavity by digital palpation. The anteroposterior diameter of the pelvis is the shortest distance between the promontory of the sacrum and the symphysis pubis, normally this measures 10cm or more. The interspinous diameter is normally at least 10 cm. The lowest plane of the pelvis, the outlet, can be examined with digital palpation. The anteroposterior diameter is the distance between the apex of the sacrum to the symphysis pubis (at least 9.5cm) and the transverse diameter is the distance between the ischial tuberosities and this normally measures 11 cm. In addition, the descent of the fetal head has been considered to indicate the appropriateness of the pelvic capacity (Maharaj 2010).

Anthropometric measurements, such as maternal height, maternal shoe size, and maternal weight have all been investigated as predictors for pelvic capacity. If they are compared with the pelvimetric measurements, they do not seem reliable (Awonuga et al. 2007) but as predictors of cephalopelvic disproportion, there is some evidence favoring the use of anthropometric measurements (Benjamin et al. 2012; Toh-Adam et al. 2012), although conflicting opinions have also been published (Dahan et al 2005; Kara, et al. 2005).

2.3.3 Pelvimetry by imaging technologies

2.3.3.1 X-ray pelvimetry

Measuring the pelvic dimensions with external maneuvers and tools were in clinical practice until the advent of x-ray technology provided measurements from the actual bony pelvic images. Pelvimetry was introduced already in the latter part of the 19th century, but the radiological method devised by Colcher and Sussman in 1949 did enter routine clinical use (Colcher et al. 1949). The pelvic parameters were measurable from the pelvic images since a ruler was also added to the images. The method was taken extensively into clinical practice and by the middle of the 20th century, almost half of all childbearing women were examined by pelvimetry. However, the role of radiation exposure was a concern. The malignancy risk for the fetus and the mother was found to be low in a Swedish study, *i.e.* it was estimated as being one case of fetal malignancy per 50 000 pelvimetries, for the mother, the risk was one tenth of the fetal risk (Lundh et al. 1984). When pelvimetry became popular, the CS rates increased and the criticisms towards pelvimetry started to rise. It was stated in several large studies that with extensive use of pelvimetry there would have been increased incidence of CS (false positive rates within the range of 55%-84%) and thus the increase of CS would not have difference in neonatal outcomes (Jagani et al. 1981; Thubisi et al. 1993; Krishnamurthy et al. 1991). It became obvious that X-ray pelvimetry, if used alone, could no longer be recommended (Rozenberg 2007) and that the fetal dimensions should be also evaluated (Abitbol et al. 1991).

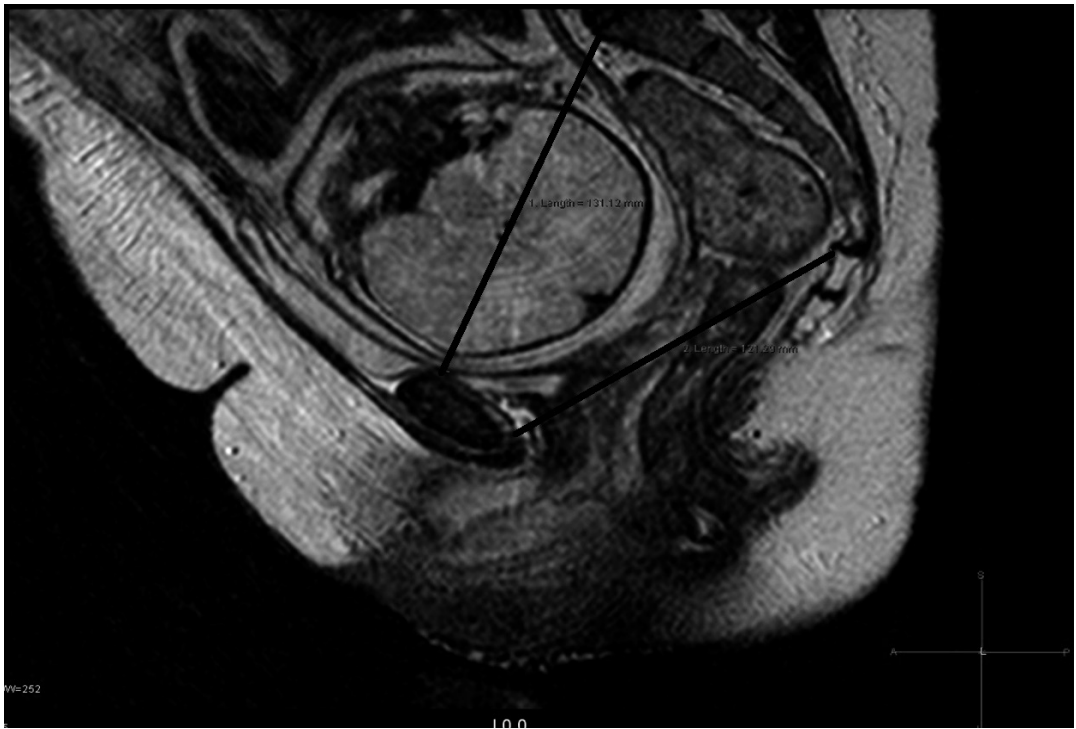
2.3.3.2 Computed tomographic scanning

Computed tomographic scanning (CT) achieves reduced radiation exposure (fetal dose of 2.3 Mgy, 0.23 rad) (Moore et al 1989) along with greater accuracy and easier performance in pelvimetric imaging compared with X-ray pelvimetry. The accuracy of the measurements have been confirmed (Anderson et al. 2005) and even the role of CT pelvimetry in the diagnosis of CPD has been investigated with promising results (Lenhard et al. 2009b). CT imaging provides also a three dimensional perspective which helps in the evaluation of the pelvic capacity (Lenhard et al. 2009a).

2.3.3.3 Magnetic resonance imaging

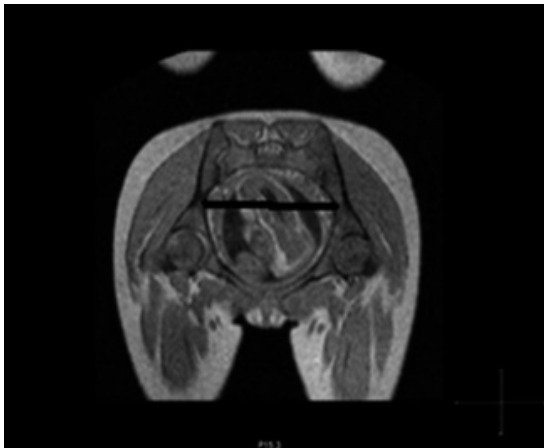
The most important advantage of magnetic resonance imaging (MRI) as compared with X-ray and CT techniques is the absence of ionizing radiation. It provides accurate pelvimetric measurements (Keller et al. 2003; Stark et al. 1985) and it also offers the potential for soft tissue imaging (Stark et al. 1985) and fetal imaging (Sporri et al. 2002). The duration of the MR pelvimetry procedure is approximately 15 minutes and the only contraindications are excessive overweight, metal implants or phobic behavior disorders. The images depicting MR pelvimetry are shown in figure 9a-c. The anteroposterior measurements are measured from sagittal sequence, inlet anteroposterior diameter is measured from the surface of the pubic symphysis to the surface of the superior edge of sacrum and at the spinous level for outlet anteroposterior diameter. The transverse diameters are measured from the oblique axial sequences. With MR imaging technology, the measurements of the fetal shoulder width with fast and ultrafast techniques have been proven to be accurate and free of any major motion artefacts (Tukeyva et al. 2001; Kastler et al. 1993). For some unexplained reason, there have been no follow-up studies considering the clinical applicability of the measurements of the shoulder width with MRI in the prediction of dystocia.

The combination of the fetal head volume measurement with the pelvic capacity measurements have also been a topic of interest (Sporri et al. 2002). Significant associations have been found between the risk for CS caused by dystocia and the combination of the measurements of the fetal head volume and maternal pelvic dimensions. Unfortunately, the accuracy of this technique to identify those women requiring CS was considered to be inadequate, *i.e.* the values of the area under curve (AUC) in receiver operating characteristic curves (ROC) being 0.6-0.8 at best (Zaretsky et al. 2005).

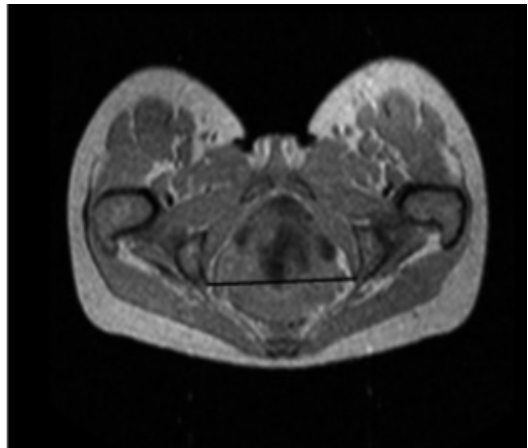


a.

