

Ingrid Volløyhaug

Pelvic Floor, Incontinence & Prolapse 15-24 Years after Delivery



Image Page 1: detail from “Du sang I” by May Bente Aronsen

Summary

Background: Up to 20% of women in western countries have been subject to surgery for urinary incontinence and pelvic organ prolapse by the age of 85 years, and many receive conservative treatment or do not seek professional health care. Cesarean delivery is associated with lower prevalence, and operative vaginal delivery is associated with increased prevalence of prolapse and incontinence symptoms, but a distinction between forceps and vacuum deliveries has only been made in a few small studies. Pelvic floor muscle trauma, i.e. levator avulsion and increased levator hiatal area demonstrated by ultrasound are risk factors for prolapse. Studies on urogynaecological patients and puerperal women have demonstrated higher prevalence of muscle trauma after forceps, but not after vacuum deliveries. We found no previous studies addressing a difference in anatomical prolapse between forceps and vacuum deliveries. There is a lack of studies on women from the normal population on the association between muscle trauma and symptoms and signs of prolapse. Palpation and perineometry are used to assess pelvic floor muscle contraction, but there is a lack of a gold standard to assess muscle contraction.

Aims: To study the prevalence of symptoms and signs of prolapse, urinary and fecal incontinence and pelvic floor muscle trauma among women from the normal population 15-24 years after delivery in association to delivery mode. Define a scale to measure pelvic floor muscle contraction with ultrasound.

Methods: We conducted a cross sectional study among parous women from the normal population that had delivered their first child at Trondheim University Hospital between 1990 and 1997, when doctors were equally trained in vacuum and forceps. A total of 1641 women responded to a postal questionnaire regarding symptoms of prolapse and incontinence and 608 women were examined with grading of prolapse, 4D transperineal ultrasound for the diagnosis of pelvic floor muscle trauma, and assessment of pelvic floor muscle contraction by palpation, perineometry and ultrasound.

Main results: Paper I: Cesarean delivery was associated with decreased risk and operative vaginal delivery with increased risk of prolapse and incontinence symptoms. There was no difference between forceps and vacuum delivery. Paper II: Cesarean delivery had decreased risk for prolapse stage 2 or surgery and for levator avulsion, and smaller hiatal areas compared to normal delivery. Forceps had increased risk for prolapse stage 2 or surgery and for levator avulsion, and larger hiatal areas compared to vacuum and normal vaginal delivery. There was no difference between vacuum and normal delivery. Paper III: Many women from the normal population had symptoms and signs of prolapse 15-24 years after first delivery, and pelvic floor muscle trauma was associated with symptoms and signs of prolapse. Paper IV: We found moderate to strong correlation between ultrasound measurements and palpation and perineometry for assessment of pelvic floor muscle contraction. The proportional change in anteroposterior levator hiatal diameter was the ultrasound measurement with strongest correlation to palpation and perineometry. We defined a contraction scale for ultrasound measurements based on the proportional change in anteroposterior diameter.

Conclusion: There was no difference in prevalence of prolapse and incontinence symptoms between forceps and vacuum deliveries. There was more pelvic floor muscle trauma and anatomical prolapse after forceps than vacuum deliveries. The association between pelvic floor muscle trauma and symptoms and signs of prolapse was confirmed in women from a normal population.

There was a moderate to strong correlation between palpation, perineometry, and ultrasound assessment of pelvic floor muscle contractions. We defined a four-point contraction scale using the proportional change in anteroposterior levator hiatal diameter on ultrasound, which can form the basis for a validation of a contraction scale for ultrasound measurements.

Sammendrag

Bakgrunn: Opp mot 20% av kvinner i den vestlige verden har gjennomgått kirurgi for urininkontinens eller descens ved fylte 85 år, og enda flere behandles konservativt, eller de søker ikke legehjelp. Keisersnitt er assosiert med lavere forekomst og operativ vaginal fødsel er assosiert med økt risiko for symptomer på descens og inkontinens, men det er ikke undersøkt for forskjell mellom tang og vakuum i tidligere studier. Skader på bekkenbunns-muskulaturen, dvs. levatoravrivning og økning i levator hiatusareal som diagnostiseres ved ultralyd, er risikofaktorer for descens. Studier blant urogynekologiske pasienter og kvinner postpartum har vist høyere forekomst av avrivningsskader og større hiatusareal etter tang, men ikke etter vakuumfødsler. Det har ikke vært undersøkt om det er økt forekomst av descens etter tang sammenliknet med vakuum. Det mangler studier på sammenheng mellom bekkenbunns-muskelskader og symptomer og tegn på descens hos kvinner fra normalbefolkningen. Palpasjon og perineometri brukes for å måle bekkenbunnskontraksjon, men det mangler en gullstandard for å undersøke kontraksjon.

Mål: Studere forekomst av descens, urin- og avføringsinkontinens og bekkenbunns-muskelskader hos kvinner fra normalbefolkningen 15-24 år etter fødsel i assosiasjon til forløsningsmetode. Definere en skala for å måle bekkenbunnskontraksjon med ultralyd.

Metode: Vi gjennomførte en tverrsnittstudie av kvinner fra normalbefolkningen som hadde født sitt første barn ved St. Olavs Hospital i perioden 1990-97, da obstetrikere var like godt trent i både tang og vakuum. Totalt 1641 kvinner svarte på et spørreskjema om symptomer på descens og inkontinens, og 608 kvinner ble undersøkt med gradering av descens, 4D ultralydundersøkelse for diagnose av bekkenbunns-muskelskade, og gradering av muskelkontraksjon med palpasjon, perineometri og ultralyd.

Hovedresultater: Artikkel I: Keisersnitt var assosiert med redusert risiko og operativ vaginal fødsel med økt risiko for symptomer på descens og inkontinens. Det var ingen forskjell mellom tang og vakuum. Artikkel II: Keisersnitt hadde redusert risiko for descens grad 2 eller kirurgi, levatoravrivning, og mindre hiatusareal sammenliknet med normal fødsel. Tang hadde økt risiko for descens grad 2 eller kirurgi, levatoravrivning, og større hiatusareal enn vakuum og normal vaginal fødsel. Det var ingen forskjell mellom vakuum og normalfødsel. Artikkel III: Mange kvinner fra normalbefolkningen hadde symptomer og tegn på descens 15-24 år etter første fødsel, og bekkenbunns-muskelskade var assosiert med symptomer og tegn på descens. Artikkel IV: Vi fant moderat til sterk korrelasjon mellom ultralydmål og palpasjon og perineometri for mål av bekkenbunnskontraksjon. Prosentvis endring i anteroposterior levatorhiatus diameter var ultralydmålet som hadde sterkest korrelasjon med palpasjon og perineometri. Vi definerte en kontraksjonsskala for ultralydmål basert på prosentvis endring i anteroposterior levator diameter.

Konklusjon: Det var ingen forskjell i forekomst av symptomer på descens og inkontinens mellom tang og vakuum. Det var mer bekkenbunns-muskelskader og objektivt descens etter tang enn etter vakuum og normal fødsel. Sammenhengen mellom bekkenbunns-muskelskader og symptomer og tegn på descens ble bekreftet hos kvinner fra normalbefolkningen 15-24 år etter fødsel.

Det var moderat til sterk korrelasjon mellom palpasjon, perineometri og ultralyd for mål av bekkenbunnskontraksjon. Vi definerte en kontraksjonsskala for prosentvis endring i levator anteroposterior diameter som kan være grunnlag for å validere en kontraksjonsskala for ultralydparametre.

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List of papers

Paper I

Volløyhaug I, Mørkved S, Salvesen Ø, Salvesen K.

Pelvic organ prolapse and incontinence 15-23 years after first delivery: a cross-sectional study.

BJOG. 2015 Jun;122(7):964-71. DOI: 10.1111/1471-0528.13322. Epub 2015 Feb 16.

Paper II

Volløyhaug I, Mørkved S, Salvesen Ø, Salvesen KÅ.

Forceps is associated with increased risk of pelvic organ prolapse and muscle trauma: a cross-sectional study 16-24 years after first delivery.

Ultrasound Obstet Gynecol. 2015;46(4):487-95. DOI: 10.1002/uog.14891. Epub 2015 Apr 29.

Paper III

Volløyhaug I, Mørkved S, Salvesen KÅ.

Association between pelvic floor muscle trauma and pelvic organ prolapse 20 years after delivery.

Int Urogynecol J. 2016;27(1):39-45. DOI 10.1007/s00192-015-2784-8. Epub 2015 Jul 22.

Paper IV

Volløyhaug I, Mørkved S, Salvesen Ø, Salvesen KÅ

Assessment of pelvic floor muscle contraction with palpation, perineometry and transperineal ultrasound: a cross-sectional study.

Ultrasound Obstet Gynecol. DOI: 10.1002/uog.15731. Epub 2015 Aug 24.

Abbreviations

2D	Two dimensional
3D/4D	Three dimensional/ four dimensional
AI	Anal incontinence
ANCOVA	Analysis of covariance
AP	Anteroposterior
BMI	Body mass index
CD	Cesarean delivery
CI	Confidence interval
CRADI	Colorectal-anal distress inventory
EMG	Electromyography
FD	Forceps delivery
FI	Fecal incontinence
MD	Mean difference
aMD	Adjusted mean difference
uMD	Unadjusted mean difference
MOS	Modified Oxford scale
MRI	Magnetic resonance imaging
NVD	Normal vaginal delivery
OASIS	Obstetric anal sphincter injuries
OR	Odds ratio
aOR	Adjusted odds ratio
cOR	Crude odds ratio
OVD	Operative vaginal delivery
PFD	Pelvic floor disorders
PFDI	Pelvic floor distress inventory
PFIQ	Pelvic floor impact questionnaire
PFMT	Pelvic floor muscle trauma
POP	Pelvic organ prolapse
sPOP	Symptomatic pelvic organ prolapse
POPDI	Pelvic organ prolapse distress inventory

POP-Q	Pelvic organ prolapse quantification
POP-Q ≥ 2	Pelvic organ prolapse equal to or larger than stage two
SD	Standard deviation
UI	Urinary incontinence
SUI	Stress urinary incontinence
UII	Urge urinary incontinence
UDI	Urinary distress inventory
VD	Vacuum delivery

1 Introduction

I started working in the field of urogynecology in 2007 and learned how to examine urogynecological patients and treat urinary incontinence and pelvic organ prolapse with conservative treatment and with surgery. I soon realized that there is no “easy fix” for prolapse and incontinence. Many women do not have the desired effect of conservative treatment such as physiotherapy, ring pessaries and medication. Recurrence after surgery is common, in particular after prolapse surgery, where up to 20-30% of patients need more than one procedure. This made me reflect that prevention of prolapse and incontinence must be better than treatment of a condition that has already occurred. What causes prolapse and incontinence? I knew some obstetrical factors such as parity and vaginal delivery, and also some non-obstetrical factors such as high body mass index (BMI), heredity, heavy lifting and menopause could be risk factors for pelvic floor disorders and pelvic organ prolapse.

Among obstetricians and gynecologists there had been much focus on instrumental vaginal deliveries and episiotomies in relation to obstetric anal sphincter injuries, as sphincter tear is one of the main risk factors for anal and fecal incontinence later in life. A common argument was that “It is not the forceps doing the damage, it is the monkey on the other side”, which was used to argue that doctors should get more training in forceps deliveries to prevent sphincter trauma to occur. There was never any concern about the Levator ani musculature or future pelvic organ prolapse and urinary incontinence, despite these conditions being more frequent than fecal incontinence.

I got the opportunity to be a visiting scholar at the Sydney Medical School Nepean, Nepean Hospital, Penrith, Australia for 5 weeks in October/ November 2011. I learned pelvic floor ultrasound in a very inspiring environment from Professor Dietz and his co-workers, who have developed this technique. After five weeks I had many new questions that I was eager to find the answer to. During 2012 I developed the protocol for this project, and hoped to find answers to some of my questions:

- Does forceps cause more trauma than vacuum to the pelvic floor?
- Do women have more prolapse symptoms and incontinence after forceps than after vacuum delivery?
- Do women have more anatomical prolapse after forceps than after vacuum delivery?

- Do we find the same associations between pelvic floor muscle trauma and symptoms and signs of prolapse in women from the normal population as we do in urogynecological patients?

We had a good opportunity to study women who delivered their first child at Trondheim University Hospital from 1990-97, when doctors were equally trained in both methods.

Assessment of pelvic floor muscle contraction is important in the evaluation of the urogynecological patient. Palpation depends on the experience of the examiner and perineometry is influenced by the placement of the probe and by increased abdominal pressure. Previous studies had demonstrated that ultrasound could be used to assess muscle contraction. One idea was therefore: Can we define an ultrasound scale for measurement of pelvic floor contraction as a more objective measurement of pelvic floor muscle contraction?

The following pages describe the project that was conducted to address these questions.

2 Background

2.1 The female pelvic floor – functional anatomy

2.1.1 Anatomy

The female pelvic floor provides a functional support for the urinary tract, female genital tract and the rectum. The bony structures, connective tissue and muscles of the pelvic floor interact to provide this functional support ¹. The function of the muscles is to provide resting tone, contraction and relaxation. Pelvic floor muscle resting tone and contraction are important components of the mechanism that prevents descent of the pelvic organs and maintains continence ¹⁻⁸. Relaxation is also important, in order to favour micturition, defecation and parturition.

Bone: A natural lordosis of the spine forces the pelvic organs towards the symphysis. The bony pelvis provides attachment for muscles and fascia. The female pelvis has a wider diameter and a more circular shape than the male pelvis, facilitating parturition, but also predisposing to subsequent pelvic floor weakness ¹.

Connective tissue: The uterosacral and cardinal ligaments are strong condensations of connective tissue that support the uterus and apex of the vagina ^{5,9}. The pubocervical (vesicovaginal) fascia provides lateral attachment of the middle part of the vagina, preventing cystocele, and the rectovaginal fascia, in the lower part of the vagina, prevents rectocele ⁹.

Pelvic floor muscles: The levator ani muscle complex provides a firm, but elastic base for the pelvic organs ⁵. The most median part of the levator ani, immediately surrounding the urethra, vagina and rectum, is referred to as the Puborectalis or Pubococcygeus muscle, see Figure 1. This part of the muscle provides a firm muscular closure of the pelvic outlet or urogenital hiatus, preventing descence of the pelvic organs ⁷. The superficial perineal muscles (M. Bulbocavernosus, M. Transversus perinei) support the distal part of the vagina. The superficial perineal muscles fuse with the external anal sphincter to form the perineal body, which is a fibromuscular structure in the midline between the anus and the vagina providing support to the distal part of the posterior vaginal wall ¹, see Figure 1.

Levator hiatus: The levator hiatus, or urogenital hiatus, is the opening in the pelvic floor muscles that is traversed by the urethra, vagina and anorectum ¹. It is the largest potential hernia portal in the body. The puborectalis muscle, which forms the inner border of the hiatus, is a curved sling, and therefore the levator hiatus has a warped shape ¹⁰, see Figure 2.

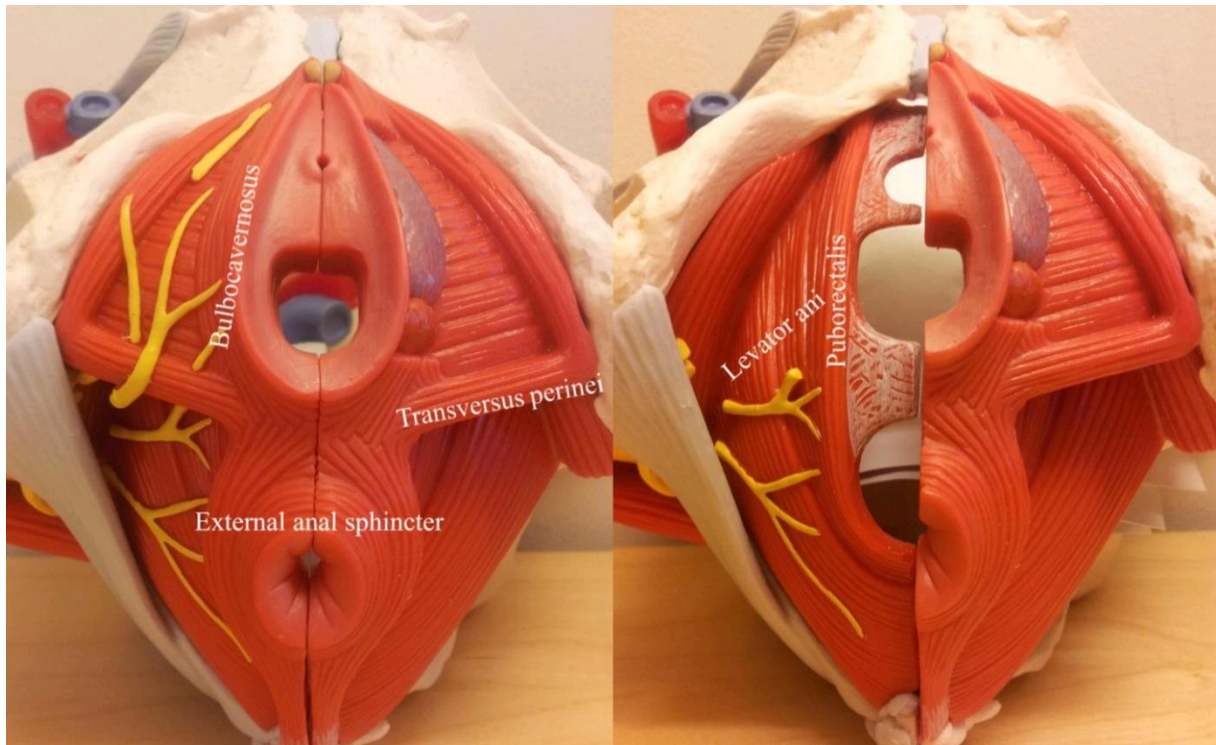


Figure 1 Pelvic floor muscles. The photo to the left demonstrates the superficial muscle layer: Bulbocavernosus, Transversus perinei and external anal sphincter. In the photo to the right, the superficial muscles have been removed to visualize the deep muscle layer: Levator ani with Puborectalis.