Figure 9a. MR pelvimetry images with measurements; a. Anteroposterior conjugate of the inlet (conjugata vera) and outlet.



b.



c.

Figure 9b-c. MR pelvimetry images with measurements; b. Transverse diameter of the inlet (diameter transversa); c. Transverse conjugate of the outlet (diameter interspina).

2.3.4 Fetal pelvic index ,FPI

Since the accuracy of pelvimetry has been found to be poor, there is a clear need to develop replacing techniques. Thurnay and Morgan introduced a method, where both the passenger and the passageway were taken into consideration by combining the fetal dimensions and the maternal pelvic inlet and outlet measurements (Morgan et al. 1986). The fetal pelvic index is calculated on the basis of four circumference differences between the fetus and the maternal pelvis by subtracting the maternal pelvic inlet (IC) and midpelvic circumferences(MC) from the fetal HC and AC (HC-IC, HC-MC, AC-IC, AC-MC) and the index value is derived by adding the two most positive circumference differences. For example, with a maternal pelvic inlet of 36 cm, an outlet of 35cm, fetal head circumference of 34 cm and abdominal circumference of 35 cm , the FPI value is -1 as shown in table 3. A positive FPI is defined as a positive value and thus it should identify those fetuses larger than the maternal pelvis, whereas a negative FPI is defined as a negative value *i.e.* fetuses smaller than the maternal pelvis (Morgan et al. 1986).

Table 3. Calculation of the fetal pelvic index. The patient with a maternal pelvic inlet (IC) of 36 cm, an outlet (MC) of 35cm, a fetal head circumference (HC) of 34 cm and an abdominal circumference (AC) of 35 cm. The index value is derived by adding the two most positive circumference differences.

HC-IC	34-36	-2
HC-MC	34-35	-1
AC-IC	35-36	-1
AC-MC	35-35	0
FPI		-1

This method has been tested in several studies with promising results (Morgan et al. 1988a) Thurnau et al. 1988; Morgan et al. 1988b; Thurnau et al. 1991; Morgan et al. 1992) However, in studies with larger cohorts, the results were not repeatable (Ferguson et al. 1998; Wong et al. 2003), as seen in table 4. After these controversial results, only one study with 25 patients was published (O'Brien et al. 2002), until the appearance of the study by Macones et al (2013), which stated that the predictive value of fetal pelvic index for CS was accurate when combined to several risk factors such as maternal age and race in a multivariable model.

Table 4. Studies of fetal pelvic index. Sensitivities, specificities, positive and negative predictive values are calculated according to the information from the studies.

Study	N	Indication	CS/ VD	CS Rate%	FPI cut off	FPI+/- (%)	CS/VD(CS%) with positive FPI with negative FPI	Sensitivity	Specificity	PPV	NPV
Morgan et al 1986	75	Disproportion	27/48	36	0	27/48 (36/64)	23/4 (85) 4/44(8)	0.85	0.92	0.85	0.64
Morgan et al 1988	34	Fetal Weight >4000g	13/21	38	0	18/16 (53/47)	12/6 (67) 1/15(6)	0.92	0.71	0.67	0.62
Morgan et al 1988	49	Induction	12/37	24	0	12/37 (24/76)	10/2 (83) 2/35 (5)	0.83	0.95	0.83	0.76
Thurnay et al 1988	46	Labour aug- mentation	19/27	41	0	18/28 (39/61)	14/4 (78) 5/23(18)	0.71	0.95	0.94	0.75
Thurnay et al 1991	65	TOLAC	18/47	28	0	13/52 (20/80)	13/0 (100) 5/47 (10)	0.72	1.0	1.0	0.72
Morgan et al1992	137	Nulliparous, disproportion	72/65	55	0	57/80 (42/58)	50/7 (88) 15/65 (19)	0.77	0.90	0.88	0.53
Ferguson et al 1998	91	Disproportion	30/61	33	0	18/73 (20/80)	8/10 (44) 22/51 (30)	0.27	0.84	0.44	0.67
O'Brien et al 2002	25	Disproportion	5/20	20	0	4/21 (16/84)	4/0 (100) 1/20 (5)	0.20	0.95		
Wong et al 2003	170	TOLAC	45/125	26	0	57/113 (34/66)	22/35 (39) 23/90 (22)	0.8	1.0	1.0	1.8
								0.49	0.72	0.39	0.74

CS Cesarean section
VD Vaginal delivery
FPI Fetal pelvic index
PPV Positive predictive value
NPV Negative predictive value
TOLAC Trial of labour after Caesarian section

2.4 ASSESSMENT OF THE POWER

2.4.1 Physiology of the uterine muscle in labor

The uterus can be described as one single muscle, since the thickest layer, the myometrium is composed of bundles of smooth muscle fibres united by connective tissue. Most of the muscle fibres are located in the inner wall of the myometrium and also, in the anterior and posterior walls with less in the lateral walls. The numbers of muscle fibres of the uterus diminish caudally, in the cervix muscle comprise only 10% of the tissue mass (Schwalm et al. 1966).The upper myometrium undergoes marked hypertrophy during pregnancy but there is no significant change in the cervical part and the uterus can be divided into active and passive segments, as illustrated in figure 10.

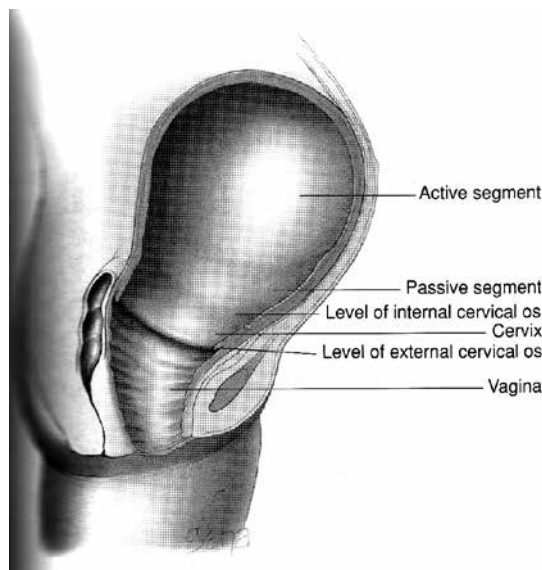


Figure 10. The segments of the uterus. (With permission of McGraw-Hill)

The factors that evoke uterine contractions at the onset of the labor are not clear. The numbers of oxytocin receptors increase, estrogen levels in the uterine muscle increase in comparison with progesterone concentrations (Lopez Bernal 2003). The growth and the dilatation of the uterus are believed to exert a mechanical effect and an increase of prostaglandin synthesis may well have a significant effect on the uterine contractile force (O'Brien 1995). The biochemical reaction involved in uterine muscle contraction involves actin-myosin coupling, a process regulated by calmodulin and thus the role of calcium channels has also been well described in detail (Wray 2007).

The origin of the contraction wave originates near one of the fallopian tubes (Larks et al. 1959) and spreads from this "pacemaker" through the whole uterine muscle. Figure 11. represents the normal contractile wave of labor, this pacemaker theory was originally introduced by Caldeyro-Barcia and Poseiro(1959). They also devised the montevideo units to measure the uterine activity by inserting small balloon into the uterine cavity. The montevideo units are a summary of measured contractions (mmHg) in 10 minutes period. The intensity of the contraction is determined from the basic tonus of the uterus, as seen in figure 11. For labor to progress then one needs to have 80-120 montevideo units (Caldeyro-Barcia 1960). In a computer aided analysis, normal labor was characterized as greater than 25mmHg contractions

with less than 4-minute intervals, with less activity leading to labor arrest (Seitchik 1981). In order to achieve effective delivery, a limit of 300 montevideo units has been proposed before the physician should have consideration whether there is insufficient uterine activity or labor dystocia present (Hauth et al. 1986).

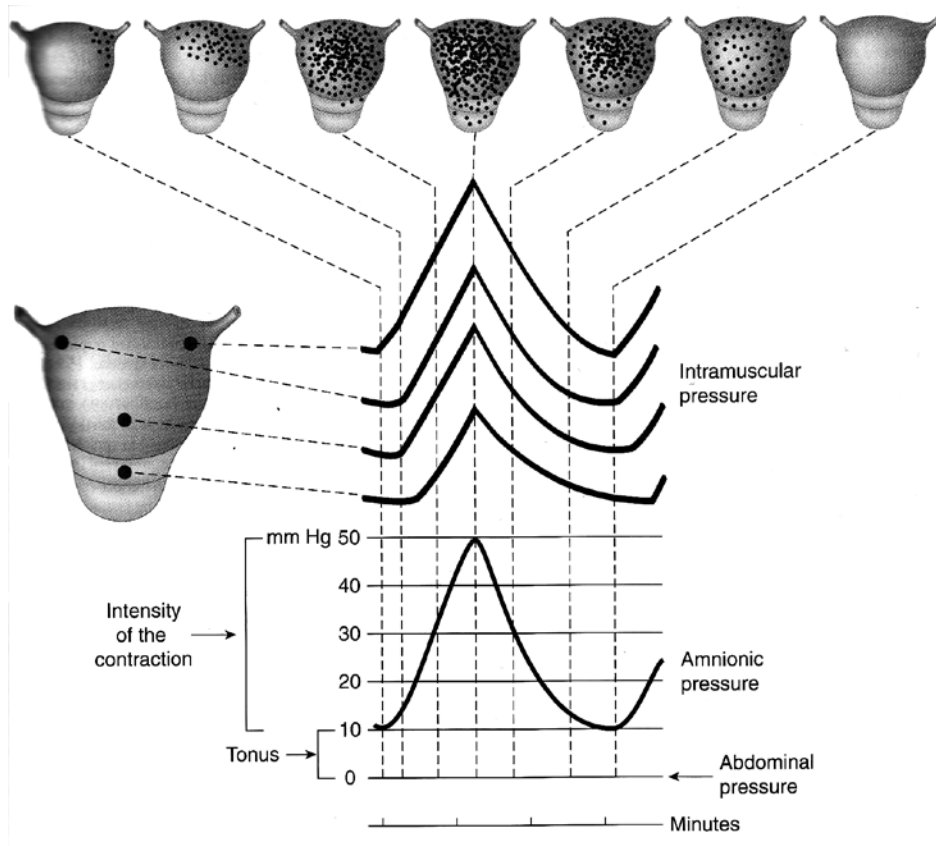


Figure 11. The normal contractile wave of labor.(With permission of McGraw-Hill)

The uterine activity can be measured with external or intrauterine methods. Duration, amplitude and frequency of contractions are of importance and therefore their monitoring is highly recommended. If there is a threat of an abnormality in labor, internal tocography should be used since these techniques provide objective information about uterine activity and it is also accurate in obese or restless patients (Bakker et al 2007).

2.4.2 Abnormal uterine activity

The uterine activity is the “power”, one of the three “P”s of labor. As stated in previous chapters, the uterine activity in the active stage of labor should exceed as the limit of 300 montevideo units (Hauth et al. 1986). Even though the two hour rule *i.e.* 2 hours of contraction patterns of at least 200 montevideo units without any cervical change (ACOG 1996) has still been valid in clinical obstetrics, there is evidence that the expectant management is preferable (Rouse et al. 2001; Zhang et al. 2010b) and for example in French guidelines published in 2013 with a respect to a trial of labour after CS, this limit was set to 3 hours (Sentilhes et al. 2013). The activity of the uterine muscle may also be dysfunctional (Althaus et al. 2006).

Maternal obesity has been reported to lengthen the first stage of the labor by 0.3-1 hour (Carlhall et al. 2013; Vahratian et al. 2004) and to increase the risk for both operative vaginal delivery (RR 1.1-1.5) and CS (RR 1.9-3.4) (Morken et al. 2013; Vahratian et al. 2005). Maternal age has also been proposed to have a decreasing effect on uterine activity, but in a recent study, this was not found to be significant in pregnant uterus even if the myometrial function did decrease in an age-related manner in the non-pregnant uterus (Arrowsmith et al. 2012).

Chorionamnionitis has been speculated to contribute to abnormal uterine activity. However, studies confirming this speculation are lacking, and it is more likely that the infection is a consequence rather than a cause of uterine dysfunction (Satin et al. 1992).

Failed labor induction has been proposed to be prognostic for CPD especially in cases with large fetal weights (Peaceman et al. 2006b), although conflicting opinions have also been presented (Harper et al. 2011; Arulkumaran et al. 1985). It has been shown that the need for induction reduces the success of vaginal delivery (57.7% vs. 67%), if there has been a previous CS caused by CPD (Landon et al. 2005). In a meta-analysis that compared the labor induction vs. expectant management with macrosomic fetuses, the risk for CS was 8.2 higher with labor induction (Sanchez-Ramos et al. 2002) although the neonatal outcome was similar. This implies that labor induction itself would not be attributable to CPD but instead the failure in progress would rather be a consequence of the prevailing condition leading to need of induction of labor. Neither suspected CPD nor fetal macrosomia are listed as indications for labor induction (Nuutila, Duodecim 2006) (Society of Obstetricians and Gynaecologists of Canada 2005).

Labor augmentation with oxytocin is the method of choice with uterine dysfunction in labor ACOG (ACOG 2003). In a large meta-analysis, the use of oxytocin along with early amniotomy was associated with a modest reduction in CS (OR 0.87, 95% CI 0.77-0.99) and it shortened the duration of the labor [MD 1.28 hours, 95% CI -1.97- (-0.59)] without exerting any significant effects on the neonatal outcomes (Wei et al. 2012). In another meta-analysis, the use of early oxytocin was significantly associated with duration *i.e.* it reduced the first stage of the labor by approximately 2 hours but it was not associated with any decrease in the incidence of CS (Bugg et al. 2011). For those women that are in trial of labor after CS, both induction and augmentation increases the risk for uterine rupture by 2-3% (Lydon-Rochelle et al. 2001b; Zelop et al. 1999), but these are not absolute contraindications (Society of Obstetricians and Gynaecologists of Canada 2005; Sentilhes et al. 2013; ACOG 2010). It has been recommended that before the diagnosis of failure in progress due to CPD can be made, the uterine activity must be monitored and the sufficient activity, *i.e.* activity of 200-300 montevideo units must have been achieved with the use of oxytocin (Hauth et al. 1986).

3 Aims of the study

The overall aim of the study was to test the accuracy of pelvimetric measurements in the prediction of labor dystocia. The individual aims were to determine:

1. The intra- and interobserver variations in pelvimetric measurements between obstetricians and radiologists.
2. The predictive value of different pelvimetric measurements in conjunction with fetal size in the diagnosis of cesarean section for labor arrest.
3. The use of the fetal pelvic index in the prediction of cesarean section for labor arrest.
4. The assessment of the maternal pelvis in the prediction of operative vaginal deliveries and the duration of the second stage of the labor.

4 Materials and methods

4.1 PATIENTS

North-Karelia Central hospital is located in Joensuu. There are approximately 1550 deliveries/year. Preterm fetuses >30 weeks of pregnancy are allowed to be delivered in the hospital. The CS rate has remained stable during the past decades, *i.e.* it has been 13-15% in the last ten years. The distribution of CS to elective and emergency CS has been close to 50% in recent decades. The number of pelvimetries performed in 2000-2008 was approximately 100/year.

This retrospective study involved originally 915 Caucasian women. All patients that had been examined by X-ray or MRI pelvimetry during the years 2000–2008 in North Karelia Central Hospital were screened for possible inclusion to the study. The flowchart of the patients included in the studies is shown in figure 12. Eligibility criteria included the fact that the pelvimetric and fetal measurements and obstetric data of the pregnancy and delivery had been recorded. Patients were numbered for identification in the order of their pelvimetry examination date and the data were transferred into a commercially available worksheet (Excel, Microsoft 2003, Ireland).

4.1.1 Patients in study I

The study involved 100 pregnant Caucasian women, who were examined by MR pelvimetry in North Carelian Central Hospital between September 2006 and January 2008. All MR pelvimetries performed during this period were included.

4.1.2 Patients in studies II and III

In studies II and III, 429 women were excluded from the total number of 915 patients, because of breech presentation, leaving a total of 486 patients for evaluation. The reasons for consulting the hospital maternity unit among these patients are shown in table 5. The findings that referred to CPD in clinical examination were a clinically small pelvis, unengaged presentation, or suspected macrosomia. Furthermore, a total of 171 women were chosen for elective CS, and they were excluded. Among those women, 92% were chosen for elective CS because of suspected disproportion and among the remaining 8% of the women, fear for childbirth was the most common reason for elective CS. In addition, since fetal measurements were used in the analysis, only those examinations that were performed within 10 days before the delivery could be included. For labour arrest, the inclusion criteria were as follows: arrested labor with no signs of fetal distress in cardiotocography, the uterine contractions were ≥ 50 mmHg and the frequency was ≥ 3 contractions in 10 minutes (Ferguson et al. 1998) cervical dilatation of ≥ 3 cm was observed and there was no obvious malpresentation diagnosed. When patients with these factors were excluded, the final number of patients in these studies amounted to 274.