Photo of a female pelvis model from 3B Scientific® by Volløyhaug.

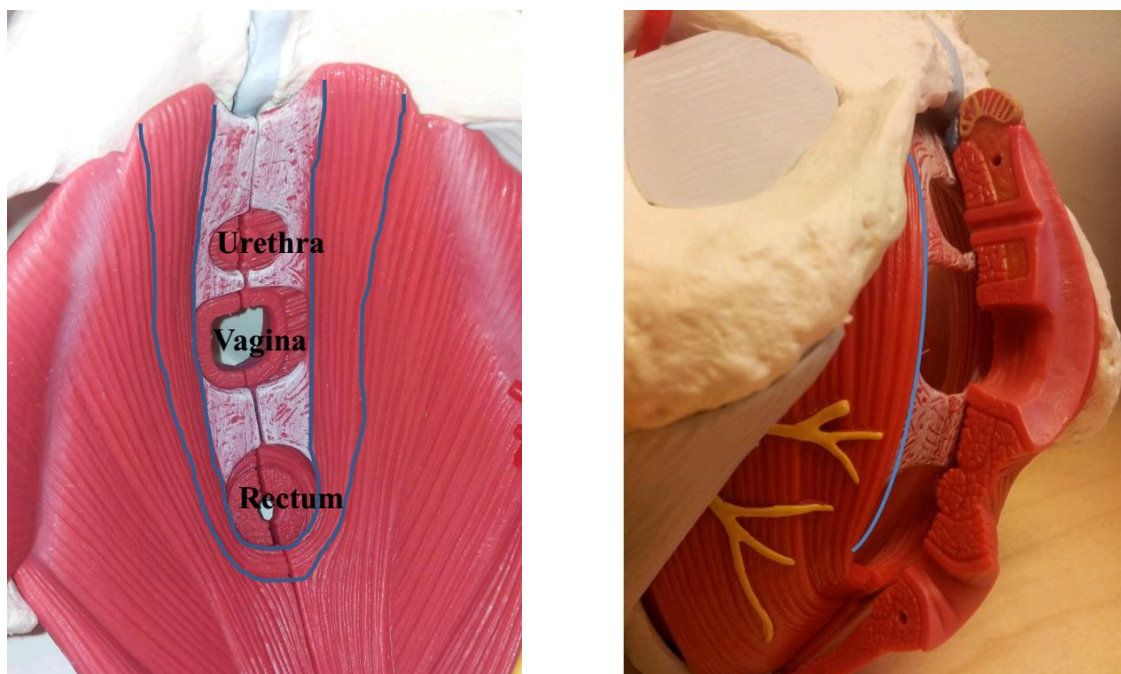


Figure 2 Levator hiatus. The levator hiatus, or urogenital hiatus, is the opening in the pelvic floor muscles that is traversed by the urethra, vagina and anorectum. In the photo to the left the Puborectalis muscle is outlined in blue. In the photo to the right, the curved shape of the puborectalis muscle is demonstrated with the blue line.

Photo of a female pelvis model from 3B Scientific® (Volløyhaug).

Nerves: The S2-4 segments of the spinal cord provide a direct innervation of the levators, coccygeus and urogenital diaphragm. The S2-4 also fuse to form the N. Pudendalis, which innervates the external anal sphincter ¹¹.

Three levels of vaginal support: DeLancey has described a widely accepted model of three levels of vaginal support ⁹ (Figure 3): Level I consists of the cardinal and uterosacral ligaments, and suspends the vaginal apex. Level II consists of the endopelvic fascia connections to the arcus tendineus fascia pelvis, which attaches the vagina to the aponeurosis of the levator ani. Level III consists of the perineal body and includes interlacing muscle fibers of the bulbospongiosus, transversus perinei, and external anal sphincter.

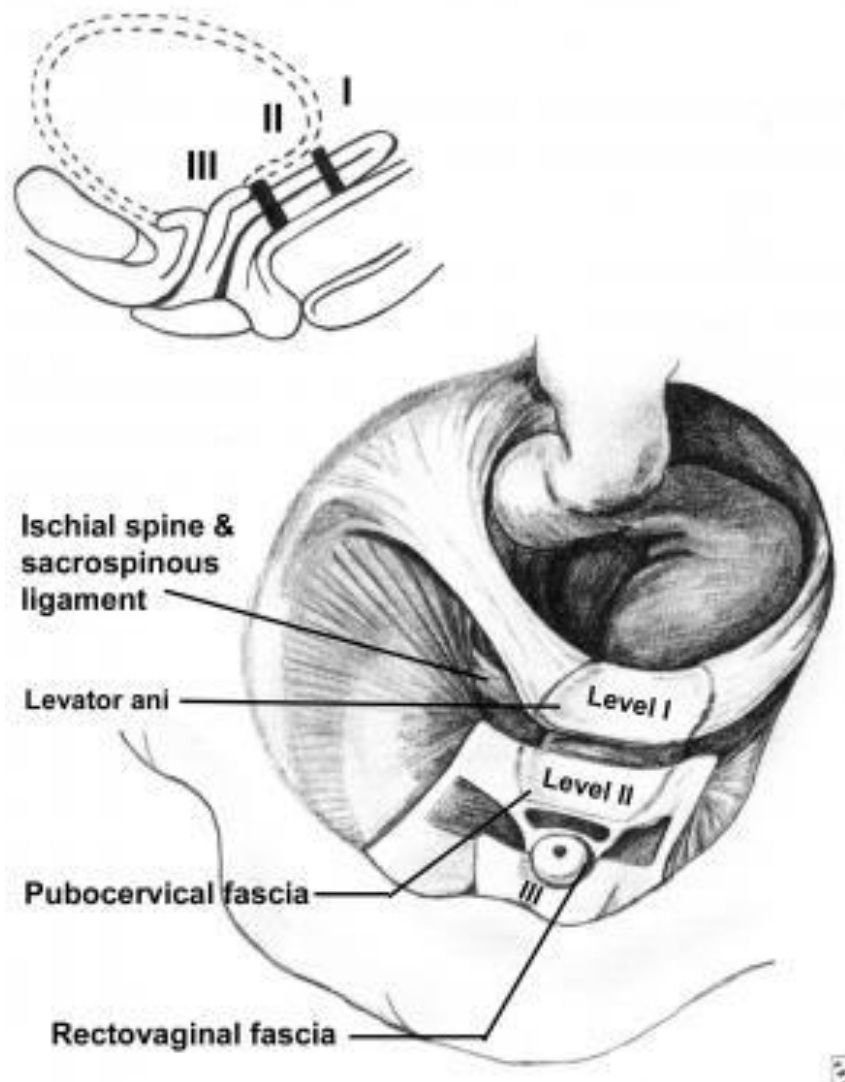


Figure 3 DeLancey levels of vaginal support

From: <http://img.medscapestatic.com/pi/meds/ckb/30/38130m.jpg>

2.1.2 Examination of pelvic floor muscle anatomy and function

Pelvic floor muscle anatomy, contraction and strength can be assessed by different techniques.

Palpation: Muscle integrity or injury can be palpated at pelvic floor muscle contraction. The Modified Oxford Scale developed by Laycock, is the most commonly used scale for assessment of pelvic floor muscle strength¹² (Table 1). An intact muscle may be difficult to palpate if it cannot contract or is traumatically over-distended. A graded scale for assessment of resting tone was developed by Dietz in concordance with the grades of the Modified Oxford Scale (MOS)^{13,14}, (Table 2). Palpation is easy to perform and does not require other diagnostic tool than the examiner's fingers, but interpretation of findings is subject to interrater differences¹³.

EMG: Electromyography (EMG) is the study of potentials produced by the depolarization of the muscle membrane. Surface or needle electrodes may be used. Innervation deficits are indicated by abnormal potentials observed in resting or active muscle¹⁵. Concentric needle EMG and pudendal nerve conduction tests can also be used to diagnose nerve injury¹⁶. Examination of pudendal neuropathy is technically complex, invasive and difficult to interpret and therefore not used in clinical practice. EMG is measuring recruitment of motor units, and not muscle strength.

Perineometry: The perineometer or manometer is a pneumatic apparatus that registers muscle contraction. Perineometry was originally described by Kegel, who constructed the perineometer specifically for the exercise of birth canal muscles¹⁷. The perineometer has been used to measure pelvic floor muscle strength^{18,19}. A vaginal balloon is connected to a fiberoptic pressure transducer and measures the vaginal squeeze pressure (Figure 4). Correct measurement by perineometry requires observation of inward/ upward lift of the perineal muscles, but measurements could be biased by concomitant increasing intraabdominal pressure¹⁹.

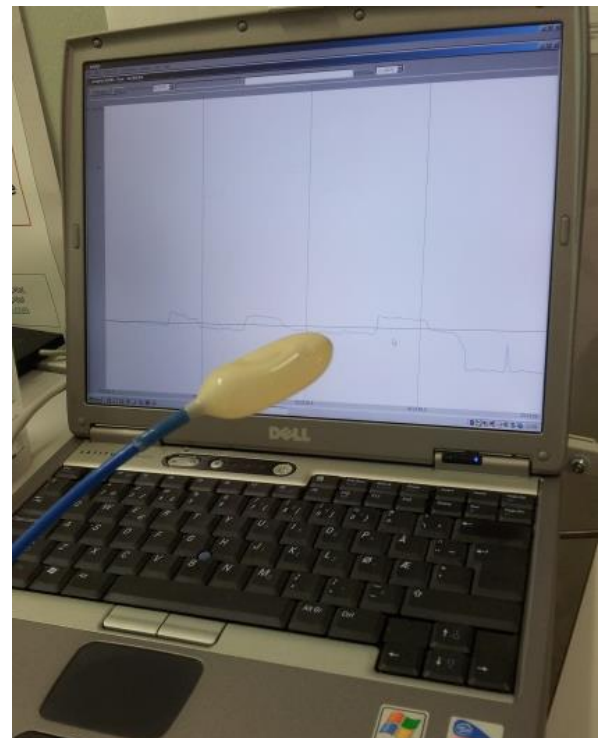


Figure 4 Perineometer. Vaginal balloon connected to a fiberoptic pressure transducer. Photo by Volløyhaug.

Table 1 Modified Oxford Scale for assessment of pelvic floor muscle strength by palpation

Grade	Description	
0	Nil	Muscle not palpable
1	Flicker	Muscle palpable, but very flaccid, wide hiatus, minimal resistance to distension
2	Weak	Hiatus wide, but some resistance to distension
3	Moderate	Hiatus fairly narrow, fair resistance to palpation but easily distended
4	Good	Narrow hiatus, muscle can be distended, but high resistance to distension, no pain.
5	Strong	Hiatus very narrow, no distension possible, “woody” feel, possibly with pain: “vaginismus”.

Table 2 Scale for assessment of resting tone by palpation

Grade	Description	
0	Nil	Lack of any discernible response in the perivaginal muscles
1	Flicker	Fluttering, quivering of the muscles
2	Weak	Contraction which is not fluttering
3	Moderate	Moderate increase in pressure, compressing the examiner’s fingers and incorporating a small degree of lift, as the fingers are moved in a cranial direction
4	Good	Firm contraction causing lifting of the pelvic floor muscles up and against resistance
5	Strong	Very strong grip of the examiner’s finger and positive movement in a cranial direction against strong resistance.

Pelvic floor ultrasound: Imaging of the pelvic floor is usually performed by transperineal ultrasound, with a 3D curved array abdominal transducer placed on the perineum and introitus of the patient. This technique has been developed by Prof. Dietz, and we have used the image orientation suggested by him in the present study^{20,21}, see Figure 5.

2D ultrasound can be used to obtain a sagittal view of the symphysis, urinary bladder, urethra, vagina, rectum and posterior aspects of the puborectalis muscle, see Figure 5.

3D/4D ultrasound is used to obtain an ultrasound volume that can be viewed in three sectional planes (sagittal, coronal, transverse /axial) or in a rendered 3D volume, see Figures 6 and 8. The 4th dimension is the time aspect, which are cineloops of 3D volumes.

“The plane of minimal hiatal dimensions” is used as a reference plane, see Figure 6. The sagittal plane is used to identify the inferior edge of the symphysis pubis ventrally and the anorectal angle dorsally, i.e. the shortest distance between the symphysis and the anterior border of the puborectalis muscle as it passes behind the rectum²². The corresponding angled axial image, representing the levator or urogenital hiatus, is then used for measurements.

Tomographic ultrasound imaging (TUI): This technique is used to examine for injury to the levator ani in the plane of minimal hiatal dimensions and the planes 2.5 and 5 mm cranial to this²³, see Figure 7. TUI can also be used for imaging of the anal sphincters, See Figure 16.

Rendered imaging: The levator hiatal areas are by convention measured in the plane of minimal hiatal dimension in a rendered volume of 1-2 cm thickness, due to the warped shape of the levator hiatus²⁴, see Figure 8.

Differences between rest and contraction in levator hiatal areas, diameters and bladder neck shift can be measured by ultrasound, and gives a measure of pelvic floor contraction²⁵⁻²⁹, see Figure 24. There is no established scale to quantify contraction by ultrasound. Ultrasound can also be used to examine the distensibility of the pelvic floor muscles on Valsalva maneuver. Changes in ultrasound measurements between rest and Valsalva maneuver give an indication of distensibility of the muscles³⁰.

Magnetic Resonance Imaging (MRI): MRI can be used for imaging of hiatal anatomy and dimensions³¹. There is good correlation between ultrasound and MRI measurements³². MRI is more expensive, more time consuming and less available in clinical practice.

Pelvic floor muscle contraction and strength can be assessed by different techniques. All techniques have disadvantages, and there is no gold standard^{8,33}.

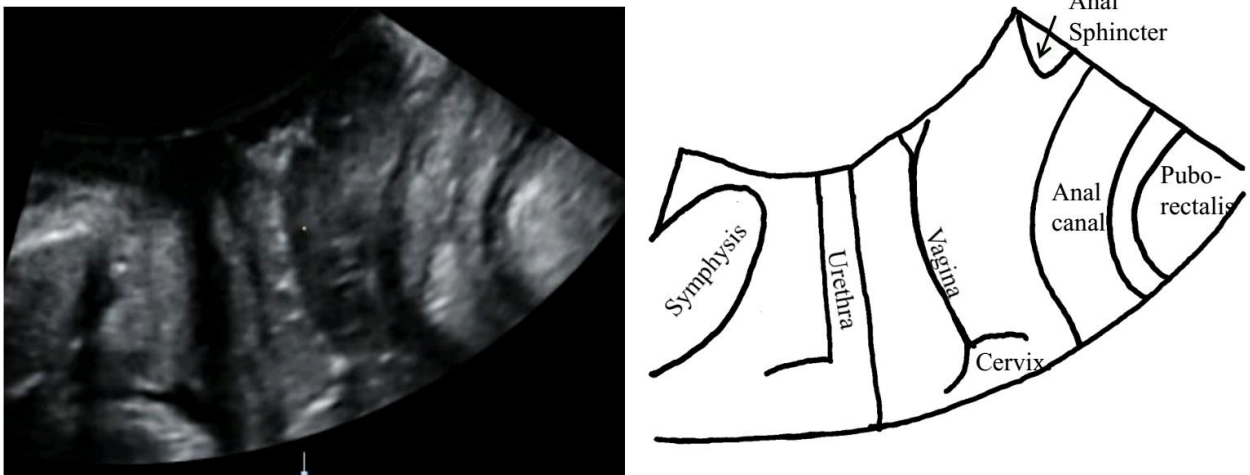


Figure 5 Two dimensional (2D) sagittal view of the pelvic floor structures. The figure to the right is a schematic drawing of what we see in the ultrasound picture. Imaging by Volløyhaug.

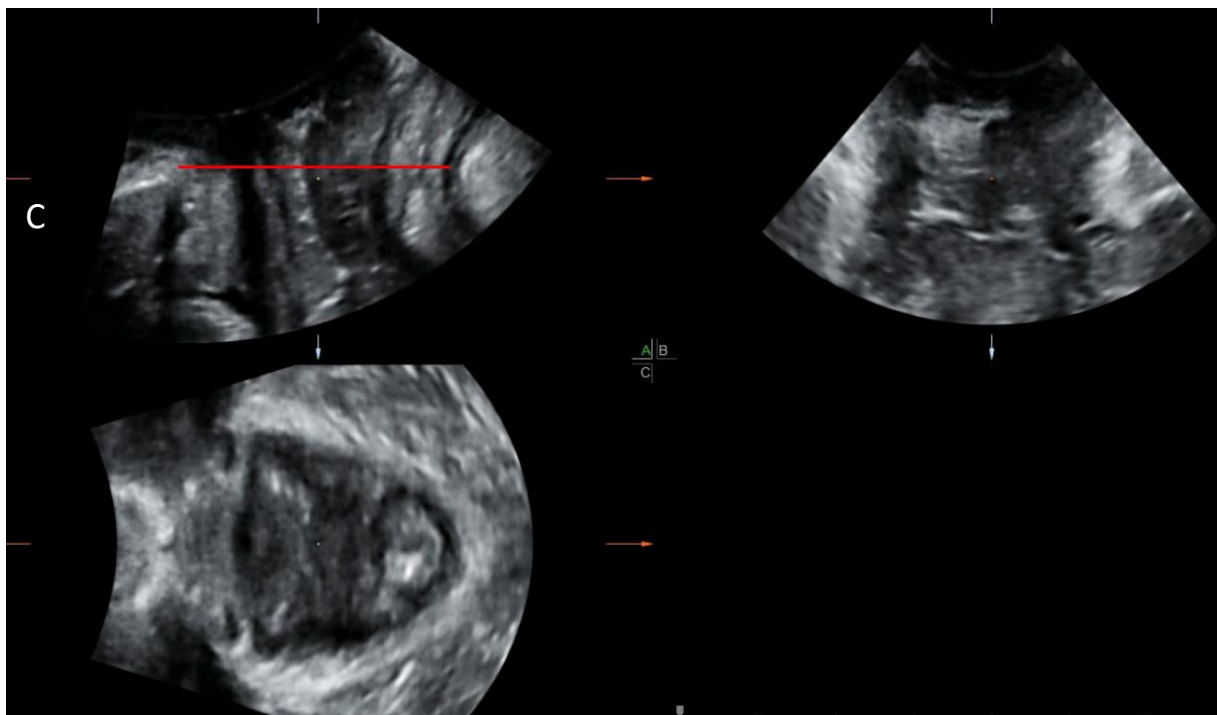


Figure 6 Three dimensional (3D) imaging, sectional planes. A) Image in the sagittal plane, with horizontal line indicating the plane of minimal hiatal dimension. B) Image in the coronal plane. C) Image in the axial plane. Imaging by Volløyhaug.

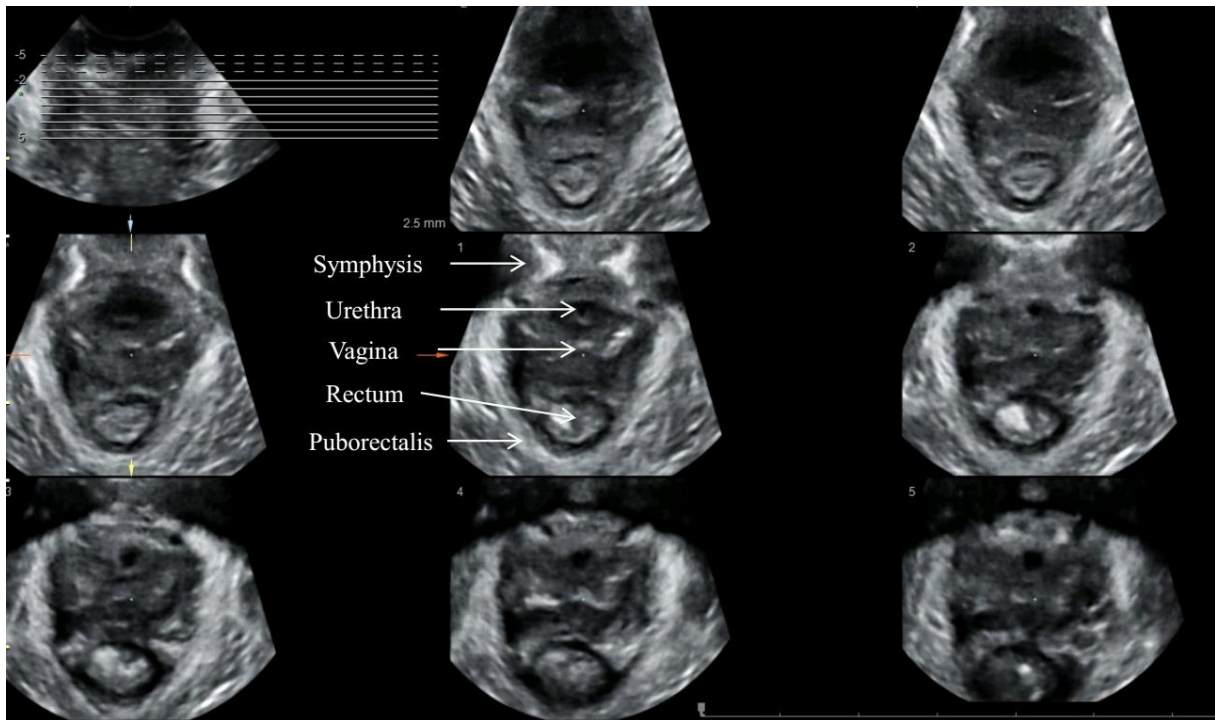


Figure 7 Tomographic ultrasound imaging (TUI) in the angled axial plane.
Imaging by Volløyhaug.

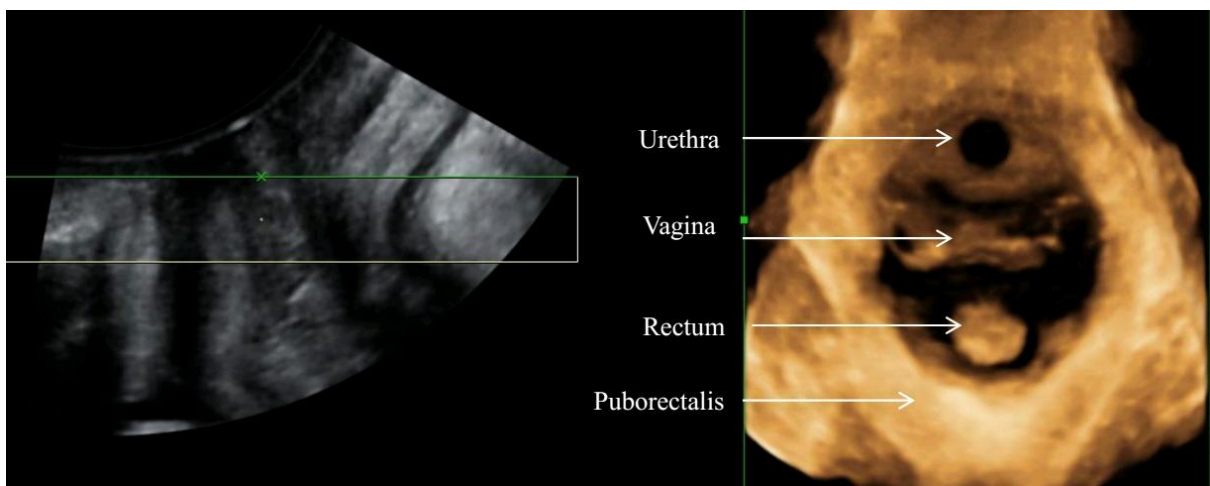


Figure 8 Rendered image in the angled axial plane to the right. The image to the left demonstrates the 1-2 cm thickness of the rendered image
Imaging by Volløyhaug.

2.2 Pelvic floor dysfunction

Pelvic floor dysfunction (PFD) or disorders may include clinical conditions such as urinary incontinence, anal/fecal incontinence, pelvic organ prolapse, sensory and emptying abnormalities of the lower urinary tract and defecatory dysfunction³⁴. Some authors also include sexual dysfunction and chronic pain syndromes, including vulvodynia^{35,36}. The three most common and definable conditions encountered clinically are urinary incontinence (UI), anal incontinence (AI) (comprising both leakage of stool, fecal incontinence (FI), and gas) and symptomatic pelvic organ prolapse (sPOP)^{34,36}. Overlapping of symptoms of two or three conditions is common³⁷⁻³⁹.

Diagnosis: In clinical practice there is a wide variety of algorithms to classify and quantify PFD, which comprises more or less structured questions and clinical examinations. The International Urogynecological Association (IUGA) and the International Continence Society (ICS) have produced a joint report on the terminology on female pelvic floor dysfunction³⁵, which includes over 250 separate definitions. For research purposes, it is important to indicate which diagnostic criteria have been used. Many investigators have defined their own diagnostic criteria based on questionnaires or single questions. The ideal is to use a validated tool for diagnosis (and quantification) of PFD.

In Norway the **severity index** has been validated for diagnosing UI⁴⁰. The severity index has also been validated against international questionnaires for UI⁴¹. For AI/FI, the **St. Marks score** has been used in previous studies also in Norway⁴². A symptom–bother questionnaire for sPOP concerning frequency of mechanical, bladder, bowel and sexual problems was developed in Denmark by **Mouritsen et al**, and has been used in previous studies in Norway⁴³. The scales referred above are scales used for diagnosis of single PFDs. There are few diagnostic systems that provide a series of questionnaire modules to assess pelvic problems with validated international standard questionnaires for lower urinary tract dysfunction, vaginal symptoms and lower bowel dysfunction. One such system is the **International Consultation on Incontinence Modular Questionnaire (ICIQ)**, which comprises questionnaire modules for POP, UI and FI⁴⁴⁻⁴⁶. Only the UI part has been validated for use in Norway⁴¹. Another system, which seems to be more widely used, is the **Pelvic floor distress inventory (PFDI)**, comprising subscales for prolapse (POPDI), urinary- (UDI) and anal/fecal incontinence and bother (CRADI) and the **Pelvic Floor Impact Questionnaire (PFIQ)**⁴⁷. This has previously been used by other Norwegian investigators, and is currently being validated for use in Norway. The PFDI has been developed in women with pelvic floor disorders and not in women from the normal population.

Prevalence: Estimates of the prevalence of PFD varies widely depending on definitions, epidemiological method used and study population ³⁶. The prevalence is reported to be 3-12% for sPOP, 15-35% for UI and 3-14% for FI ^{37-39, 48-51}.

2.3 Pelvic organ prolapse

Pelvic organ prolapse (POP) is defined as a downward descent of the pelvic organs that results in a protrusion of the vagina and or uterus⁵². Figure 9 and 10 illustrate different types of prolapse. Commonly used terms to describe specific sites of female genital prolapse include⁵³:

Anterior compartment prolapse: Herniation of the anterior vaginal wall. This is usually associated with descent of the urinary bladder (cystocele).

Posterior compartment prolapse: Herniation of the posterior vaginal wall. This is often associated with descent of the rectum (rectocele) or an enterocele, hernia of the intestines, through the vaginal wall.

Apical or middle compartment prolapse: Descent of the apex of the vagina into the lower vagina, to the hymen, or beyond the vaginal introitus. The apex can be both the uterus and cervix, the cervix alone, or the vaginal vault after previous hysterectomy. Apical prolapse is often associated with enterocele.

Uterine procidentia: Complete herniation of the uterus, and of all three compartments through the vaginal introitus.

The terms anterior vaginal wall prolapse and posterior vaginal wall prolapse are preferred to cystocele and rectocele because vaginal topography does not reliably predict the location of the associated viscera in POP^{53, 54}.

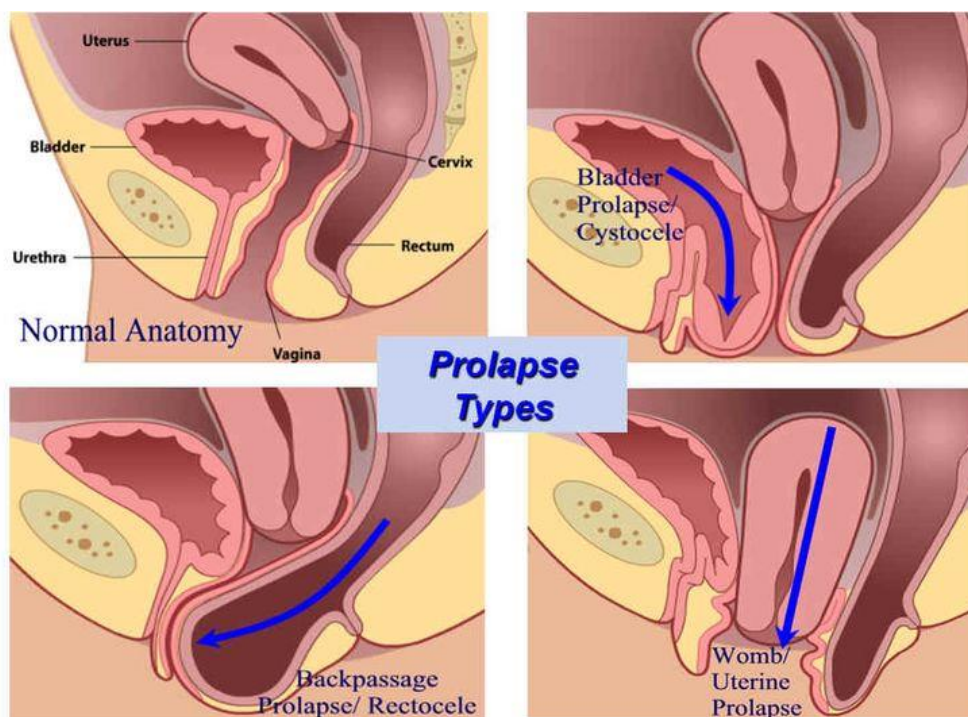


Figure 9 Schematic illustration of different types of prolapse.

From:
[http://www.bendandmen
d.com.au/physiotherapy
/pop-pelvic-organ-
prolapse/](http://www.bendandmen d.com.au/physiotherapy /pop-pelvic-organ- prolapse/)

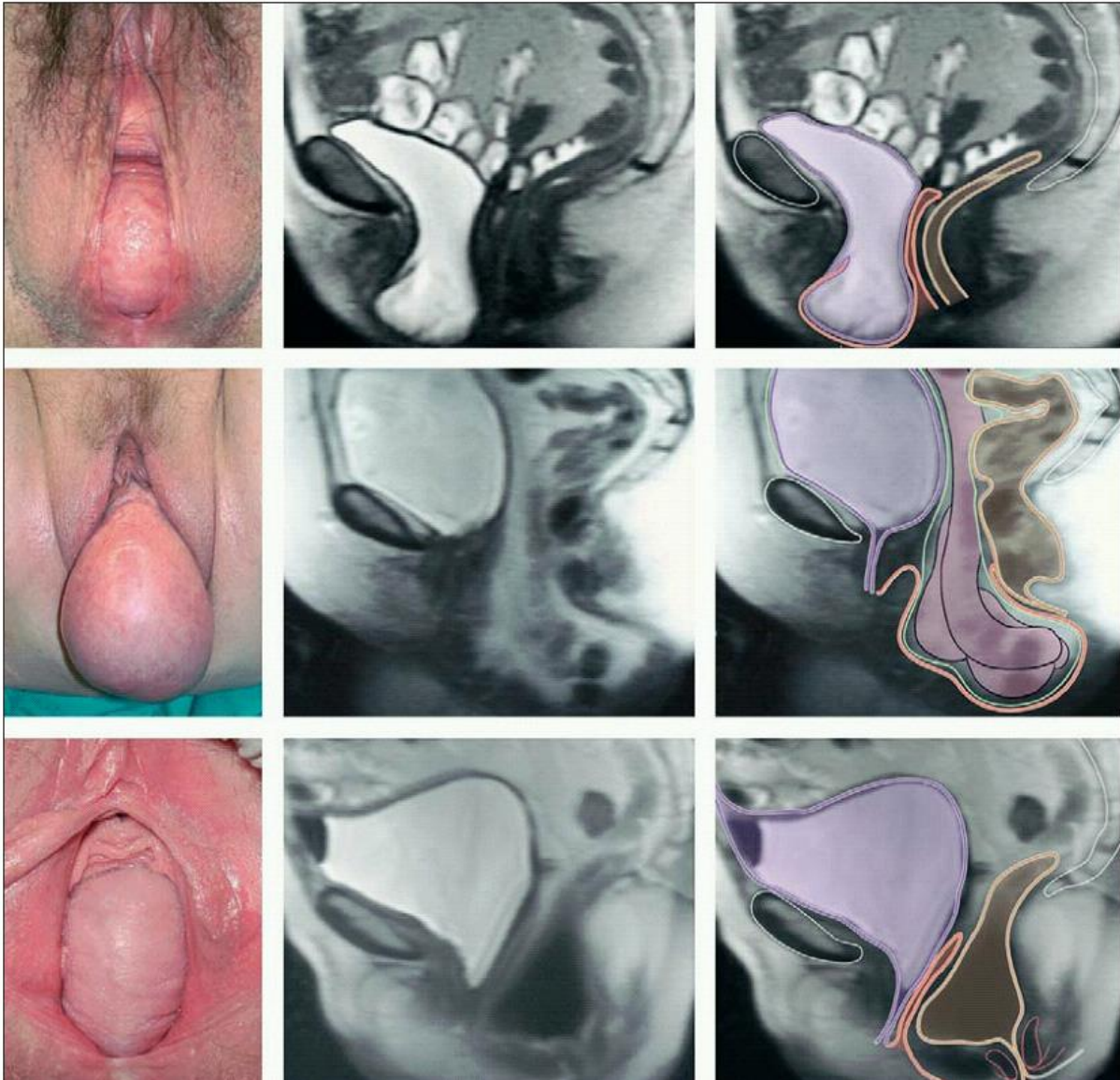


Figure 10 Photographs in lithotomy position and sagittal MRI showing vaginal-wall prolapse. Prolapse might include (top to bottom): bladder (cystocele), small bowel (enterocele), or rectum (rectocele). Colour codes include purple (bladder), orange (vagina), brown (colon and rectum), and green (peritoneum).

From Jelovsek et al 2007: Pelvic organ prolapse, with permission from Elsevier

Diagnosis: Since 1996 there has been a standardization of terminology of POP quantification (POP-Q)⁵³. This standardized terminology requires the description of six points (two on the anterior vaginal wall, two in the superior vagina, and two on the posterior vaginal wall) with reference to the plane of the hymen, thus a quantification of prolapse at straining in each compartment separately, see Table 3 and Figure 11. Positions are expressed as centimeters above or proximal to the hymen (negative number) or centimeters

below or distal to the hymen (positive number) with the plane of the hymen being defined as zero. In addition to the points in the vagina, three lengths are measured (Table 3 and figure 6).

POP-Q provides a staging of POP according to the most severe portion of the prolapse when the full extent of protrusion is demonstrated: Stage 0 (no prolapse demonstrated), stage 1 (most distal part of the prolapse >1 cm above the hymen) stage 2 (most distal part of the prolapse \leq 1 cm above or below the plane of the hymen), stage 3 (most distal part of the prolapse >1 cm below the hymen) and stage 4 (complete eversion of the vagina and uterus).