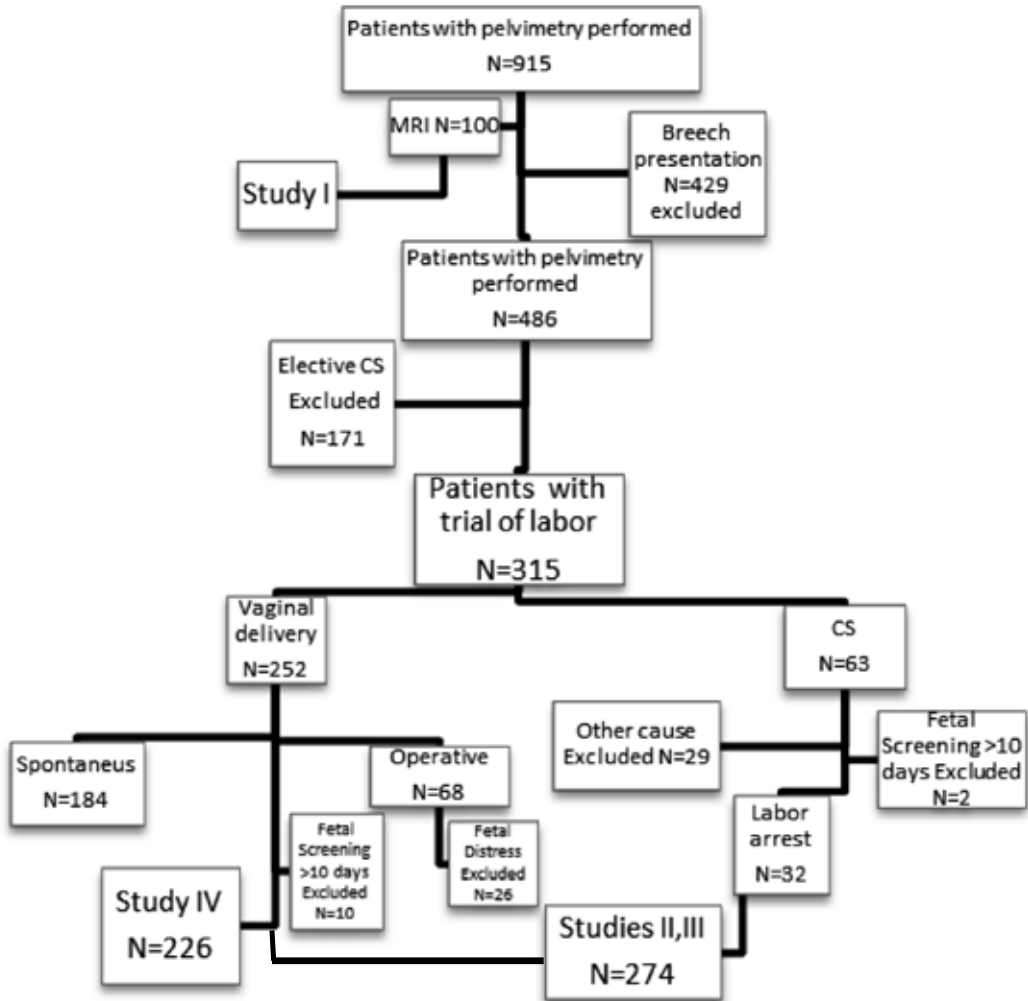


Figure 12. Flow chart of the patients in studies I-IV.

Table 5. The reasons for consulting the hospital maternity unit.

Reason for consulting:	N (%)
Suspected disproportion	417 (86)
Pregnancy duration > 41 weeks	22 (5)
Gestational diabetes, fetal maturity	5 (1)
Fetal presentation	4 (1)
Maternal blood pressure	17 (3)
Miscellaneous (i.e. suspected PROM, contractions, suspected fetal distress)	21 (4)

4.1.3 Patients in study IV

Out of a total of 486 patients with the fetus in the cephalic presentation, those 234 women that went through elective or acute cesarean section were excluded from the analysis. There were 252 participants with fetal cephalic presentation who delivered vaginally, of these 184 women delivered spontaneously and 68 women went through operative vaginal delivery with vacuum extraction. With respect to this latter group of women, there were 26 patients in whom the vacuum extraction was undertaken primarily because of fetal distress and inertia and these patients were excluded from the final analysis, leaving 42 women in the operative vaginal delivery group. The total number of participants evaluated in the final stage of this study was 226.

4.2 METHODS

4.2.1 Pelvimetric measurements

In study I, the clinical indications for MR pelvimetry were suspected disproportion (N=66) or breech presentation of the fetus (N=34) and all the patients were in the third trimester of their pregnancy. In studies II-IV, the indication was a history of operative delivery or dystocia in a previous labour or suspected cephalopelvic disproportion in clinical examination. The findings that referred to CPD in clinical examination were the suspicion of clinically small pelvis, unengaged presentation, or suspected macrosomia.

In the pelvimetric measurements, the following pelvimetric parameters were used: anteroposterior (conjugata vera) and transverse diameter for pelvic inlet and interspinous diameter and sagittal diameter from the surface of the pubic symphysis to the surface of the sacrum measured at the spinous level for outlet. Pelvic inlet and outlet circumference values were calculated from the pelvic anteroposterior and transverse diameters using the formula $ap + dt \times 1.57$ (Morgan et al. 1986)

4.2.1.1 Measurements in study I

Images were originally measured by both radiologists and obstetricians and these values were used to help to determine the mode of delivery. MR pelvimetry images were retrieved from patients' medical database (NeaPACS) and they were measured without knowledge of the results of previous measurements carried out by either an obstetrician or a radiologist. In study I, a junior consultant (the author) in Department of Obstetrics and Gynecology was designated as observer 1, she had been supervised by a radiologist and had conducted at least 30 guided measurements of MR pelvimetry images. The second measurement by observer 1 was made one month after the first measurement and the results of previous measurements were not available for comparison until the final analysis was carried out. Original values measured by obstetricians (observer 2) were collected from obstetric data after the first measurement by observer 1. The measurements were originally performed by

obstetricians on duty. All obstetricians were experienced senior consultants and had been supervised and received training from a radiologist. If the original measurement values were not found, the measurement was made retrospectively by one senior consultant. These measurements were made blindly *i.e.* not knowing the results of the previous measurement values. In the observer 3 group, MR pelvimetry images had been originally measured by radiologists on duty. All radiologists were experienced senior consultants. The measurement values were collected from radiologic data.

In order to obtain a reference standard, all four measurements of each parameter were compared and the one with the highest difference was excluded. The mean of the remaining three measurements was considered as the reference standard. Based on a previous CT- study it was deemed that measurements within a 5 mm range of the reference standard were accurate and those outside this range were considered as being inaccurate (Anderson 2005). Apparently inaccurate measurements were considered inconclusive and were excluded from the analysis. Further analyses of the validity of the measurement were made with the analysis of the inter- and intra-observer variations conducted separately. The measurement variations were determined for all four pelvimetric parameters. The median of the two measurements of observer 1 was first determined and interobserver variation between observer 1 and the two other observers was determined by calculating the median of these two measurements.

4.2.1.2 Measurements in studies II-IV

The pelvimetric measurements were collected from the obstetrical data, since they were required for the calculation of FPI. Until the year 2003, all pelvimetries were performed with an X-ray technique, and from the year 2004, with MRI. During the 3-month transition period, both X-ray and MRI pelvimetry were performed to verify the reproducibility of the measurements (Sporri et al. 1997). At the beginning of 1990, to minimize the variability in pelvimetric measurements, they were centralized so that instead of being conducted by several radiologists, they were conducted by trained obstetricians. When MRI pelvimetry was taken into clinical practice, there was one radiologist with previous experience of MRI pelvimetry, and during a 2-year period (2004–2006), three radiologists and also three obstetricians were trained to be able to evaluate the images.

The target condition of patients chosen for the trial of labor was vaginal delivery in studies II and III and spontaneous vaginal delivery in study IV. In order to evaluate diagnostic accuracy, this mode of delivery was chosen to represent the reference standard. In study II, patients that were exposed to a trial of labor were categorized into subgroups according to the fetal HC to evaluate the variability reflecting differences in the patient groups. The cutoff value of 340 mm was chosen because it represents the mean of the cohort. In study IV, the patients were divided into subgroups according to the size of the fetus in order to evaluate the variability reflecting differences in patient groups.

4.2.2 Sonographic measurements

Sonographic weight estimation was conducted in all patients by an experienced midwife or an obstetrician who had performed >300 fetal sonographic examinations annually and had more than 5 years' experience in ultrasound screening. Fetal measurements of HC and AC were had been recorded in the obstetric data and were used to estimate the fetal weight. Fetal HC was measured at the level of the thalami and cavum septum pellucidum and the Fetal AC was measured at the level of fetal stomach and umbilical vein, and the same calculation programs were used with all types of ultrasound equipment.

4.2.3 Technical information

X-ray pelvimetry was performed with Philips Optimus 50 with the following parameters; Antero posterior view; 80 kV, 63 mAs, lateral view; 110 kV, automatic exposure control (AEC), source-image receptor distance (SID) of 115 cm, Al filters (both tube filtration and beam shaping filter) and with field of view (FOV) 24x30 cm and with focus vario.

MR pelvimetry was performed with the patient in the supine position in a 1.5 T system (Philips Gyroscan ACS-NT 1.5 T, powertrack 6000, Netherlands) with the use of a Q-body coil. The workstation for the radiologist was Philip EasyVision 4.3. Images were sent and stored in NearIS and NeaPACS. T2 weighted turbo-spin-echo (TSE) sagittal sequences were performed with the following parameters: field of view(FOV) 320mm, rectangular field of view (RFOV) 80%, TR 3500 msec, TE 90 ms, TSE factor of 18, 256 matrix and, number of signal averages (NSA) was two. Section thickness was 3 mm and section gap 1 mm. The duration of one T2 sagittal sequence was 2 minutes. T1 weighted (inphase/outphase) fast-field echo (FFE) axial sequences were performed with the following parameters: FOV 355mm, TR 145msec, TE (6.9/9.2 msec), flip angle 70, 160 matrix, one signal acquired, section thickness of 5 mm and section gap of 0.1 mm. The duration of one axial T1 FFE serial was 18 seconds. The mean of total duration of the examination was approximately 14 minutes. Oblique axial sequences were planned in T2 weighted TSE image to obtain the axial images of the birth canal.

In the sonographic examinations, the following three items of sonographic equipment were used: Toshiba Eccocee SSA-340A (1994), Hitachi EUB 535 (1999), and GE Logiq 7 (2002), and the Hadlock C (Hadlock et al. 1985) formula was used.

4.2.4 Fetal pelvic index

The FPI was calculated by obstetricians on the basis of four circumference differences between the fetus and the maternal pelvis by subtracting the maternal pelvic inlet and midpelvic circumferences from the fetal HC and AC (HC-IC, HC-MC, AC-IC, AC-MC). An index value was obtained by adding the two most positive circumference differences (Morgan et al. 1986). For the pooled analysis of the studies considering FPI, PubMed search was carried out using the keywords "fetal pelvic index" and the additional keyword "disproportion" to specify the study. The studies were included if the results provided information required to determine sensitivity and specificity with cutoff values. The actual numbers of vaginal and cesarean deliveries were collected from the studies. Sensitivity, specificity and predictive values were calculated for each study.

4.3 STATISTICAL ANALYSIS

In the statistical analysis, SPSS 17.0 (SPSS Inc. 2009, Chicago, USA) was used. The intraclass correlation coefficient (ICC) was determined and an ICC value above 0.7 was considered to be acceptable. Bland-Altman plot figures were used to analyse observer-related variation (Bland et al. 1986). The chi-square test was used to assess statistical significance when comparing frequencies between groups. For multivariate modeling, logistic regression analyses were performed. For multivariable modeling, the significant and nearly significant (p-value <0.1) exposure variables from the univariate analysis were included. Receiver operating characteristic (ROC) curves (Metz 2006) were established, and the area under the curve (AUC) values with statistical significances were calculated using SPSS. The cutoff points were estimated and calculated from the curve, if possible.

4.4 ETHICAL CONSIDERATIONS

The study was approved by the Ethical Committee of North Karelia Central Hospital 12.11.2007.

5 Results

5.1 THE OBSERVER RELATED VARIATION OF THE MEASUREMENTS

The inlet anteroposterior and transverse measurements were accurate (difference to reference value < 5 mm) in up to 95% and 99% of the cases, whereas pelvic outlet measurements were inaccurate in 13% and 10% of the cases, respectively. The flow charts of the pelvic inlet transverse and outlet anteroposterior measurements are seen in figures 13a-b. The observer-related measurement variation for different pelvimetric parameters and intraclass correlation coefficients are shown in table 6. The descriptive data reveal that in the intraobserver measurements, the standard deviations were acceptable. The intraobserver variation between the measurements in all the pelvic parameters was 8mm at highest, whereas the interobserver variation was as high as 31.5mm and this was not considered to be acceptable for clinical purposes. According to Bland-Altman analysis, the intraobserver variation was acceptable in all measurements when 0.5 cm was used as a cut off for clinically significant deviation. The interobserver difference was acceptable in pelvic inlet parameters, but not in any of the pelvic outlet measurements.

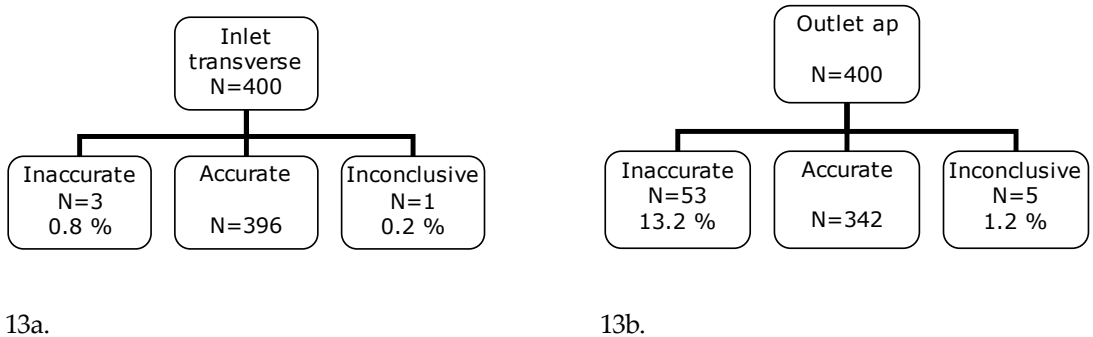


Figure 13 a-b. Flow chart of the validity of the a. pelvic inlet transverse and b. pelvic outlet anteroposterior measurements. The limit of accuracy was difference ≤ 0.5 cm.

Table 6. Observer related variation of the pelvic measurements with intraclass correlation coefficient values of measurements.

Measurements and observer variation	Inlet ap	Inlet transverse	Outlet ap	Outlet transverse
	Mean value Min-max(SD) ICC (95%CI)	Mean value Min-max (SD) ICC (95%CI)	Mean value Min-max (SD) ICC (95%CI)	Mean Value Min-max (SD) ICC (95%CI)
OB1-OB1 (intraobserver)	120 mm 0mm-7.0mm (1.3mm) 0.981 (0.972-0.987)	129 mm 0mm-8.0mm (1.6mm) 0.959(0.940-0.972)	116mm 0mm-7.0mm (1.8mm) 0.956(0.936-0.970)	109mm 0mm-7.0mm (1.5mm) 0.957(0.936-0.985)
OB1/OB2 (interobserver)	120mm/118mm 0mm-17.0mm (2.6mm) 0.955(0.934-0.969)	129mm/128mm 0mm-8.5mm (1.7mm) 0.953(0.932-0.968)	116mm/117mm 0mm-19.5mm (3.7mm) 0.797(0.713-0.859)	109mm/111mm 0mm-15.0mm (2.9mm) 0.873(0.818-0.913)
OB1/OB3 (interobserver)	120mm/118mm 0mm-11.0mm (2.4mm) 0.956(0.935-0.970)	129mm/129mm 0mm-12.0mm (1.6mm) 0.945(0.919-0.962)	116mm/120mm 0mm-31.5mm (6.0mm) 0.710(0.598-0.795)	109mm/109mm 0mm-15.0mm (3.0mm) 0.813(0.735-0.870)
OB2/OB3 (interobserver)	118mm/118mm 0mm-12.0mm (2.4mm) 0.950(0.927-0.966)	128mm/129mm 0mm-18.0mm (2.4mm) 0.925(0.891-0.949)	117mm/120mm 0mm-27.0mm (6.0mm) 0.735(0.631-0.813)	111mm/109mm 0mm-15.0mm (4.2mm) 0.812(0.733-0.869)

Mean value, mean value of 100 measurements of one parameter by each observer;
 Min-max, Minimum-Maximum variation between the measurements;
 SD, standard deviation determined from measurement variation;
 ICC, Intraclass correlation coefficient values of measurements;
 95%CI, 95% confidence interval;
 OB1, Observer 1;
 OB2, Observer 2;
 OB3, Observer 3

5.2 PELVIMETRIC MEASUREMENTS AND THE MODE OF DELIVERY

The demographic data, reasons for consulting the maternity unit and the mode of delivery of the patients in studies II-IV are shown in table 7. The range of maternal pelvic anteroposterior diameter size was 98mm-148mm, the mean size being 123±9mm and for the inlet circumference it was 330mm-460mm, with the mean size of 398±21mm. For the pelvic outlet transverse size the range was 80mm-136mm with the mean size of 106±9mm. There were 58 patients with the pelvic inlet anteroposterior measurement smaller than 115mm in the study group.