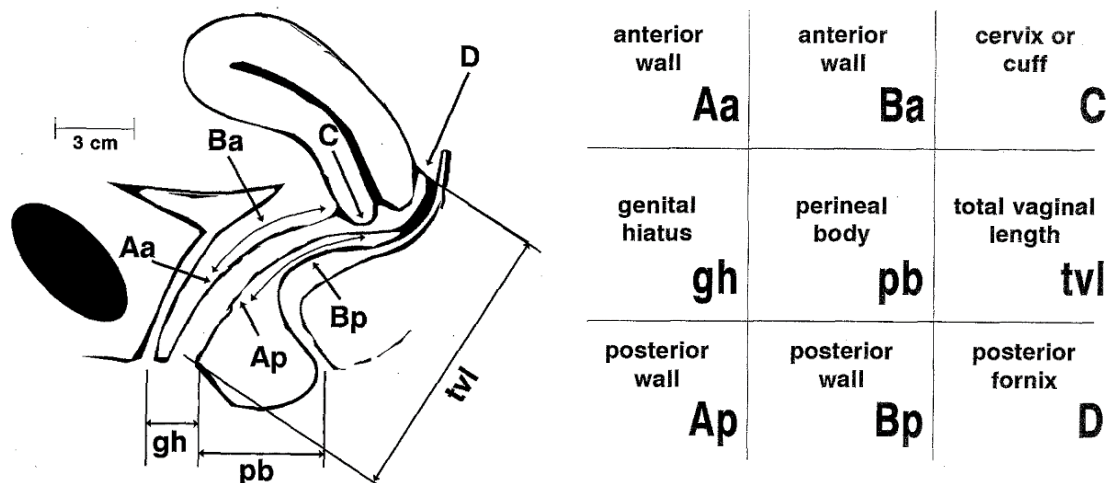


Figure 11 Six points (Aa, Ba, C, D, Ap, Bp) and three lengths (gh, pb, tvl) measured for pelvic organ prolapse quantification.

From Bump et al 1996: *The standardization of terminology of female pelvic organ prolapse and pelvic floor dysfunction*, with permission from Elsevier.

Prevalence: The prevalence of anatomical prolapse depends on the definition used. Commonly used definitions for significant prolapse are prolapse to or beyond the plane of the hymen⁵⁵ or prolapse stage 2, which also includes prolapses that descend to 1 cm above the hymen⁵⁶. The prevalence is reported to vary between 2-63% in different populations⁵⁵⁻⁵⁹. Cystocele is most frequent, followed by rectocele and uterine prolapse⁵⁹.

Table 3 Points and measurements included in the standardized terminology of pelvic organ prolapse quantification (POP-Q)

Two points are on the <i>anterior vaginal wall</i>	
Aa	A point located in the midline of the anterior vaginal wall 3 cm proximal to the external urethral meatus. By definition, the range of position of point Aa relative to the hymen is -3 to +3 cm
Ba	A point that represents the most distal position of any part of the upper anterior vaginal wall from the vaginal cuff or anterior vaginal fornix to point Aa. By definition, point Ba is at -3 cm in the absence of prolapse and would have a positive value equal to the position of the cuff in women with total posthysterectomy vaginal eversion
Two points are in the <i>superior vagina</i> . These points represent the most proximal locations of the normally positioned lower reproductive tract	
C	A point that represents either the most distal edge of the cervix or the leading edge of the vaginal cuff (hysterectomy scar) after total hysterectomy
D	A point that represents the location of the posterior fornix (or pouch of Douglas) in a woman who still has a cervix.
Two points are on the <i>posterior vaginal wall</i>	
Bp	A point that represents the most distal position of any part of the upper posterior vaginal wall from the vaginal cuff or posterior vaginal fornix to point Ap. By definition, point Bp is at -3 cm in the absence of prolapse and would have a positive value equal to the position of the cuff in a woman with total posthysterectomy vaginal eversion.
Ap	A point located in the midline of the posterior vaginal wall 3 cm proximal to the hymen. By definition, the range of position of point Ap relative to the hymen is -3 to +3 cm
Three lengths are measured	
Gh	Length of the genital hiatus from urethra to posterior border of hymen expressed in cm
pb	Length of the perineal body from posterior border of hymen to the anus expressed in cm
tvL	Total vaginal length measured from the posterior fornix or vaginal cuff to the hymen

Symptoms: Many women with anatomical prolapse are asymptomatic. The most common and most specific symptom of prolapse is a sensation of pelvic pressure/ heaviness or seeing/ feeling a protrusion of tissue from the vagina ⁵². The proportion of women reporting symptom of vaginal bulge increases with increasing prolapse grade ⁶⁰. Other typical, but not specific, symptoms of POP are urinary tract symptoms and symptoms related to bowel function, listed in Table 4 ^{52,53}. Symptoms do not necessarily correlate with compartment-specific defects, and increasing severity of pelvic organ prolapse is weakly to moderately associated with symptoms that are related to urinary incontinence and voiding, defecatory, and sexual dysfunction ^{61,62}. Common symptoms related to pelvic organ prolapse are listed in Table 4.

Table 4 Symptoms related to pelvic organ prolapse

Vaginal symptoms
Seeing and or feeling a vaginal bulge
Pelvic pressure and heaviness
Urinary tract symptoms
Incontinence
Frequency
Urgency
Weak or prolonged urinary stream
Hesitancy
Feeling of incomplete emptying
Manual reduction of prolapse to start or complete voiding
Position change to start or complete voiding
Bowel symptoms
Incontinence of flatus, or liquid or solid stool
Feeling of incomplete emptying
Straining during defecation
Urgency to defecate
Digital evacuation to complete defecation
Splinting, pushing on or around the vagina/perineum, to start or complete defecation
Feeling of blockage or obstruction during defecation
Sexual symptoms
Dyspareunia
Mechanical problems

2.4 Pelvic floor muscle trauma

Three major groups of pelvic floor muscle trauma (PFMT) are described: Macrotrauma /levator avulsion, levator microtrauma and obstetric anal sphincter injuries (OASIS).

2.4.1 Macrotrauma - levator avulsion

Levator avulsion is defined as an injury to the inferomedial aspects of the pubovisceral/puborectalis muscle, that is a detachment of this muscle from its insertion on the arcus tendineus fasciae pelvis, see Figure 12 ^{63,64}.

Levator avulsion was first described by Gainey in 1943, and originally diagnosed by palpation ⁶⁵. In some cases it is possible to diagnose levator avulsions by inspection and palpation immediately after delivery ⁶⁶, but a tear of the puborectalis muscle does not necessarily involve injury to the vaginal mucosa, and is therefore usually not detected immediately after delivery ⁶⁶. An avulsion injury can be unilateral or bilateral, complete or incomplete. Levator avulsion can be diagnosed by ultrasound using the TUI mode or on MRI ^{23, 64, 67, 68}, see Figure 13 and 14.

When, on 3D ultrasound, all three central slices (in the plane of minimal hiatal distension and 2.5-5.0 mm cranial to this) on TUI show abnormal muscle insertion, the levator avulsion is defined as *complete*, see Figure 13. Measurement of the levator-urethral gap can be used when there is doubt about avulsion diagnosis, as it has been demonstrated that a distance >25 mm between the center of the urethra and the levator insertion on the symphysis is strongly associated with levator avulsion ⁶⁹. It is also possible to use palpation to detect avulsion several years after delivery ⁶⁷, and a measurement of Gh + Pb >8.5cm could help identify women with levator avulsion ⁷⁰.

Prevalence: The prevalence of levator avulsion is different after different modes of delivery. It does not occur after Cesarean delivery (CD). The prevalence is 6-20% after Normal vaginal delivery (NVD) ^{71,72}, 9-41% after Vacuum delivery (VD) ^{71,73} and 35-89% after forceps delivery (FD) ^{71,73}.

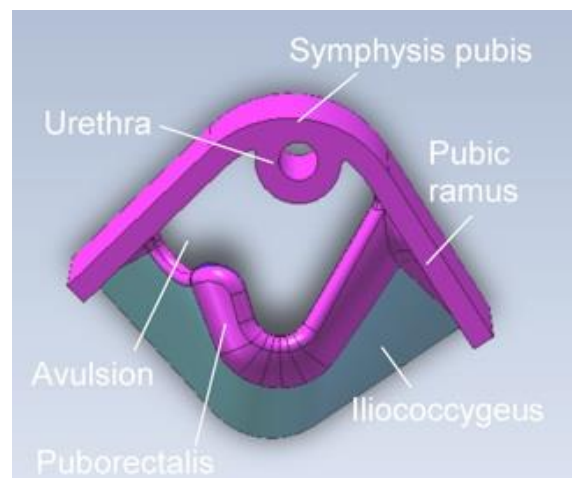


Figure 12 Schematic illustration of levator avulsion.

From:

http://sydney.edu.au/medicine/nepean/research/obstetrics/pelvic-floor-assessment/Pelvic_Floor_Assessment/Klinische_Untersuchung_des_Levator_Ani.html

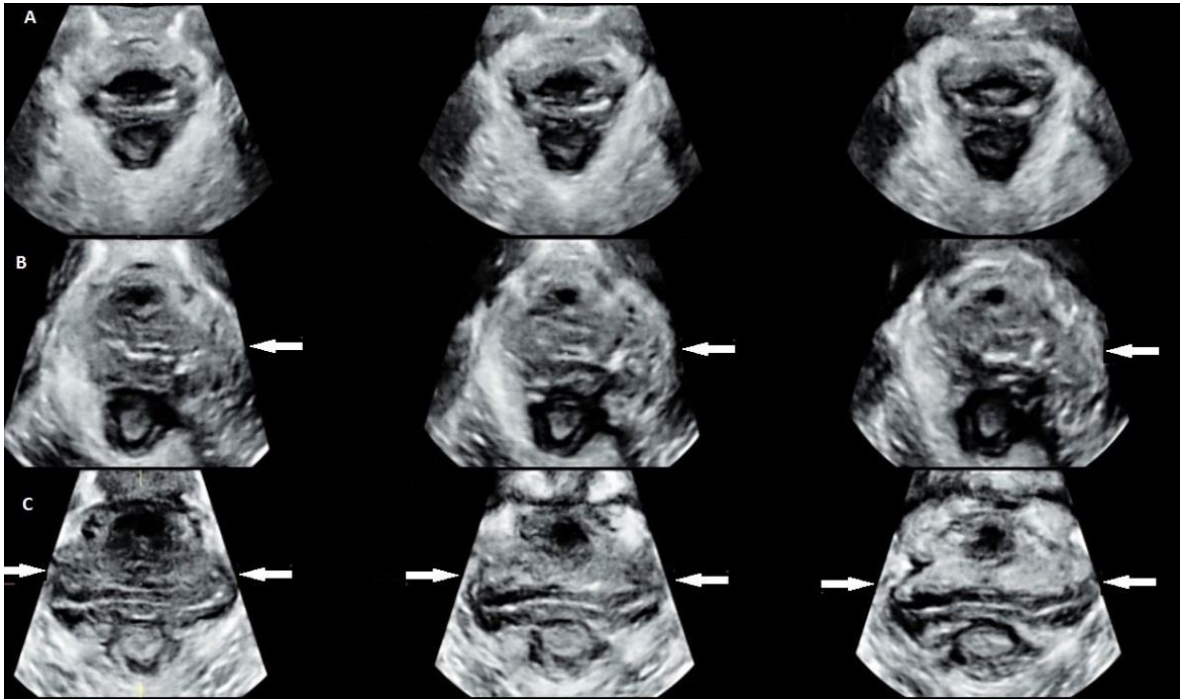


Figure 13 Tomographic Ultrasound Imaging. Levator avulsion is indicated by arrow. A) Intact levator, B) unilateral and C) bilateral avulsion in the three central planes on ultrasound. From Volløyhaug et al 2015: Forceps is associated with increased risk of pelvic organ prolapse and muscle trauma, with permission from John Wiley and sons. Copyright © 2015 ISUOG.

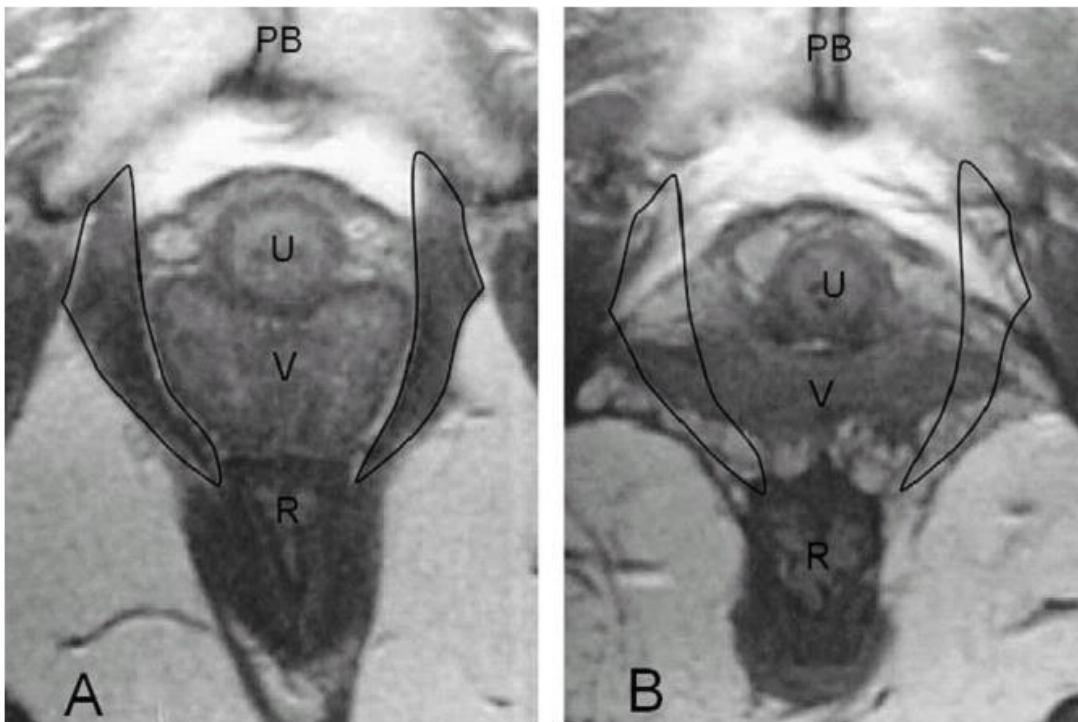


Figure 14 Axial Magnetic Resonance Image on left shows normal pubococcygeal muscle with the muscle outlined at the level of the midurethra. On the right is a similar image from a woman with complete loss of the pubococcygeal muscle (expected location of pubococcygeal muscle shown by outline).

From DeLancey 2005: The hidden epidemic of pelvic floor dysfunction: Achievable goals for improved prevention and treatment, with permission from Elsevier. Copyright © 2005 Elsevier

2.4.2 Microtrauma and abnormal distensibility

Diagnosis of microtrauma and abnormal distensibility of the levator hiatus requires examination of the patient when performing a Valsalva maneuver, i.e. performing a moderately forceful exhalation against a closed airway with simultaneous relaxation of the pelvic floor with a minimum of 6s duration⁷⁴.

Levator microtrauma is defined as >20% increased hiatal area on Valsalva after delivery on ultrasound⁷³, and examination of women both prior to and after delivery is necessary.

Diagnosis of abnormal distensibility has been described as “ballooning” of the levator hiatus at Valsalva on ultrasound, and requires examination at only one time point⁷⁵. A hiatal area on Valsalva of 25–29.9 cm² has been defined as ‘mild’, 30–34.9 cm² as ‘moderate’, 35–39.9 cm² as ‘marked’ and ≥ 40 cm² as ‘severe’ ballooning or overdilatation⁷⁵.

Both definitions describe increased distensibility of the levator hiatus, either in relation to a previous measure in the same individual, or to a reference population. A levator avulsion contributes to increased levator hiatal area, but women can have increased hiatal areas without levator avulsion³⁰. Figure 15 demonstrates the difference in levator hiatal areas at rest, contraction and Valsalva in three different women: one with intact levator, one with unilateral avulsion and one with bilateral avulsion.

MRI can also be used to measure levator hiatal areas³². An easier way to diagnose, but not quantify, overdilatation is by palpation of a wide hiatus, or by measuring the Gh+Pb distance at Valsalva, where a cutoff of 7 cm for Gh+Pb has been proposed as a clinical definition of excessive levator hiatal distensibility⁷⁶.

Prevalence: The prevalence of hiatal overdilatation depends on the cutoffs used, and in the literature hiatal areas are usually described as continuous variables. When applying >20% peripartum increase in hiatal area on Valsalva as the cutoff, 29% of vaginally parous women were diagnosed with irreversible overdilatation in a previous study⁷³. By applying cut offs for ballooning previously established, 12% had mild ballooning and 4% had severe ballooning of the levator hiatus⁷⁵.