Table 7. Demographics, reasons for the consultation and the mode of the delivery of all the patients in studies II-IV.

	N (%)	Mean	Min-Max
Maternal age years		28.7	17-49
Gravida		2.0	1-8
Primiparous	243 (50)		
Maternal height cm		162.5	144-178
Maternal weight kg		68.0	43-150
Body mass index		25.7	17-52
Infant weight g		3780	2026-5200
Reason for consulting:			
suspected disproportion	417 (86)		
pregnancy duration > 41 weeks	22 (5)		
Gestational diabetes, fetal maturity	5 (1)		
Fetal presentation	4 (1)		
Maternal blood pressure	17 (3)		
Miscellaneous (i.e. suspected PROM, contractions, suspected fetal distress)	21 (4)		
Route of delivery:			
spontaneous vaginal	185 (38)		
operative vaginal	68 (14)		
cesarean elective	171 (35)		
cesarean acute	61 (13)		
Cesarean acute diagnosis:			
arrested labour	32 (53)		
miscellaneous (i.e. fetal distress, secondary inertia, malpresentation)	29 (47)		

In the assessment of the predictive value of the pelvimetric measurements, only those women that were exposed to trial of labor were chosen for analysis and thus the final number of patient was 274, since only CS caused by labor arrest were included. In logistic regression analysis, several maternal and fetal variables were investigated as independent variables for labor arrest and CS, as shown in table 8. In the multivariable risk analysis for this group, advanced maternal age, increasing fetal head circumference, decreasing maternal inlet size and increasing fetal pelvic index were found to be independent risk factors for CS caused by labor arrest. An increase of the maternal age, fetal size and the FPI value increased also the risk for CS with the ORs of 1.05-1.33 whereas an increase of the size of the maternal inlet diminished the risk with an OR of 0.94 (table 8).

Table 8. Uni- and multivariable models of the relationships between the maternal and fetal risk variables and cesarean section caused by protracted labor. The odds ratio (OR) is determined as 1 SD change in risk variable.

	VD (N=242)	CS (N=32)	P-value	Unadjusted OR (95%CI)	Adjusted OR (95%CI)
Mean Age \pm SD (years)	28 \pm 9.9	30 \pm 6.7	<0.05	1.08(1.01-1.16)	1.09 (1.02-1.17)
Parity(nulliparous/multiparous) (%)	48/52	61/39	0.18	1.66(0.79-3.48)	
Mean Maternal height \pm SD (cm)	163 \pm 5.7	161 \pm 5.2	<0.05	0.92 (0.86-0.99)	0.98 (0.89-1.07)
Mean Maternal weight \pm SD (kg)	68 \pm 16	71 \pm 7.1	0.38	1.01(0.99-1.03)	
Mean Weight gain \pm SD (kg)	15 \pm 6.1	15 \pm 4.6	0.92	1.00(0.94-1.06)	
Mean Maternal pelvic Inlet \pm SD (mm)	401 \pm 22	384 \pm 16	<0.05	0.96(0.93-0.98)	0.95 (0.92-0.97)
Mean Maternal pelvic CV (mm)	124 (\pm 9)	118(6.5)	<0.05	0.90(0.86-0.94)	0.92 (0.85-1.00)
Mean Maternal pelvic outlet \pm SD (mm)	360 \pm 20	356 \pm 19	0.27	0.99(0.97-1.01)	
Mean Fetal HC estimate \pm SD (mm)	339 \pm 14	344 \pm 12	0.08	1.02(0.99-1.05)	1.05 (1.02-1.09)
Mean Infant weight \pm SD (g)	3730 \pm 511	3790 \pm 475	0.48	1.00(1.00-1.001)	
Mean Gest. age at delivery \pm SD (days)	281 \pm 7.0	280 \pm 8.8	0.40	0.98(0.93-1.03)	
Labor Induction (%)	73%	70%	0.69	0.85(0.38-1.88)	
Augmentation (%)	82%	73%	0.20	0.58(0.25-3.98)	
FPI \pm SD	-2.5 \pm 3.4	-0.40 \pm 2.6	<0.05	1.30(1.12-1.50)	1.33 (1.13-1.55)

SD, standard deviation; Inlet, pelvic inlet circumference; CV, conjugata vera; Outlet, pelvic outlet circumference; HC, fetal head circumference; Gest., gestational; VD, vaginal delivery; CS, cesarean section caused by labor arrest; OR, odds ratio; CI, confidence interval

5.3 THE ACCURACY OF FPI AND PELVIMETRIC MEASUREMENTS

The accuracy of FPI and pelvimetric measurements in the prediction of arrested labor leading to CS or operative vaginal delivery was moderate or poor. Cut off values with sensitivities, specificities and predictive values for pelvimetric inlet and outlet parameters to detect CS are presented in table 9. The fetal pelvic index at cutoff value of zero had the following statistical measures: sensitivity for detecting CS 0.47 with a 95% CI of 0.30–0.64 and the specificity 0.76 (0.71–0.82), the positive predictive value (PPV) 0.21 (0.11–0.30), and the negative predictive value (NPV) 0.88 (0.85–0.92). The sensitivities and specificities of the different FPI values are shown in table 10. The pooled results that include all the previous studies presented in table 4 (p.18) along with those from study III are also shown in table 10.

Table 9. Sensitivity, specificity, positive and negative predictive values for pelvic inlet anteroposterior (conjugata vera) and outlet transverse diameters.

	Cut off (mm)	CS/VD Below the cutoff	Sensitivity	Spesificity	PPV	NPV
CV	105	2/6	0.06	0.98	0.25	0.88
	115	16/34	0.50	0.88	0.32	0.90
	125	27/135	0.91	0.51	0.18	0.90
	130	32/191	1.00	0.30	0.14	0.90
Outlet tr.	100	10/62	0.31	0.77	0.14	0.90
	110	25/170	0.78	0.38	0.13	0.90

CV, conjugata vera, inlet anteroposterion diameter; Outlet tr., outlet transverse, the interspinous diameter; CS, cesarean section; VD, vaginal delivery; PPV, positive predictive value; NPV, negative predictive value.

Table 10. The results from the study III. The pooled results include the studies presented in table 4 on page 18.

	N	CS/ VD	CS Rate %	FPI cut off	FPI+/- (%)	CS/VD(CS%) with positive FPI with negative FPI	Sensitivity	Specificity	PPV	NPV
Study III	274	32/242	11	-0.65	94/180 (34/66)	20/82(20) 12/160(7)	0.63	0.66	0.20	0.88
				0	72/202 (26/74)	15/57 (19) 18/184 (9)	0.47	0.76	0.21	0.88
				1	36/238 (13/87)	7/29 (5) 25/213(10)	0.22	0.88	0.19	0.88
				2	13/261 (5/95)	6/7 (50) 26/235(10)	0.19	0.97	0.46	0.88
Pooled with a cut off 0	966	266/700	28	0	296/670 (31/69)	170/126(57) 96/574 (14)	0.64	0.82	0.57	0.72

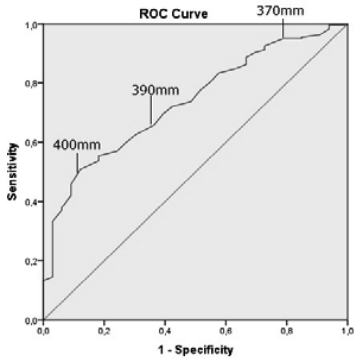
CS, cesarean section; VD, vaginal delivery; FPI, fetal pelvic index; PPV, positive predictive value; NPV, negative predictive value.

FPI, as well as the maternal inlet size, displayed poor accuracy in predicting the need for CS in the ROC analysis (figures 14a-e). The area under the curve (AUC) value for the pelvic inlet was 0.736 ($p < 0.001$, 95% CI = 0.656–0.816) (figure 14a) and for FPI the AUC value was 0.632, $p = 0.001$ (95% confidence interval [CI] of 0.555–0.709) (figure 14c).

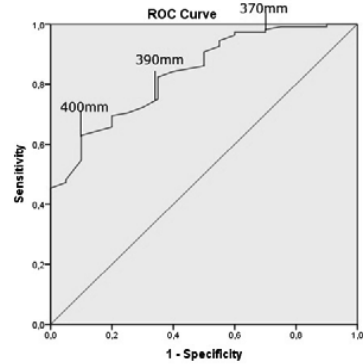
The accuracy of the pelvimetric measurements for the risk of operative vaginal delivery and the effect on the duration of the second stage of the labor were also investigated. The duration of the second stage of the delivery was 54 minutes longer ($P < 0.01$) in the operative vaginal delivery group. Similar to the CS studies, the accuracy of the pelvic measurements in predicting the need for intervention in vaginal delivery was found to be poor, the AUC value for the maternal inlet being only 0.566 ($p=0.18$, 95%CI 0.465-0.667) (figure 14d) and a similar value for the maternal outlet, 0.573 ($p=0.14$, 95%CI 0.484-0.622) (figure 14e).

5.4 FETAL SIZE AND PELVIMETRIC MEASUREMENTS

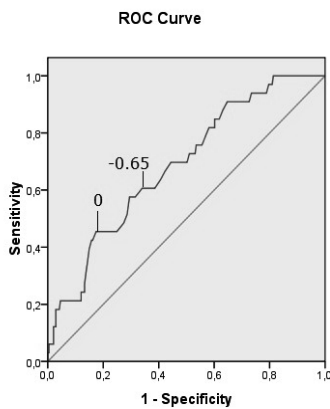
When the effect of the fetal size on the accuracy of pelvimetric measurements was investigated, the patients were divided into subgroups according to the size of the fetal dimensions, *i.e.* fetal HC, AC and fetal weight. The mean size of the maternal inlet was 1.0 cm larger in fetal HC >340 mm group as compared with ≤ 340 mm. When the mode of the delivery was taken into consideration, the difference was 1.3 cm in the vaginal delivery group and in the HC <340 group, the inlet was 2.4 cm larger in the vaginal delivery group than in CS group. It was noticeable, that in ROC analysis, in the subgroup of larger infants with the HC ≤ 340 mm, the AUC value was 0.836 ($p < 0.001$, 95% CI = 0.751–0.921) (figure 14b). The results were similar in all of the fetal size variables that were tested. In the operative vaginal delivery study, when the fetal size was taken into account, the maternal pelvic size was 4-5% larger in the mothers with infant weight ≥ 3700 g.



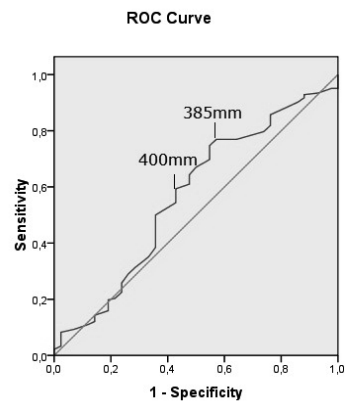
14a.



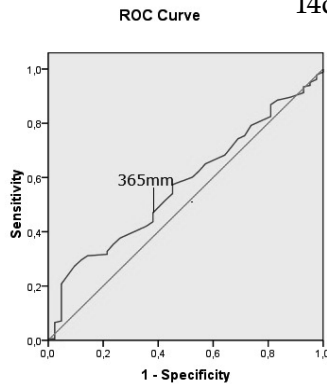
14b.



14c.



14d.



14e.

Figure 14a-e. ROC curves for FPI and pelvic parameters. The x-axis represents the false positive rate and the y-axis is the true positive rate. The Area under the Curve refers to the diagnostic accuracy of the test variable. 14a) ROC curve for pelvic inlet for predicting CS; AUC value=0.736 ($p < 0.001$, 95% CI = 0.656–0.816). 14b) ROC curve for pelvic inlet for predicting CS in HC>340mm; AUC value =0.836 ($p < 0.001$, 95% CI = 0.751–0.921). 14c) ROC curve for FPI for predicting CS; AUC value=0.632, ($p < 0.001$ 95%CI of 0.555–0.709). 14d) ROC curve for pelvic inlet for predicting operative vaginal delivery; AUC value= 0.566 ($p=0.18$, 95%CI 0.465–0.667). 14e) ROC curve for pelvic outlet for predicting operative vaginal delivery; AUC value= 0.573 ($p= 0.14$, 95%CI 0.484–0.622)

6 Discussion

In clinical obstetrics, several variables have been proposed to influence the risks of dystocia and fetopelvic disproportion in labour. Even though there has been substantial criticisms raised against the use of pelvimetry, no alternative methods for evaluating the size of the maternal pelvis have been introduced. This paucity of methods has meant that obstetricians are bereft of tools to help in clinical decision-making. The reliability and observer-related variations in pelvimetric measurements, (Keller et al. 2003) are other possible sources of bias in confusion. The criticism of the use of pelvimetry is also raised by the fact that it increases the CS rate and furthermore, there are reports that it may increase the mortality and even morbidity rates (Pattinson 2000). In previous studies, pelvimetry has been used with pre-selected threshold values regardless of the fetal size. The results emerging from the studies assessing the usability of the fetal pelvic index have been controversial (Thurnau et al. 1991; Ferguson et al. 1998). For these reasons, it was deemed necessary to investigate the effect of the fetal size on the accuracy of the pelvic measurements as well as assessing usability of the FPI as a method for detecting the risk of labor arrest and CPD.

6.1 THE MAIN FINDINGS

Arrest of labor was associated with the maternal pelvic dimensions and the fetal size. However, the variation in the measurements represents a serious source of bias in the pelvimetry-related methods, as is the lack of a method for predicting the uterine activity. The main findings of studies I-IV are listed in table 11.

MR pelvimetry was found to have a considerable variation in the measurements between observers, especially in the pelvic outlet parameters. The intraobserver variation was mostly acceptable, if a measurement difference below 0.5 cm is considered clinically sufficiently accurate. However, if the measurements were used to predict labor arrest or operative vaginal delivery, then the accuracy was poor and according to this study, the use of pelvimetric measurements or fetal pelvic index cannot be recommended. When the measurements were tested with larger fetuses, the accuracy values improved. The assessment of maternal inlet in fetuses HC>340mm group showed the best accuracy but it did not reach an adequate accuracy to be useful in the decision making about the mode of delivery according to the ROC analysis.

Table 11. The main findings of the studies I-IV

Study	Main result	Findings
I	The inter- observer variation was remarkable especially in pelvic outlet measurements	Intraobserver variation was acceptable in all measurements.
II	Labor arrest was associated with the maternal pelvic dimensions and the fetal size.	The accuracy of the pelvic inlet measurements increased in the larger fetus groups.
III	The FPI was not a versatile tool with which to predict the mode of delivery for patients at a high risk of CPD.	The pooled analysis including previous studies strengthened the negative result.
IV	The maternal bony pelvic dimensions exhibited no correlation with the need for operative vaginal deliveries.	

6.2 FINDINGS IN RELATION TO OTHER STUDIES

The reliability of the pelvimetric measurements has been investigated with different imaging techniques. The variation between radiologists has been evaluated with different techniques *e.g.* CT pelvimetry (Anderson et al. 2005), X-ray pelvimetry (Colcher et al 1949; Lundh et al.1986) and MR pelvimetry (Keller et al. 2003). Observer-related errors have been reported to have clinical relevance with all methods. In previous studies it has been also shown that sagittal outlet measurements and intertuberous distances exhibit the highest intra- and interobserver variations (Colcher et al. 1949). The present findings are in broad agreement with those of previous studies. The value of 0.5 cm was chosen to represent a clinically significant difference in the measurements, since it had been used also in a previous CT-study (Anderson et al. 2005).