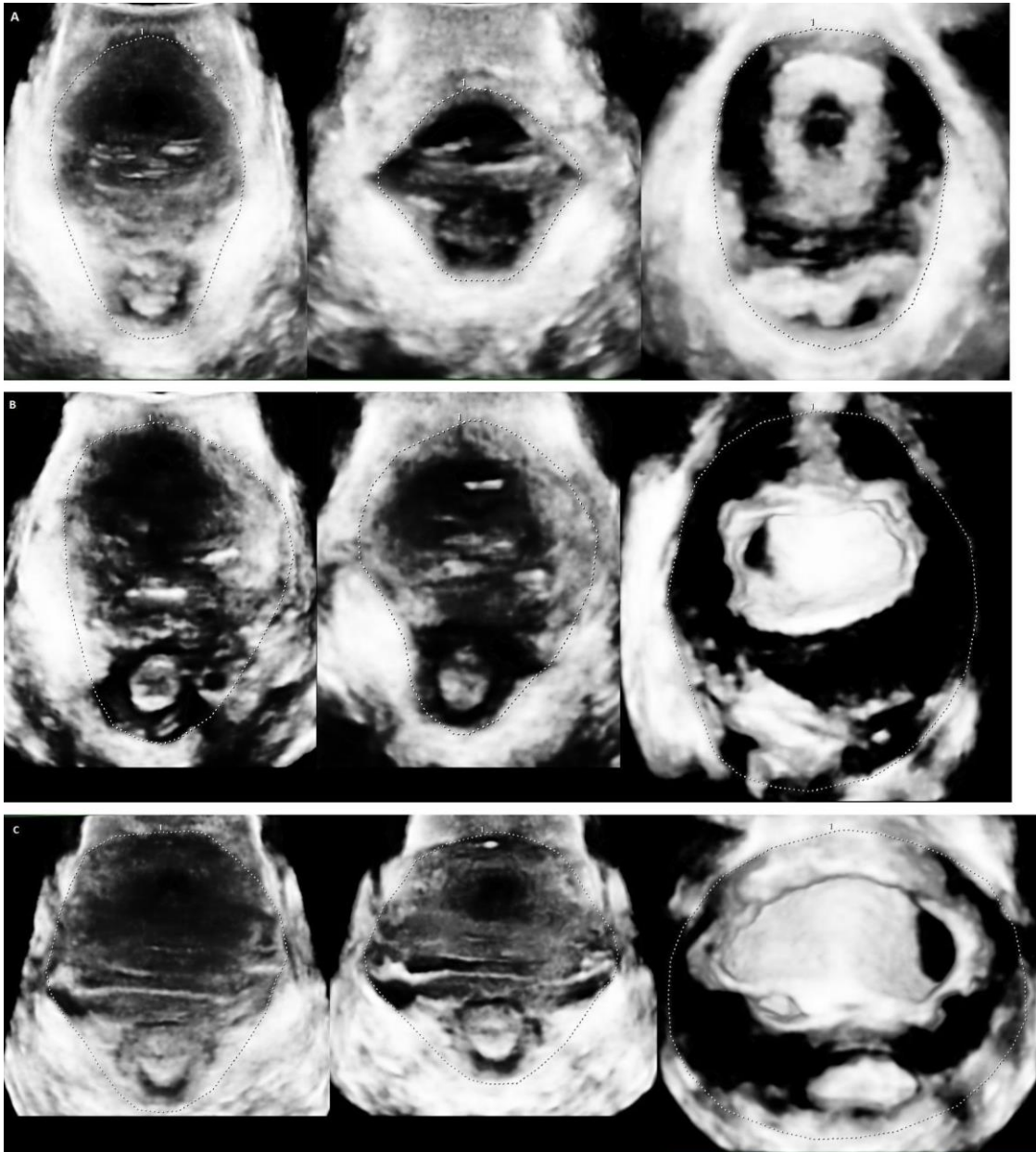


Figure 15 Hiatal areas at rest, pelvic floor muscle contraction and Valsalva maneuver in women with a) intact levator (19.7 cm^2 , 9.6 cm^2 , 23.8 cm^2) b) unilateral avulsion (27.3 cm^2 , 19.8 cm^2 , 46.1 cm^2) and c) bilateral avulsion (27.3 cm^2 , 25.6 cm^2 , 47.3 cm^2)

From Volløyhaug et al 2015: Forceps is associated with increased risk of pelvic organ prolapse and muscle trauma, with permission from John Wiley and sons. Copyright © 2015 ISUOG.

2.4.3 Obstetric anal sphincter injuries

OASIS are tears of the external and/or internal anal sphincters. OASIS are defined as grade three or four perineal tears, according to the extent of the injury ⁷⁷. A third degree tear is a disruption of the anal sphincter muscles, and is further subdivided into 3a: <50% thickness of external sphincter torn, 3b: >50% thickness of external sphincter torn, 3c: external and internal sphincter torn. A fourth degree tear is a third degree tear with disruption of the anal epithelium.

OASIS are usually diagnosed immediately after delivery by palpation and inspection. Transanal ultrasound has traditionally been used to detect defects in the sphincters ⁷⁸, but more recently transperineal ultrasound has become a diagnostic tool ⁷⁹, see Figure 16. Some authors have described occult OASIS, which is sphincter tears that are *not* diagnosed immediately after delivery, but visible on ultrasound examination in distance from delivery ⁸⁰. Defects in the sphincters may also persist after correct diagnosis and proper suturing and are evident by ultrasound ⁸¹.

Prevalence: OASIS only occurs in women with vaginal deliveries, and the prevalence of OASIS differs in different countries. In Norway the occurrence of obstetric anal sphincter injuries increased from 0.5% in 1967 to 4.1% in 2004, and was higher after operative vaginal deliveries (OVD) compared to NVD ⁸². Studies on occult OASIS have shown a prevalence of 20% after NVD and close to 50% after OVD, with higher prevalence after FD than VD ⁸³.

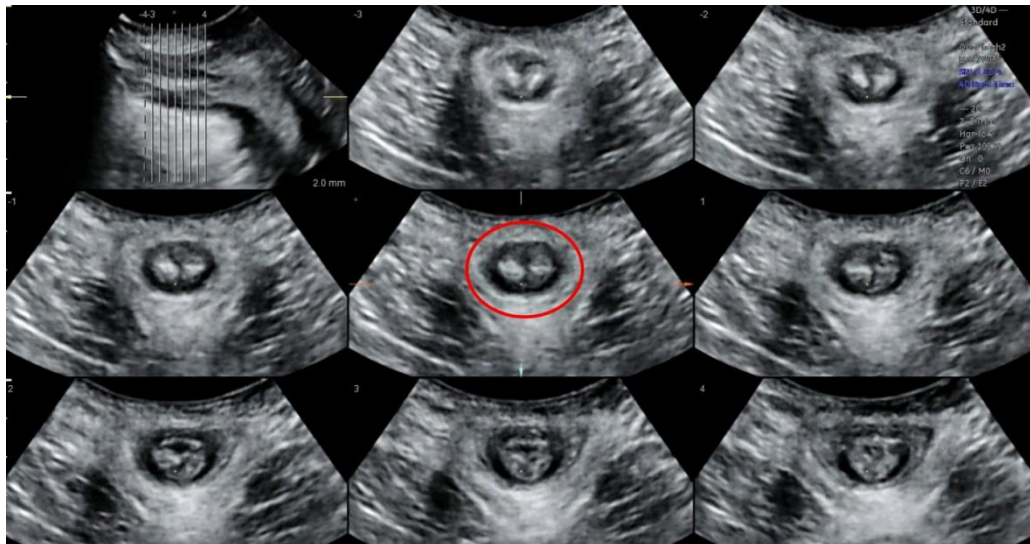


Figure 16 Tomographic ultrasound imaging (TUI) of the anal sphincters. The external anal sphincter is outlined with the circle. The internal anal sphincter is the darker ring structure, and the white structure in the middle is the anal mucosa. Imaging by Volløyhaug.

2.5 Birth mechanics

2.5.1 Muscle stretch during vaginal delivery

The pelvic floor undergoes remarkable changes to allow a baby to be passed down the birth canal. When assuming the average diameter of the molded fetal head is 9 cm, then the cross-sectional area is approximately 63 cm²⁸⁴. This means that a great enlargement of the levator hiatus, which measures 12-16 cm² in pregnant women, is needed during delivery. A computer model has been used to quantify pelvic floor muscle stretch induced during the second stage of delivery as a model fetal head progressively engaged and then stretched the levator ani muscles⁸⁵, see Figure 17. This showed that the medial part of the levator ani muscles undergoes the largest stretch during vaginal birth. These muscles are therefore at the greatest risk for stretch-related injury⁸⁵.

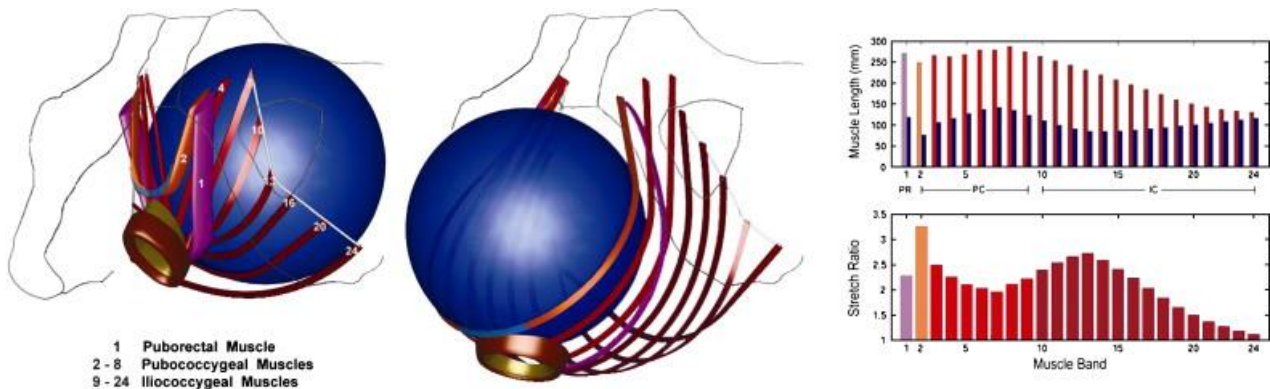


Figure 17 Left, computer model of selected levator ani muscle bands before birth with muscle fibers numbered and the groups identified middle, muscle band lengthening present at the end of the second stage of labor; right, graphic representation of the original and final muscle (top) and the stretch ratio (bottom), indicating the degree to which each muscle band must lengthen to accommodate a normal sized fetal head.

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2.5.2 Episiotomy

The reason to perform an episiotomy is to prevent perineal trauma and in particular anal sphincter tears. There are two ways of making an episiotomy; medial and mediolateral. The mediolateral episiotomy is associated with less OASIS, and is commonly recommended⁸⁶. The anatomical structures incised when performing a mediolateral episiotomy include the vaginal epithelium, transverse perineal and bulbocavernosus muscles, and perineal skin⁸⁷, see Figure 18. The major advantage of the mediolateral episiotomy is that the surgical incision is

directed away from the maternal anal sphincter, thereby partially protecting the sphincter and the rectum from injury due to extension. The levator ani muscles are not incised when performing an episiotomy. Restrictive use of episiotomy is probably better than routine episiotomy, associated with less AI and local symptoms⁸⁸. Episiotomy may extend into a anal sphincter tear or a deep vaginal tear, which can include the levator ani.

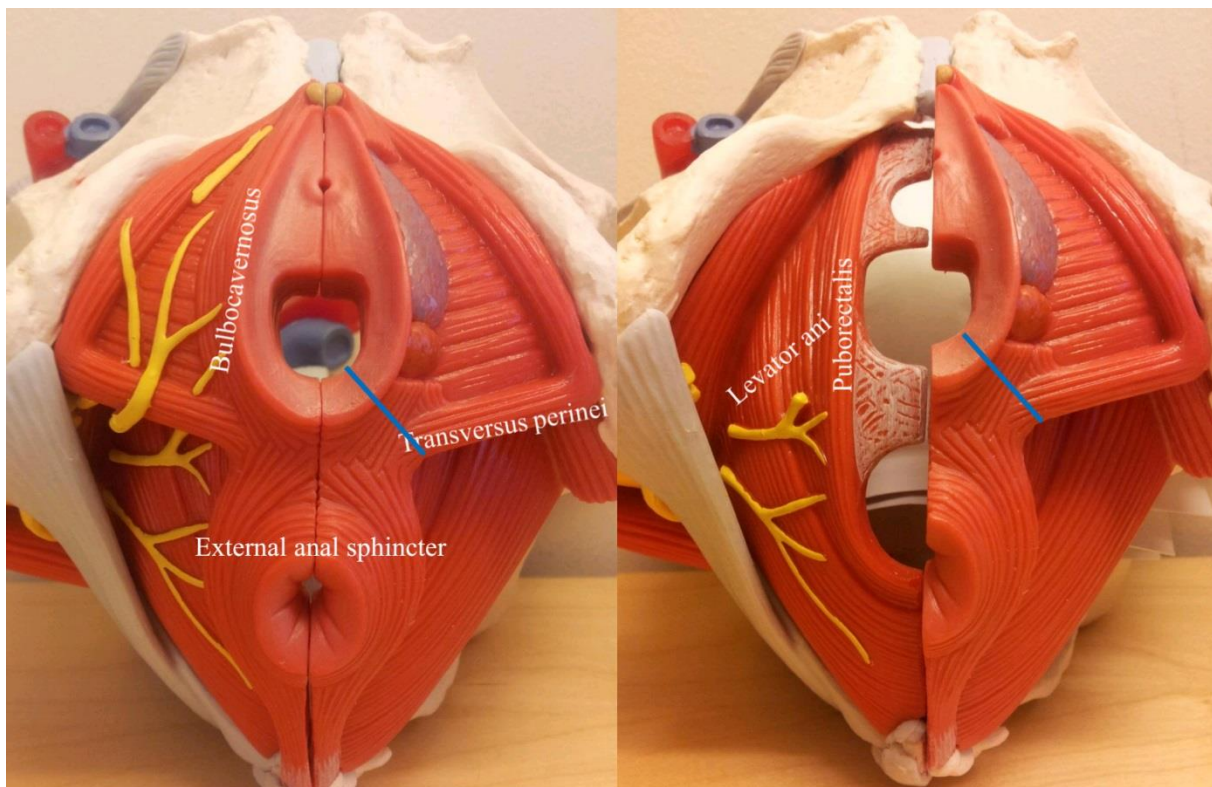


Figure 18 The anatomical structures incised when performing a mediolateral episiotomy include transverse perineal and bulbocavernosus muscles, but not the levator ani muscles. Photo of a female pelvis model from 3B Scientific® by Volløyhaug.

2.6 Patophysiology –risk factors

2.6.1 Pelvic floor disorders in association to obstetric and non obstetric risk factors

PFD prevalence increases with advancing age, obesity, parity and is different for different ethnic groups^{37-39, 48-52, 89-92}. Congenital malformations such as spina bifida and urinary bladder extrophy predispose to PFD⁹³, and connective tissue disorders such as Marfan or Ehler Danlos syndrome are risk factors⁹⁴. Heridity could play a role, and women are more likely to develop urinary incontinence if their mother or older sisters are incontinent⁹⁵.

Pregnancy, and in particular childbirth are risk factors for PFD, and mode of delivery is associated with the prevalence of PFD. Previous studies have shown that CD is associated with lower prevalence of PFD in later life, and some studies have suggested that OVD is associated with increased prevalence of prolapse and incontinence^{39, 89, 90, 96-99}. Increased risk after OVD is controversial, and the distinction between FD and VD had only been made in few studies prior to 2013 and mainly with focus on FI short time after delivery^{78, 100-102}. It was not stated whether doctors were equally trained in both methods in these studies.

In the Tables 5-7 both established and potential or controversial risk factors for each PFD, based on information from UpToDate[®] prior to the start of our study in 2013 are listed^{103, 104}. It was well known that pelvic floor disorders were associated with pregnancy and child birth, nevertheless it was stated that “the available literature cannot distinguish the effects of pregnancy from the effects of child birth”¹⁰⁴.

Obesity is the strongest risk factor for incontinence^{37, 105}. The strongest risk factors for POP are parity, advancing age and obesity⁵². Anal and fecal incontinence is usually multifactorial (dysfunction in anal sphincters, abnormal rectal compliance, decreased rectal sensation, altered stool consistency)¹⁰⁶. It is therefore difficult to state one main risk factor for AI/FI. OASIS is one important risk factor for anal sphincter weakness in women. Advancing age, obesity and pregnancy, regardless of delivery mode, are common risk factors for all PFD. Parity is a stronger risk factor for POP than for UI, as demonstrated in Figure 19¹⁰⁷.

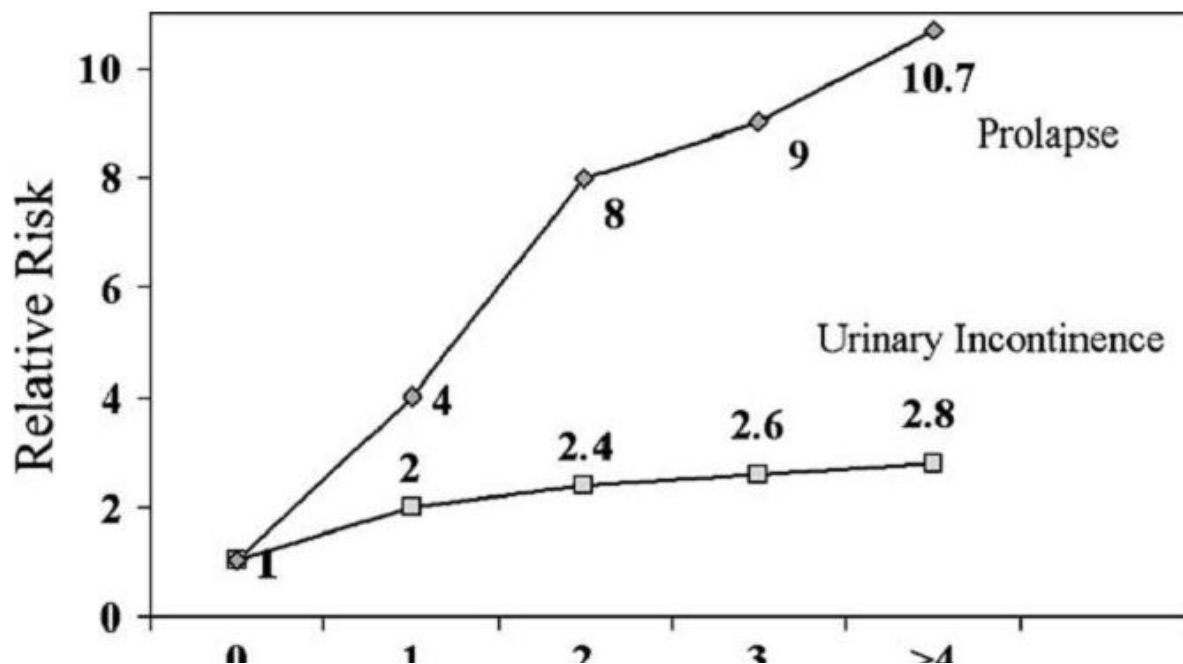


Figure 19 Graph of the effect of vaginal parity on the development of urinary incontinence and pelvic organ prolapse.

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Table 5 Risk factors for urinary incontinence

Established risk factors for UI:	
Obesity	37, 38, 90, 92, 105, 108-114
Parity	37-39, 97, 110, 114
Delivery mode	90, 96, 97, 99, 109, 110
Age	37-39, 51, 110, 112, 114, 115
Family history	95, 115
Potential/controversial risk factors for UI:	
Ethnicity	38, 91, 111, 112
Coffein	113
Smoking	38, 113, 116
Diabetes	38, 108
Surgery/ hysterectomy	38, 112, 117
HRT	38

Table 6 Risk factors for symptomatic and anatomic pelvic organ prolapse

Established risk factors for POP	
Parity	37, 38, 48, 55, 57-59, 89, 98, 118-121
Delivery mode	52, 58, 89, 90, 96, 98-100, 119, 121
Age	37, 48, 52, 55, 56, 58, 59, 89, 90, 118, 119, 121
Obesity	52, 56, 59, 118, 119, 121
Potential/controversial risk factors for POP	
Chronic constipation	120
Congenital malformations/ connective tissue disorders	93, 94 55-58
Infant birth weight	37, 38, 56, 59, 120, 121
Ethnicity	56
Heavy lifting	122
Family history	58, 59, 123
Hysterectomy	

Table 7 Risk factors for fecal incontinence

Established risk factors for FI	
Age	37, 38, 49, 50, 109, 110
Obesity	50, 108-110, 124, 125
Lung disease	124
Irritable bowel, diarrhoea	49, 124, 126
UI	49, 109, 124-126
Delivery mode	81, 90, 96, 101, 110, 125, 127
OASIS	81, 109, 128-130
Potential/controversial risk factors for FI	
Ethnicity	37, 49, 90, 109, 124, 126
Parity	49, 50, 110
Menopause	50
Episiotomy	88, 100

2.6.2 Levator trauma in association to obstetric risk factors

Vaginal delivery is the main risk factor for PFMT^{63, 131, 132}. Levator avulsion injury may occur during normal vaginal delivery, and forceps delivery carries higher risk of trauma to the pelvic floor muscles compared to normal vaginal delivery^{71-73, 133-138}. There were only few studies indicating prevalence of **levator avulsions** separately after FD and VD prior to 2013^{71, 73, 134, 138}. Few women with FD or VD were included, ranging from a minimum of 12 to a maximum of 48 in each delivery group (Kearney 2006: 18 FD 12 VD, Shek 2010: 20 FD 34VD, Eisenberg 2011: 27 FD 17 VD, Chan 2012: 14 FD 48 VD), and they had a short follow up of maximum one year. Previous studies had also found that **hiatal areas** were increased after forceps delivery^{73, 136, 137}, but not vacuum⁷³, but also for hiatal areas there was a lack of direct comparison between FD and VD prior to 2013. Other factors related to vaginal delivery are listed in Table 8.

Table 8 Risk factors for pelvic floor muscle trauma

Established risk factors	
Vaginal delivery	30, 63, 131, 132
Potential/controversial risk factors	
Mode of vaginal delivery	71-73, 133-138
High infant birth weight and head circumference	73
Epidural, protective effect?	73, 134
Prolonged 2 nd stage	72, 73, 134
Oxytocin	73, 134
Episiotomy, protective or aggravating effect?	73, 134
High maternal age at delivery	134, 136

2.6.3 Levator trauma in association to symptoms and signs of pelvic organ prolapse

PFMT diagnosed by ultrasound and MRI is a risk factor for POP^{23, 68, 75, 133, 139-143}, but previous studies on association between PFMT and POP have only been conducted in urogynecological patient populations or among women a few months after delivery^{23, 68, 75, 133, 139-143}. POP usually occurs several years after delivery. We found no studies confirming the association between PFMT and POP among healthy women several years after delivery.

2.6.4 Summary of risk factors for pelvic floor disorders, pelvic organ prolapse and pelvic floor muscle trauma

Figure 20 illustrates the influence of risk factors on anatomical structures and anatomical (PMFT and POP) and functional consequences (PFD).

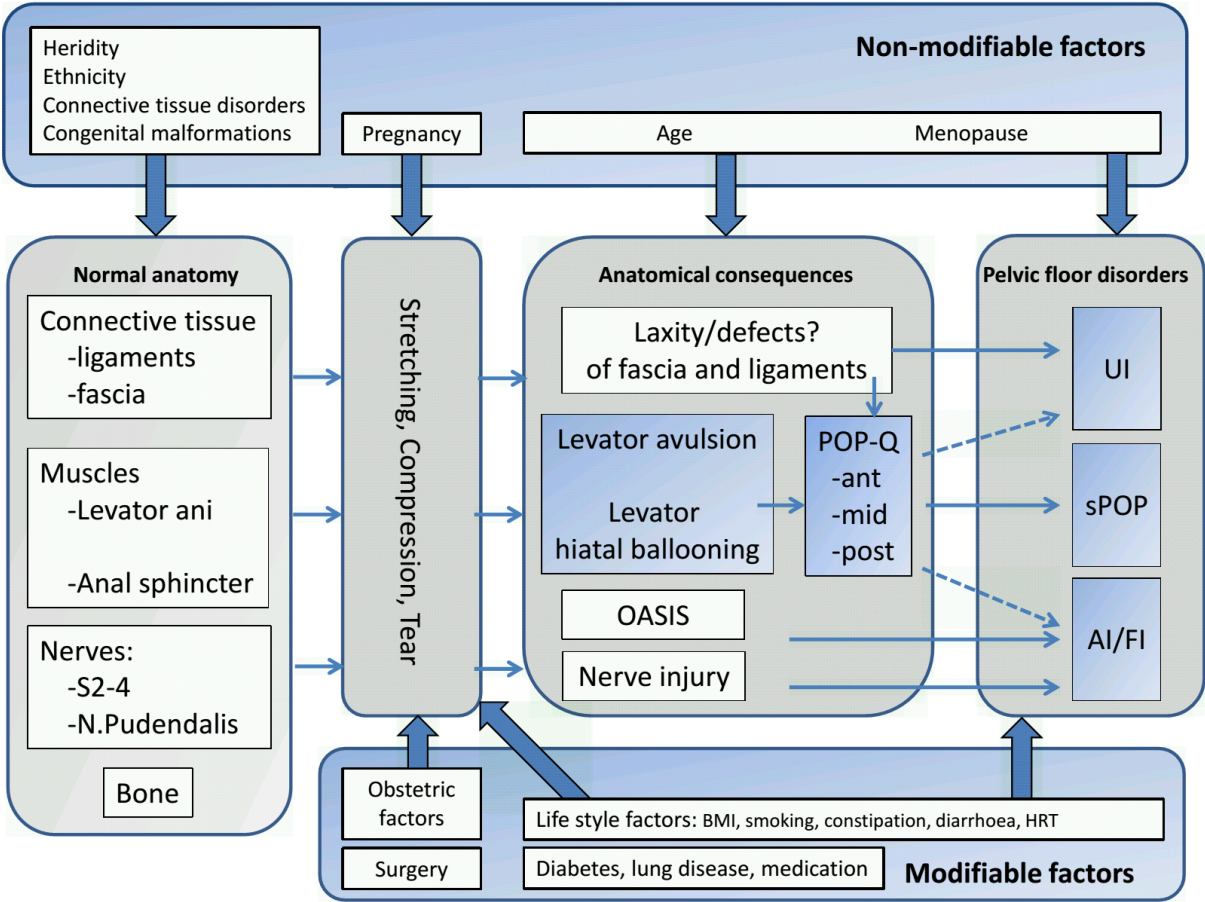


Figure 20 Schematic illustration of pelvic floor anatomy, modifiable and non-modifiable risk factors for pelvic floor muscle trauma (levator avulsion and levator hiatal ballooning), pelvic organ prolapse (POP-Q-ant,-mid,-post) and pelvic floor disorders (urinary incontinence (UI) symptomatic pelvic organ prolapse (sPOP) and anal/fecal incontinence (AI/FI). Volløyhaug 2015.

2.7 Gaps of knowledge

There is lack of studies on:

- 1) PFD in association to delivery mode, in particular with a distinction between FD and VD and many years after delivery.
- 2) PFMT and POP-Q in association to delivery mode in women from a normal population, in particular with a distinction between FD and VD. Previous studies have only been conducted on patient populations or puerperal women.
- 3) Association between PFMT, POP-Q and sPOP in women from a normal population. Previous studies have only been conducted on patient populations or puerperal women.
- 4) Quantification of changes in ultrasound parameters in relation to other validated scales for pelvic floor muscle contraction.

Studies comparing assessment of pelvic floor muscle contraction by ultrasound, digital assessment, and perineometry are sparse, and we have not found any validated scale for pelvic floor muscle contraction using ultrasound measurements.

3 Aims

3.1 General objectives

The main aim of the study was to explore the anatomical and functional status of the pelvic floor in women from a normal population 15-24 years after their first delivery, and to study a possible association to mode of delivery.

3.2 Specific objectives

3.2.1 Paper I

The aims were to study the association between PFD and mode of delivery and to calculate the risks of PFD comparing CD and OVD to NVD 15-23 years after child birth. A subgroup analysis comparing FD and VD was planned.

3.2.2 Paper II

The aims were to study possible associations between mode of delivery and POP-Q \geq 2 and PFMT 16-24 years after first delivery and in particular study differences between FD and VD.

3.2.3 Paper III

The aims were to establish the prevalence and investigate a possible association between PFMT and sPOP and POP-Q \geq 2 in women from the normal population 16-24 years after first delivery.

3.2.4 Paper IV

The aims were to study the correlation between palpation, perineometry and transperineal ultrasound for assessment of pelvic floor muscle contraction and to develop a contraction scale for ultrasound measurements.

4 Material and methods

4.1 Design

This was a cross sectional study of women who had their first delivery 15-24 years prior to data collection.

4.2 Participants

A total of 11185 women delivered their first baby at Trondheim University Hospital between January 1st 1990 and December 31st 1997. Women who were still alive and had postal address in Norway in 2013 were identified from the Hospital Patient Administrative System. We included all primiparous women with OVD or CD during 1990-97, and all primiparous women with NVD from 1 January to 1 July of each calendar year, to include a similar number of women with NVD stratified by year of first delivery. A total of 3268 women were invited to participate.

The reason for choosing women who delivered during this time period, was that doctors were performing FD and VD at approximately the same rate between 1990-97 (3-5% of all deliveries), and we assumed they were equally trained in both methods, see Figure 21. In addition, development of PFD and POP usually takes some time. A time interval of 15-24 years was considered sufficient.

Exclusion criteria were stillbirth, breech delivery and infant birth weight < 2000g at the index birth, but women were not excluded if these conditions occurred in subsequent pregnancies. Women were also excluded if Trondheim University Hospital was not their primary hospital at the index delivery.

We defined three main study groups: NVD, CD and OVD, and the OVD group was divided into FD and VD for subgroup analysis. Women were allocated to groups considering all their deliveries (the first delivery in 1990-97 and all subsequent deliveries) and were placed in the delivery group that was likely to have caused most harm to the pelvic floor: CD<NVD<OVD. Women in the CD group had only delivered by Cesarean section and never had a vaginal delivery. Women in the NVD group had at least one normal vaginal delivery (including deliveries with oxytocin augmentation, epidural analgesia, episiotomy and/or perineal tears) and other deliveries could be NVD or CD, but not OVD. A group of 195

women were allocated to the NVD group after previous CD. Women in the OVD group had delivered by either FD or VD, and other deliveries could be any mode of delivery (NVD, CD or OVD). In the subgroup analysis, we divided women into a FD group and VD group according to their first delivery. We excluded women with prior NVD (n=8) or CD (n=28) and women having had both vacuum and forceps (n=22), but not women with subsequent same type of OVD, NVD or CD.

The women invited to clinical examination belonged to four clearly defined delivery groups where delivery mode at first delivery defined delivery group: 1) CD only, 2) NVD at first delivery, and other deliveries could be NVD or CD, but not OVD, 3) FD at first delivery, subsequent deliveries could be FD, NVD or CD but not VD, and 4) VD at first delivery subsequent deliveries could be VD, NVD or CD but not FD.

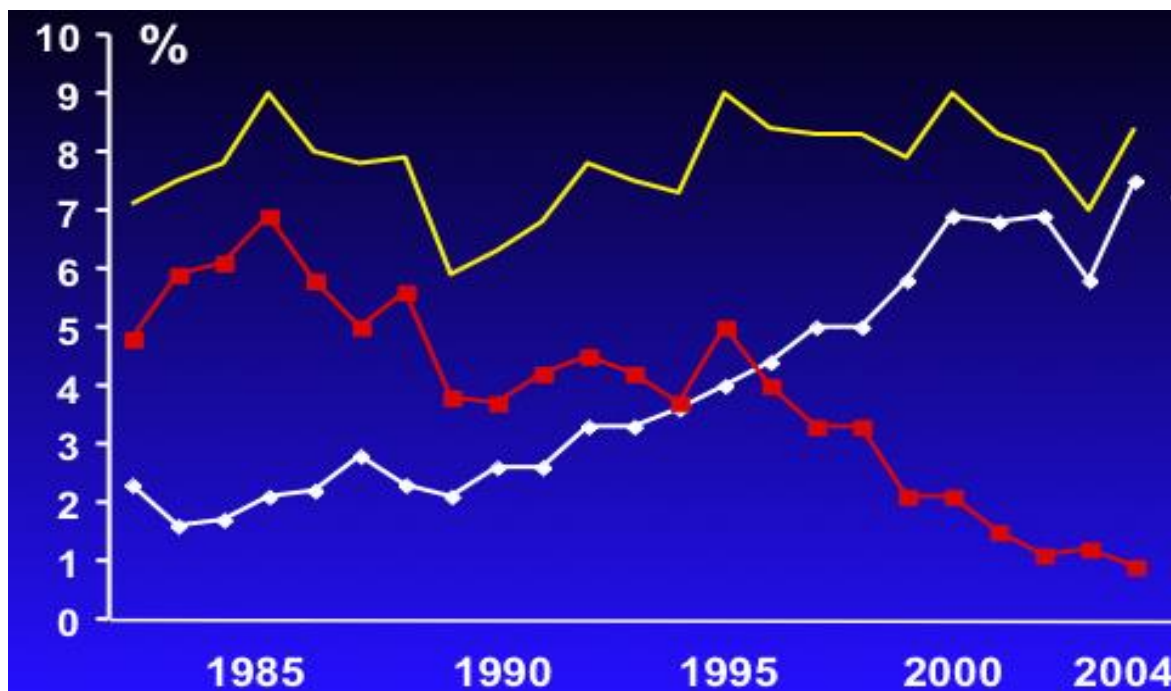
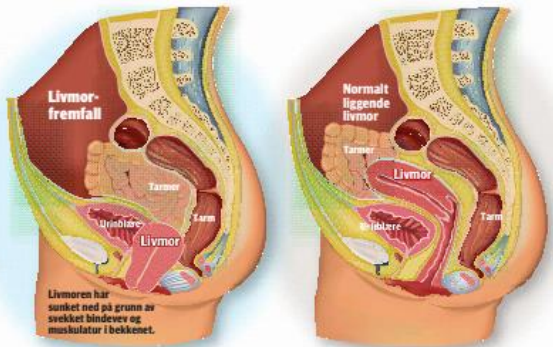


Figure 21 Prevalence of operative vaginal deliveries at Trondheim University Hospital 1984-2004, yellow line. Forceps prevalence in red line, and vacuum prevalence in white line. Data were collected from hospital records.

Personal communication from K.Å. Salvesen.



Fødsel påvirker tabu-sykdom

Urinlekkasje og livmor-fremfall rammer mer enn hver tiende kvinne. Nå vil forskere i Trondheim finne ut mer om hvordan de tabubelagte sykdommene kan forebygges.

– Vi vet at svangerskap og fødsel i seg selv er en risikofaktor, sier doktorgradstipendiat og overlege Ingrid Volloyhaug.

– Men vi vet lite om hvilke forhold ved fødselen som fører til at kvinnene kan komme til å utvikle livmor-fremfall eller urinlekkasje. Volloyhaug har sendt brev til 3000 kvinner som fødte sitt første barn ved St. Olavs Hospital (tidligere RIT) i perioden 1990–1997. Hun understreker at forskerne er interessert i kontakt både med kvinner som er plaget og de som ikke har merket noe.

Pinlig og hemmende

Mens det er velkjent at litt eldre kvinner ofte plaget av urinlekkasje, er livmor-fremfall mindre kjent. Det vil si at livmoren nærmest faller ned, og kan bli liggende på utsiden av skjeden. I begge tilfellene er det snakk om en lidelse som oppleves som både pinlig og hemmende.

– Som gynekolog ser jeg at mange kvinner sliter med disse plagene. Men det er et tabubelagt tema som en nødig snakker om. Derfor er det viktig å få frem kunnskap om hvordan sykdommen kan forebygges. Er for eksempel bruk av tang ved fødselen mer skadelig for bekkenbunnen enn sugekopp? Ofte kan vi fødselsleger velge metode, sier Volloyhaug.