In general, clinical decision making has relied to a great extent on randomized controlled trials, and the role of pelvimetry has been evaluated under such study settings (Pattinson 2000). In addition, the risk factors for CPD have recently been studied, *i.e.* with anthropometric measurements (Awonuga et al. 2007), other maternal variables (obesity and infertility treatment) (Tsvieli et al. 2012; Henrichs et al. 2003), and fetal weight alone (Harper et al. 2011). A few studies have been published recently also on pelvimetry or pelvimetry-related techniques to find the women who are at the risk for CPD (Lenhard et al. 2009b; Sibony et al. 2006). In the present study, the risk factors for labor arrest in multivariable regression analysis were maternal age, maternal inlet size, fetal head circumference and fetal pelvic index. However, the increase or decrease of the risk was so minimal that these factors can not be used in clinical decision making. Since the diagnostic accuracy of the pelvimetric measurements to predict CPD and operative vaginal delivery was found to be poor, the present study is in agreement with most of the recent published literature. Furthermore, the FPI did not predict arrested labour caused by CPD, as postulated in some studies (O'Brien et al. 2002; Fox et al. 2004). As stated above, the multivariable regression analysis did not reveal any factors that would have improved significantly the predictive value of FPI, as claimed in a recent study (Macones et al. 2013).

6.3 VALIDITY AND LIMITATIONS

In North Karelia Central Hospital, FPI was taken into clinical use in 1995. Initially, it was considered to be promising: the CS rate did not increase, and clinicians were forced to pay more attention to the diagnosis of CPD. Subsequently, FPI was used to help to predict the possibility of CPD. Since the CS rate remained stable (13%–16%) over the next decade, the use of FPI became the clinic's policy until the end of the last decade. Since pelvimetry is required for the calculation of the FPI, it was possible to collect a large cohort with pertinent pelvimetric data, in conjunction with the outcome of the delivery.

However, due to the retrospective nature of the study there are some limitations that must be considered. The measurements were made by several radiologists and obstetricians. A major problem with all the methods that include fetal and pelvimetric measurements is the deviations inherent in the measurements. As an example, with the maternal pelvic parameters of inlet conjugate 12.5cm, inlet transverse of 13.0cm, midpelvic conjugate 11.5cm and transverse of 10.5cm and both fetal HC and AC of 35 cm, with the measurement deviation of 0.5 cm in parametric measurements and 1.0cm in fetal measurements, the FPI can range a value as low as -5.6 up to 4.5. Furthermore, the obstetricians who were in charge of the labor were not blinded to the results of the pelvimetric or fetal measurements. Both pelvimetric and sonographic measurements are a possible source of assessment bias.

Even if the cohort in this study was larger than in any previous FPI trials, the patient sample was small in the final stages of the analysis. Since the aim was to study CPD, the pelvimetric measurements represent values that can be considered as normal or close to normal. The results are not usable in cases with obviously inadequate pelvic dimensions. Also, the clinic's contemporary policy did not encourage favouring vaginal delivery if the FPI value was > 2 . This represents a possible selection bias. However, the mean value of FPI in the present study was -2.3, which was the highest value reported in all of the studies so far and the number of patients with positive FPI was comparable with other studies. This indicates that when compared with other studies, it is likely that in the present cohort, the patients who were exposed to the trial of labor were at least at a similar, if no greater risk for CPD in labor.

The number of women that were chosen to have an elective CS was rather large. Without a trial of labor, it is impossible to know how many of them would have ended up to CS caused by CPD and how many of them would have had an uncomplicated vaginal delivery despite discouraging pelvimetric findings. However, it may not be possible to perform a prospective study where a trial of labor would be offered to all.

The diagnostic criteria for labor arrest in this study are in agreement with other studies that have evaluated FPI (Morgan et al. 1992b; Ferguson et al. 1998; O'Brien et al. 2002). However, during the last decade, convincing evidence has been presented that the diagnostic criteria for labor arrest should be re-evaluated since the duration of normal labour has a large variation (Zhang et al. 2010a). It is possible, that with the present diagnostic criteria there may have been an overdiagnosis of dystocia representing a source of classification bias.

In operative vaginal deliveries, those cases that were affected by fetal distress or malrotation of the fetal head or insufficient contraction activity were excluded. However, the success of the operative vaginal delivery is dependent on the experience of the obstetrician and it demands a careful case-by-case consideration. It is possible that the experience of the obstetrician had an effect on the decision of the mode of delivery and this represents another possible bias in this the study.

In all the studies that have investigated the mode of delivery, the outcome of the delivery has always been dependent not only on the psychosocial factors of the mother but also on the

experience of the caregivers, especially in the difficult diagnosis of labor arrest (Charoenboon, et al. 2013). In the present study, the number of caregivers was relatively small and the decisions to perform CS were taken by experienced specialists.

6.4 CLINICAL SIGNIFIGANCE

This study was undertaken in women whose pelvimetric measures were in normal range or only slightly restricted and therefore, the conclusions of the study concern only these women.

Labor arrest and CPD is the outcome of the mismatch between the passageway and the passenger but in addition, it is influenced by the power of the uterine contractions. Pelvimetry, used as a single diagnostic tool to predict the risk for CPD is not useful, since it provides information only about the passageway. In the present study, the attempts to add the other two factors, especially the passenger to the diagnosis did not create a clinically useful method. Unpredictable factors, such as uterine power, play a significant role in labor arrest

In this study, maternal inlet size adjusted for the large fetal HC size was the best parameter to predict CPD even if the accuracy was not in acceptable limits in this patient group. The use of fetal pelvic index along with multivariable modelling has been suggested to be accurate useful tool in clinical decision making (Macones et al. 2013), but based on this study the fetal pelvic index did not increase the accuracy.

6.5 GENERALIZABILITY

The patients in this study were Caucasian women who were treated with modern obstetric guidelines, technology and resources. Thus the generalizability of the results is limited with patients that are treated with the same management policies. This would exclude deliveries in the developing countries as well as planned home deliveries.

As stated in previous studies, pelvimetry does not represent an accurate tool to predict labor arrest or difficulties in vaginal delivery, even if the method itself was found to be valid. According to the pooled analysis of FPI studies, the combination of fetal and maternal measurements does not greatly improve the predictive value. It seems inevitable that the third component, the power of the uterus must play crucial role in labor arrest. Pelvimetry, however is in clinical use especially in planning of the vaginal breech delivery. When pelvimetric measurements are used in decision making, millimeter accurate limits are not recommended due to measurement variations. Measurements should be conducted in a centralized location to decrease observer-related variations.

6.6 FUTURE PERSPECTIVES

This retrospective study was designed to test the accuracy of the methods to find women at the risk for labor dystocia. In the future, one can predict that it will be possible to decrease the measurement variability in both maternal and fetal measurements. However, even the state-of-art modern equipment with 3/4D technology has not improved the predictive value of the fetal measurements. The fusion imaging of MRI and sonography has not been studied but should be investigated in fetal weight estimation. In CPD, the role of fetal shoulder width has not been investigated. In addition, a measurement assessing subcutaneous tissue could be added to fetal dimension and circumference measurements in order to improve the accuracy of EFW, especially in macrosomia.

The overdiagnosis of the CPD has been recognized. The uterine contractile activity is not included in any of the diagnostic methods that have been introduced -and subsequently abandoned. Even if the understanding of the biology of uterine activity is at a high level, the search risk factors for uterine activity disorders will require more investigation. CPD is a challenge for clinicians and it is a common reason for consultation within the maternity unit. One way to improve the diagnostical methods to predict CPD in labor would be to devise an international consensus of definition of labor arrest. At present, the trial of labor is the only valid method with which to diagnose CPD in labor.

7 Conclusions

On the basis of this study the following conclusions can be drawn:

1. MR pelvimetry measurements were accurate in pelvic inlet measurements, but they were subjected to considerable observer-related measurement variations. The intraobserver variation was acceptable with the measurement deviations within 0.5 cm.
2. The independent risk factors for CS caused by labor arrest were advanced maternal age, small pelvic inlet dimensions, large fetal HC and increasing fetal pelvic index.
3. The ability of pelvimetric measurements was poor in the prediction of labor arrest or in the prediction of operative vaginal delivery. The accuracy of inlet size in the prediction of CS was moderate, if the fetal HC size was taken into consideration.
4. Pelvimetric measurements or fetal pelvic index cannot be used for the decision of the mode of delivery in suspected CPD or in the second stage of vaginal delivery.

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ULLA KORHONEN
*Maternal pelvis,
feto-pelvic index and
labor dystocia*



Cephalopelvic disproportion (CPD) occurs when there is a mismatch between the fetus and the maternal birth canal. In the previous century, a variety of methods were introduced to predict CPD. The objective of this retrospective study was to evaluate pelvimetry and fetal pelvic index in predicting labor dystocia. In the prediction of labor arrest and operative vaginal delivery, the accuracy of pelvimetric measurements and the fetal pelvic index proved to be poor.



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