Både urinlekkasje og fremfall av livmor, endetarm eller blære har sammenheng med at bekkenbunnen blir skadet eller svekket. Vanligvis opptrer plagene mange år etter fødselen.

Ulike fødselsmetoder

Deltakerne i studien vil bli delt inn etter hva slags fødselsmetode som ble brukt: keisersnitt, tang, vakuumsug eller normal, spontan fødsel.

Alle deltakerne skal fylle ut et spørreskjema og et utvalg vil også bli innkalt til en klinisk undersøkelse av bekkenbunnen.

– Hvis vi oppdager tendenser til fremfall, vil deltakeren bli henviset til videre undersøkelse. Det kan være en fordel å starte behandling på et tidlig tidspunkt, sier Volloyhaug.

– Hva slags behandling er aktuelt?

– Ringpessarbehandling kan hjelpe ved livmor-fremfall. Man setter inn et pessari i skjeden som holder livmoren på plass. Ved urinlekkasje vil det være aktuelt med bekkenbunnstrening slik at musklene styrkes og dermed hindrer lekkasje. Men for ti prosent av den kvinnelige befolkningen blir plagene så alvorlige at de må gjennomgå operasjon for urinlekkasje eller fremfall før fylte 80 år. For noen opptrer plagene allerede i 40-årsalderen eller enda tidligere, sier Ingrid Volloyhaug.

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Kvinesykdom: Vi trenger mer kunnskap om hvilke fødselsmetoder som øker risikoen for å utvikle urinlekkasje eller livmor-fremfall senere i livet, sier Ingrid Volloyhaug.

Figure 22 Adresseavisen, the largest newspaper in the region, published a commentary on the study timed with the last mailing cycle. From: www.adressa.no/ Photo and text by Agnete Weisser.

4.3 Recruitment

Questionnaires were sent in three mailing cycles; in March 2013, and in June and September 2013 reminders were sent to non-responders. It was possible to answer the questionnaire on a paper form or on a web form. To increase the response rate we lotted an iPad among the responders. We also used the local newspaper to inform women of the study at the time of the last mailing cycle, see Figure 22.

One problem was that addresses obtained from the Hospital Patient Administrative System were not linked to the Civil Population registry. We were able to find new addresses for most of the women from <http://www.1881.no/>, but we know that 148 women did not receive any invitation to participate and we suspect that several more women never got invitation letters due to problems with the postal service. Some women gave reason for unwillingness to participate, such as not having PFD, having other diseases or knowing the investigator, but most women gave no reason for unwillingness to participate.

Questionnaire responders accepting clinical examination were invited if they did not live too far from Trondheim, defined by postal code. Some women cancelled the appointment because they did not have the time to participate, had no pelvic floor

problems or other reasons. “No show” women were contacted by telephone, and were offered a new visit if they were willing to participate.

4.4 Data sources and variables

The study data were obtained mainly from two sources:

- 1) Postal questionnaire on PFD, previous surgery and life style factors (paper I and III).
- 2) Clinical and sonographical examination of muscle anatomy and function and of POP-Q (paper II, III and IV).

Additional information about perineal tears and indication for OVD at first delivery was obtained from the hospital records, and information about subsequent deliveries (delivery mode, infant birth weight, head circumference, parity, elective or emergency CD, and year of delivery) was obtained from the Norwegian Medical Birth Registry. Figure 23 illustrates the main study variables, their sources, and the published papers.

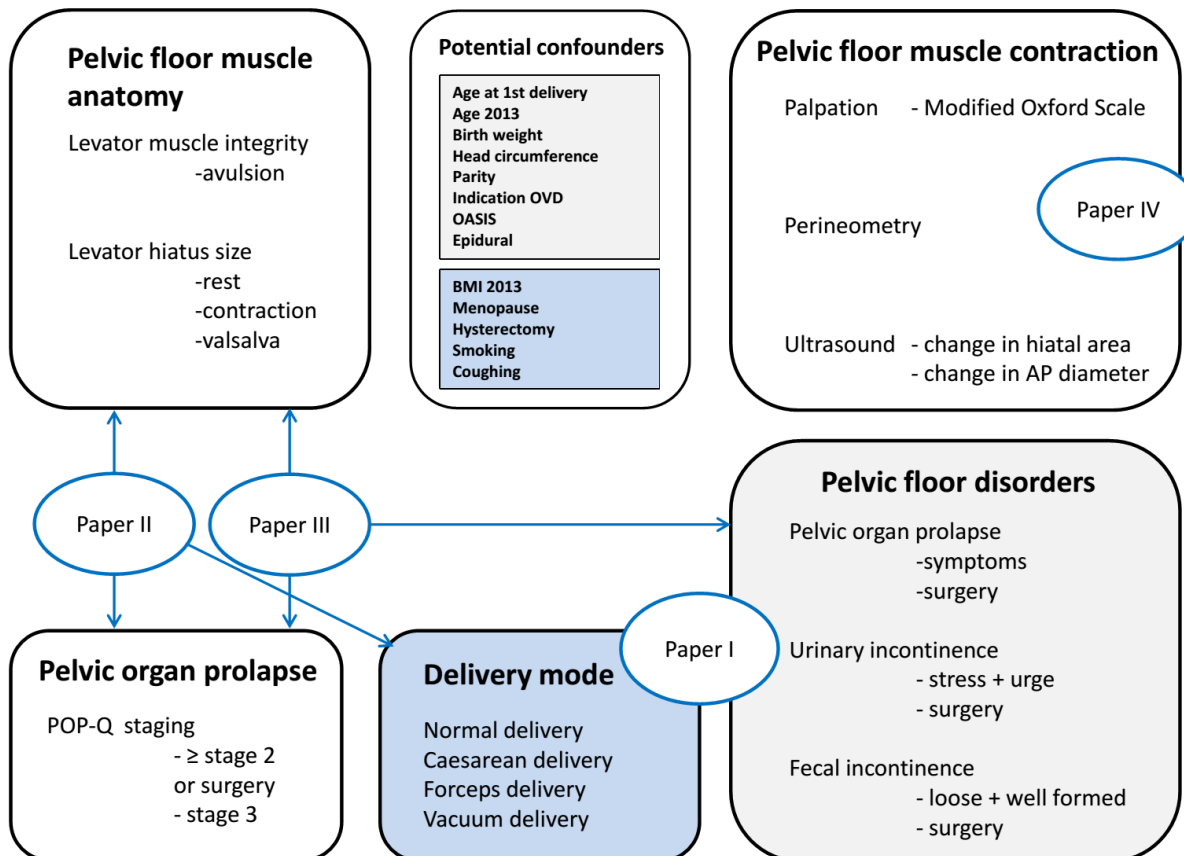


Figure 23 Variables of interest and their contribution to each paper. Variables obtained from questionnaire in light grey. Variables obtained from the Norwegian medical Birth Registry and Hospital records in light blue. Variables obtained from clinical and sonographical examination in white. Volløyhaug 2015.

4.4.1 Postal questionnaire

The questionnaire included questions about all the women's deliveries (parity, infant birth weight and delivery method), menopause and use of hormone replacement therapy, weight, height, smoking habits, chronic coughing, hysterectomy and surgery for pelvic organ prolapse, urinary and faecal incontinence, see Appendix 2. Information from the questionnaires regarding delivery method and infant birth weight was cross-checked with the Hospital Patient Administrative System and the Norwegian Medical Birth Registry. After this comparison there was a discrepancy for mode of first delivery in 13 women, and individual hospital records were scrutinized and delivery mode confirmed.

The questionnaire included a Norwegian translation of the PFDI and of the PFIQ⁴⁷. Mean scores for POPDI, CRADI and UDI was calculated, with a possible range from 0-100 for each subscale and 0-300 for the PFDI total score. PFIQ score was not used in the analyses.

Diagnosis of sPOP, UI and FI was based on five key questions from the PFDI. A positive response to "seeing or feeling a vaginal bulge" qualified for the diagnosis of sPOP. Positive response to "urinary incontinence at urgency" or "urinary incontinence at coughing, sneezing, laughing" qualified for the diagnosis of UI, and positive response to "incontinence for loose stool" or "incontinence for well formed stool" qualified for the diagnosis of FI, counting any positive response as diagnostic without regard to severity of symptoms.

The main outcome variables were three composite variables consisting of symptoms and/or having had surgery:

- 1) sPOP: Symptomatic pelvic organ prolapse and/or current use of ring pessary and/or having had surgery for pelvic organ prolapse.
- 2) UI: Urge and/or stress urinary incontinence and/or having had surgery for urinary incontinence.
- 3) FI: Incontinence for loose and/or well-formed stool and/or having had surgery for fecal incontinence.

4.4.2 Clinical examination

Study participants presented with an empty urinary bladder and bowel and were asked to withhold any information regarding previous deliveries, prolapse and incontinence symptoms, pelvic floor muscle exercise, and gynecological surgeries until the examination had been completed. They were examined in the supine position in a gynecological examination chair, with knees and hips semiflexed and abducted.

The gynecological examination included digital assessment of pelvic floor muscle integrity and contraction, perineometry, staging of pelvic organ prolapse according to the POP-Q system⁵³ and a 4D pelvic floor ultrasound scan. All women were instructed regarding correct pelvic floor muscle contraction: to squeeze their pelvic floor muscle (pull in and lift up the urethra, vagina, and rectum, or imagine trying to control passing gas). The same instructions were used during all assessments of pelvic floor muscle contraction. They were also instructed in performing a Valsalva maneuver of minimum 6 seconds duration without coactivation of pelvic floor muscles. All examinations were performed by one person, who was blinded to demographical and clinical background data at the time of the examination.

Digital assessment of pelvic floor muscle integrity, resting tone and contraction was performed by the examiner inserting the index and middle finger approximately 4 cm into the vagina (only the index finger in the case of very narrow hiatus) and palpating the puborectalis muscle at each side of the vagina at rest and during contraction. The palpation method proposed by Dietz was used to assess levator muscle integrity¹³ and resting tone¹⁴. The Modified Oxford Scale (MOS) was used to rate pelvic floor muscle contraction on a scale of 0–5¹². The mean MOS (right + left/2) was used for the correlation analysis.

Perineometry was conducted by using a vaginal balloon catheter connected to a fiberoptic microtip transducer (Camtech AS, Sandvika, Norway) placed in the vagina, with the middle of the balloon located approximately 3.5 cm inside the introitus¹⁸. Study participants performed three maximal pelvic floor muscle contractions, and the strongest contraction (creating the highest intravaginal pressure) was used.

The POP-Q provided quantification of prolapse from stage 0 to 4 in each compartment (anterior, middle, posterior). Measurements were performed in 0.5 cm intervals. Data from the POP-Q were analyzed for each compartment separately, and the presence of POP-Q \geq 2 in at least one of all three compartments was registered and counted as clinically relevant prolapse. Some had undergone prolapse surgery and were objectively cured (POP<grade2). We did not check their hospital records for POP stage before surgery, but in Norway the agreed indication for POP surgery is POP \geq stage 2 with concomitant prolapse symptoms. We defined a composite outcome variable combining POP \geq stage 2 or previous surgery. The registration of POP stage 3 included women with more severe prolapses.

Ultrasound volumes were acquired with a GE Voluson S6 device using the RAB 4-8rs abdominal 3D probe and acquisition angle of 85° placed on the perineum. Volumes were acquired at rest, during pelvic floor muscle contraction and during Valsalva maneuver of minimum 6 seconds duration⁷⁴. Three volumes were acquired for contraction (including a

relaxed state at the beginning of each volume) and Valsalva, yielding a total of six volumes per woman.

Offline analysis of the ultrasound volumes was performed 6-14 months after the ultrasound scan on a computer using the 4Dview Version 14 Ext.0 (GE Healthcare, Austria) software. The analysis was done by one person, who at the time of the analysis was blinded to clinical and demographical data. PFMT was defined by either levator avulsion or larger levator hiatal areas.

TUI technique was used to identify levator avulsion at pelvic floor muscle contraction. Avulsion was diagnosed if all three central slices; the slice in the plane of minimal hiatal dimensions (ie. where the distance between the posterior border of the symphysis and the anterior border of the puborectalis muscle is shortest) and the slices 2.5 and 5.0 mm cranial to this, showed abnormal muscle insertion²³. Avulsion was diagnosed as unilateral or bilateral (see Figure 13), and the number of women with unilateral or bilateral levator avulsion was registered.

Hiatal area was measured in the plane of minimal hiatal dimensions in a rendered volume of 1-2 cm thickness as described previously²⁴. All six volumes for rest, contraction and Valsalva were analyzed. Examples of ultrasound images defining the hiatal area at rest, contraction and Valsalva in women without or with unilateral or bilateral avulsions are presented in Figure 15. The largest hiatal area at rest and during Valsalva maneuver was registered for each woman. The smallest hiatal area, representing the best contraction, was registered for pelvic floor muscle contraction. Some women were unable to perform a proper Valsalva maneuver without co-activation of the pelvic floor muscles. When the hiatal area produced at Valsalva maneuver was smaller than the area at rest, the hiatal area during Valsalva was defined as invalid and registered as missing. We also registered all women with hiatal area $>40 \text{ cm}^2$, as this cut off previously has been used to diagnose women with severe hiatal overdistension⁷⁵.

For ultrasound assessment of pelvic floor muscle contraction, we examined three volumes per woman, starting at rest and recording the maximal pelvic floor muscle contraction. Hiatal area and antero-posterior (AP) diameter both at rest and during maximal pelvic floor muscle contraction were measured in the rendered axial plane of the minimal hiatal dimensions as previously described²⁴, see Figure 24. The strongest pelvic floor muscle contraction, creating the largest difference in the levator hiatal area between rest and contraction for each woman was used. We first calculated the absolute difference in hiatal area and the AP diameter between rest and pelvic floor muscle contraction. Subsequently, we

used the formula suggested by van Delft et al. to calculate the proportional (percent) difference in measurements between maximum contraction and rest: $\text{proportional difference} = ((\text{Measure}_{\text{rest}} - \text{Measure}_{\text{squeeze}}) / \text{Measure}_{\text{rest}}) \times 100\%$ for both hiatal area and AP diameter¹⁴⁴.

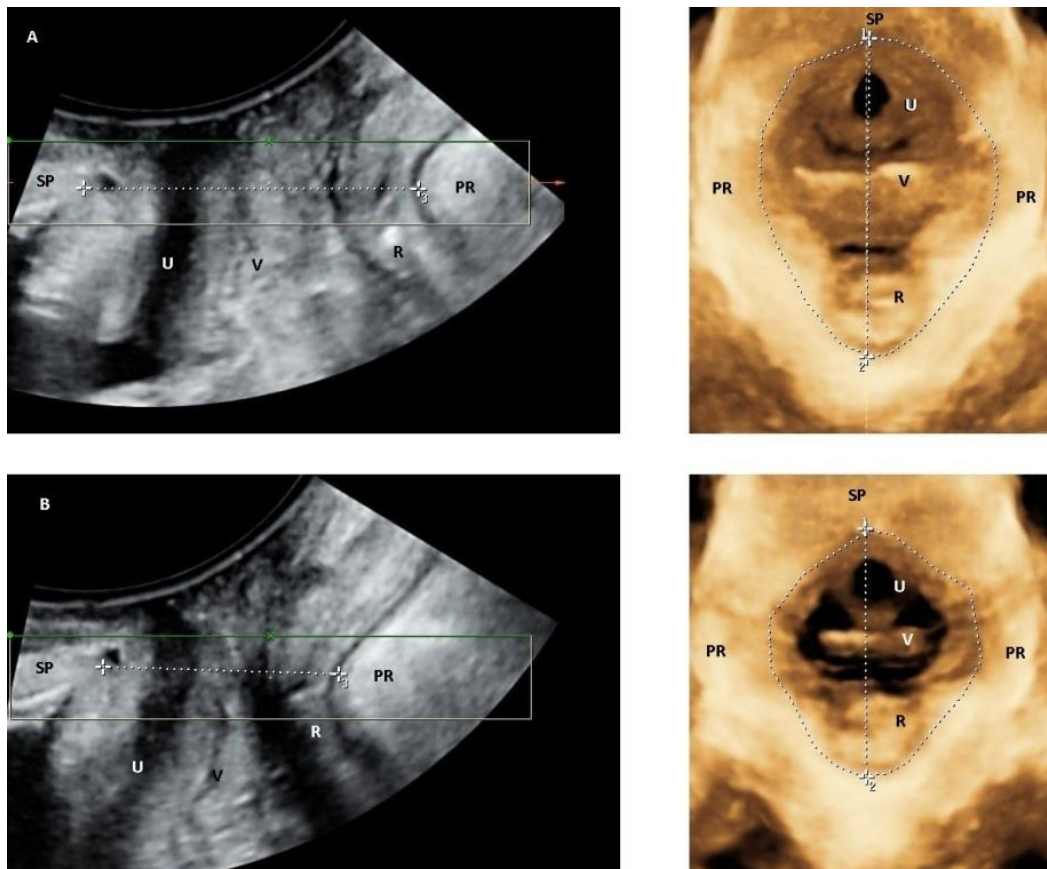


Figure 24 Ultrasound imaging of pelvic floor muscle contraction. The images on the right demonstrate measurements of the hiatal area and the antero-posterior (AP) diameter at (a) rest and (b) contraction in the oblique axial plane of minimal hiatal dimensions in a rendered volume of 1-2 cm thickness. The images to the left demonstrate measurements of AP diameter from the upper border of the symphysis pubis to the puborectalis muscle in a corresponding 2D image in the mid-sagittal plane. SP: symphysis pubis; PR: puborectalis muscle; U: urethra; V: vagina; R: Rectum.

From Volløyahug et al 2015: Assessment of pelvic floor muscle contraction with palpation, perineometry and transperineal ultrasound: a cross-sectional study, with permission from Johns Wiley and Sons

4.5 Study size

4.5.1 Power calculation for data from questionnaire

A power calculation was based on previous studies of primiparous women indicating a higher risk of PFMT after FD (35%) than after NVD (13%) and VD (9%)⁷³, and a study demonstrating that ultrasound verified PFMT doubled the risk for POP¹³⁹. We assumed a lower prevalence of symptomatic than anatomical POP. Assuming a prevalence of sPOP of 12.0% in the OVD group and 5.5% in the NVD group we found that 296 women in each group would be sufficient to detect a statistically significant ($p < 0.05$) and clinically relevant difference between groups with power 80%. The prevalence of UI is higher than for sPOP and the FI prevalence is similar to sPOP. Thus, the study should be sufficiently powered to detect clinically important differences between groups for UI and FI as well.

4.5.2 Power calculation for data from clinical examination

A power calculation was based on one previous study of primiparous women indicating a higher risk of PFMT after FD (35%) than after NVD (13%) and VD (9%)⁷³, and a study identifying ultrasound verified muscle trauma as a factor doubling the risk for POP¹³⁹. To detect a similar difference in prevalence of levator avulsion between delivery groups (35% vs 13%), we would need 58 women in each group with a power of 80% and 5% significance level. We assumed a smaller difference in POP prevalence (12.5% in the normal vaginal delivery group and 25.0% in the forceps group) and found that a sample size of 152 women in each delivery group would be sufficient to find a statistically significant and clinically relevant difference between delivery groups with power 80% and significance level 5%. We did not perform power calculations for the detection of differences in hiatal area.

4.6 Statistical analyses

Statistical analyses were performed with IBM SPSS statistics version 21 (IBM SPSS, Armonk, NY, USA). Continuous variables were tested for normal distribution. We used the two sample *t*-test for continuous variables and the chi-square test or Fisher's exact test for categorical variables to identify any differences between study groups in demographics and clinical background data. $P < 0.05$ was considered statistically significant. When data were missing, analyses were run on study participants with complete data. Table 9 summarises all statistical analyses that was done for each paper.

4.6.1 Statistical analyses Paper I

The prevalence of the outcome variables was compared between CD, OVD and NVD, and in a subgroup analysis FD was compared with VD. The main outcome variables (sPOP, UI, FI) were analysed using univariable logistic regression for calculation of crude odds ratios (cOR) for delivery modes. In addition, multivariable logistic regression analysis was used to correct for possible confounding factors and calculate adjusted odds ratio (aOR) with 95% confidence intervals (CI). On the basis of clinical knowledge and results from previous studies, we selected parity (number of deliveries), maternal age at delivery, current BMI, hysterectomy, menopause, smoking habits, chronic coughing and infant birth weight (the largest infant delivered by each woman) as possible confounders. Univariable logistic regression was used to test their association to main outcome variables one by one before entering into the multivariable regression model. The woman's age in 2013 was omitted from the model because of correlation with age at delivery and menopause. Head circumference was omitted because of correlation to birth weight. Smoking and chronic coughing were independent variables and both were entered into the final regression model. A low percentage of the women provided reliable information on the use of hormone replacement therapy, and therefore no analysis was done for this potential confounder. For comparison of FD and VD the following potential confounders were added into the model; indication for OVD (fetal distress or prolonged second stage of labour), OASIS, and the largest infant delivered vaginally, excluding any infants delivered by CD.

Background data		Variables of interest	Aim	Statistical analysis	Outcome measure	Confounders in multivariable analysis
Paper I						
Descriptive statistics	Comparison between delivery groups					
Prevalence in % or mean and SD	Testing of normal distribution.	PFD Delivery mode	Find prevalence of PFD	Descriptive statistics	Prevalence, %	
-according to delivery group	t-test for continuous variables and chi-square test for categorical variables		Test association between PFD and delivery mode	Simple and multiple logistic regression	cOR, 95% CI aOR, 95% CI	Age at 1st delivery BMI 2013 Birth weight Parity Menopause Hysterectomy Indication for OVD Smoking Coughing OASIS
Paper II						
Prevalence in % or mean and SD	Testing of normal distribution.	POP-Q \geq 2 PFMT Delivery mode	Find prevalence of PFMT and POP-Q \geq 2	Descriptive statistics	Prevalence, % Mean, SD	
-according to delivery group	t-test for continuous variables and chi-square test for categorical variables		Test association between levator avulsion, POP-Q \geq 2 and delivery mode	Simple and multiple logistic regression	cOR, 95% CI aOR, 95% CI	Age 2013 BMI 2013 Birth weight Parity
			Test association between hiatal areas and delivery mode	Univariable and multivariable ANCOVA	uMD, 95% CI aMD, 95% CI	
Paper III						
Prevalence in % or mean and SD		POP-Q \geq 2 sPOP PFMT	Find prevalence of PFMT, POP-Q \geq 2 and sPOP	Descriptive statistics	Prevalence, %	
-for the whole study population			Test association between PFMT, POP-Q \geq 2 and sPOP	Chi-square test (Multiple logistic regression)	cOR, 95% CI aOR, 95% CI	Age BMI Birth weight Parity Hysterectomy
Paper IV						
Prevalence in % or mean and SD		MOS Perineometry Ultrasound measurements	Find mean score for MOS, perineometry and Ultrasound measurements	Descriptive statistics	Mean, SD	
-for the whole study population			Test correlation between different assessment methods for muscle contraction	Testing of normal distribution Spearman's rank correlation	Correlation coefficient	
			Establish an ultrasound contraction scale	Calculation of percentage	Cut off's range 0-100% AP change	

Table 9 Summary of statistical analyses performed for each paper

4.6.2 Statistical analyses Paper II

The primary statistical analysis was to compare POP, levator avulsion and hiatal area between FD and VD. Secondary analyses were comparisons of outcomes between CD, FD, VD and NVD.

We used univariable logistic regression for calculation of cOR for delivery modes. Multivariable logistic regression analysis was used to correct for possible confounding factors and calculation of aOR with 95% CI. Analysis of covariance (ANCOVA) was used to test for significant differences between delivery modes for hiatal areas at rest, contraction and Valsalva. Both univariable ANCOVA for unadjusted mean difference (uMD) with 95% CI between delivery groups and multivariable ANCOVA corrected for possible confounding factors for adjusted mean difference (aMD) with 95% CI are reported. When the numbers were small (eg. POP grade 3), the Fisher's Exact test for calculation of cOR with 95% CI was used (<http://www.r-fiddle.org/#/>).

On the basis of clinical knowledge and results from previous studies we considered several potential confounding variables. Univariable logistic regression was used to test their association to POP \geq stage 2 or surgery and levator avulsion one by one before entering into the multivariable model. ANCOVA was used to test the association of each factor to hiatal area on Valsalva. For comparison of risk between delivery groups in the final logistic regression model and for the multivariable ANCOVA analysis we selected age (2013), parity, BMI, and largest infant's birth weight. Head circumference was omitted because of correlation to birth weight, and both menopause and age at delivery were omitted because of correlation to age in 2013. Other potential confounding variables (smoking, coughing, hysterectomy, epidural, indication for operative vaginal delivery and perineal tears) showed no statistically significant association to the main outcome variables and were not entered into the multivariable regression model. Reliable information on the use of hormone replacement therapy, oxytocin augmentation during delivery and episiotomy was not available.

4.6.3 Statistical analyses Paper III

We used the Chi-square test to calculate cOR for the associations between PFMT and POP-Q \geq 2 and sPOP, and for the association between sPOP and POP-Q \geq 2. When numbers were small, the Fisher's Exact test for calculation of cOR with 95% CI was used (<http://www.r-fiddle.org/#/>). Multivariable logistic regression analysis was then performed for calculation of aORs with 95% CI for the associations between possible confounding factors (age, BMI, parity,

infant birth weight and hysterectomy, chosen on the basis of clinical knowledge and results of previous studies) and PFMT and POP-Q \geq 2, sPOP and POP surgery.

4.6.4 Statistical analyses Paper IV

Data from ultrasound parameters were normally distributed, but MOS and perineometry data were not. Thus, the Spearman's rank test was used to assess the correlation between the methods. Increasing rank correlation implied increasing agreement between the tests: $r_s = 0$, no agreement; $r_s > 0.3$, weak agreement; $r_s > 0.5$; moderate agreement; $r_s > 0.7$, strong agreement; $r_s = 1$, perfect agreement.

After determination of the ultrasound method with the strongest correlation to digital assessment, we calculated cut offs corresponding with palpation. The International Continence Society has recommended that quantification of contractions by digital palpation should be divided into four categories (absent, weak, normal, strong) ⁸, and we used these four categories when defining cut offs for an ultrasound scale, yielding the same percentage of women in each category. For this purpose, mean MOS = 0 was classified as absent, 0.5-2 was weak, 2.5-4 was normal and 4.5-5 was strong.

4.7 Ethical considerations

Informed consent was obtained from all participants included in the study. The study was approved by the Regional Committee for Medical and Health Research Ethics (REK midt 2012/666). A potential benefit for study participants was the clinical examination which had the potential to reveal conditions or diseases and refer women to further diagnosis and treatment if necessary. The examination had no known side effects. It was not painful, but could be experienced as uncomfortable for some women. Study participants were not given any economic compensation for travelling costs or taking time off from work.

4.8 Data registration

The study was registered in Clinical Trials with ClinicalTrials.gov Identifier: NCT01766193.

The questionnaire could be answered either on paper form (Appendix 2) or web form:

<http://www.nsfm.no/uopro/>. The paper version was scanned and entered into an SPSS-file.

Data from the web responses were entered manually into the SPSS file.

Data from the Norwegian Medical Birth Registry were obtained on encrypted SPSS files. Once these files were merged with the questionnaire files, all information that could identify a woman was deleted, keeping only the study participant number.

Data from the clinical examination were registered on a paper form during examination (Appendix 3), and immediately after the woman left, data were entered into a web crf on <https://webcrf.medisin.ntnu.no>, with a woman's study participation number and without any information that could identify the woman. At the end of the data collection this was converted into an SPSS file.

All ultrasound volumes were stored with the woman's study participation number on the ultrasound machine and copied to a separate hard disk with regular intervals. All ultrasound volumes were deleted from the ultrasound machine at the end of the study after copying the volumes on a separate back up hard disk. After analysis of ultrasound volumes, data were entered manually into an SPSS file.

5 Results

5.1 Response rate

The response rate for the questionnaire was 53% (1641/3115) and 72% (608/847) of women invited for clinical examination participated. A flow chart of study participants is presented in Figure 24. The questionnaire response rate was similar for all delivery groups (NVD 51%, FD 53%, VD 57%, CD 52%), however slightly higher in the VD group compared to NVD ($p=0.02$) and CD ($p=0.04$). There was no difference in participation rate at clinical examination between delivery groups: NVD 71% (217/306), CD 73% (101/139), FD 72% (159/220), VD 72% (131/182).

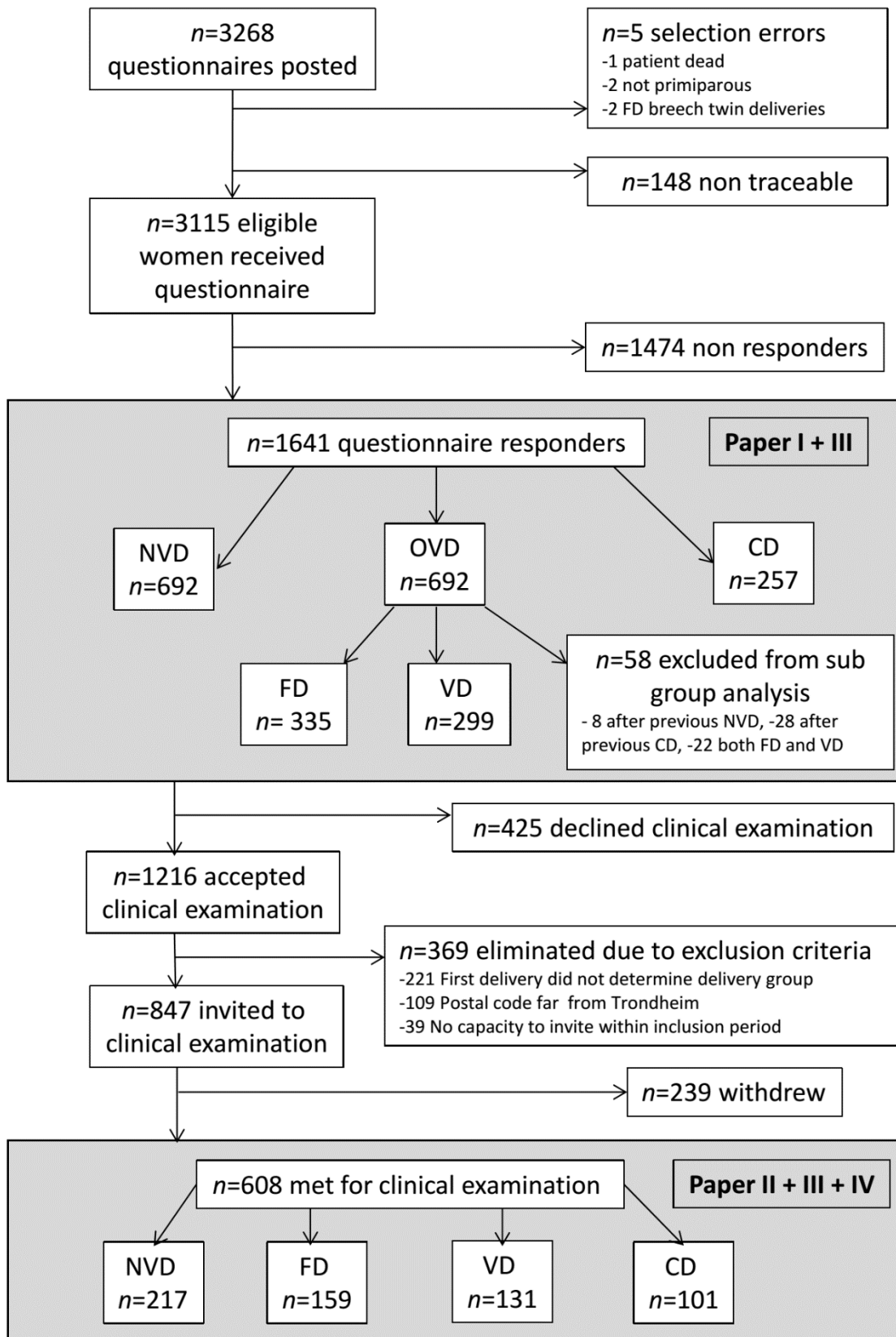


Figure 24 Flow chart of study participants

5.2 Background characteristics

Background characteristics for questionnaire responders and for women attending clinical examination are presented in Table 10. Non-responders had mean age 46 years and were significantly younger than responders (mean age 47 years, $p < 0.01$). Also more non-responders lived far from Trondheim in 2013 according to their postal code (17% vs 13%, $p < 0.01$). Further data for comparison of non-responders was not available.

Table 10 Characteristics for questionnaire responders and women attending clinical examination.

	Questionnaire responders	Women examined Mean (SD) or % (N)
Age in 2013 (years)	47.3 (4.9)	47.9 (4.9)
Age at 1 st delivery (years)	27.7 (4.5)	28.3 (4.6)
Parity (N of deliveries)	2.2 (0.8)	2.2 (0.8)
Largest infant`s birth weight (g)	3834 (524)	3861 (506)
Head circumference largest infant (cm)	36.4 (1.5)	36.5 (1.4)
BMI (kg/m ²)	25.8 (4.7)	25.8 (4.5)
Menopause	20% (299/1499)	23% (126/541)
Hysterectomy	4% (63/1632)	5% 30/606)
Smoking	18% (297/1630)	20% (119/606)
Chronic coughing	4% (67/1630)	6% (34/606)
Outcome variables		
sPOP	11% (172/1580)	15% (87/589)
UI	47% (752/1603)	51% (303/592)
FI	9% (145/1594)	11% (65/593)

The women examined were significantly older than the background population of questionnaire responders and older at first delivery, but there were no statistically significant differences for parity, largest infant`s birth weight or BMI.

Women in the NVD group were significantly younger, had lower BMI and higher parity compared to other delivery groups. Women in the CD group were older, had higher BMI and lower parity than the vaginal delivery groups. Women in the FD and VD groups

were comparable for age, BMI and parity, but infants were significantly larger in the VD group. There was no significant difference in indication for OVD, OASIS prevalence and use of epidural analgesia between FD and VD.

Significantly more women with sPOP were included in the clinical examination part of the study compared to the background population of questionnaire responders (15% vs. 11%, $p=0.01$), see Table 10. There was also a tendency towards more FI and UI among women that were examined, but the difference was not statistically significant.

Episiotomy was performed as routine for OVD during the study period, and episiotomy rates were reported to be between 73-82% from 1995 through 97, with no reliable data prior to 1995. Analysis including episiotomy as a variable was not possible.

5.3 Paper I

Main results

Cesarean delivery was associated with decreased risk of pelvic floor dysfunction 15-23 years after first delivery.

Operative vaginal delivery was associated with increased risk of pelvic floor dysfunction 15-23 years after first delivery.

There was no difference between forceps and vacuum delivery.

Overall, the prevalence of the main outcomes was: sPOP 11% (172/1580), UI 47% (752/1603) and FI 9% (145/1594), and 47% (727/1549) of women were asymptomatic. Prevalence according to delivery group is presented in Table 11.

Table 11 Prevalence of pelvic floor disorders according to delivery group

	Normal vaginal delivery	Cesarean delivery	Operative vaginal delivery	Vacuum delivery	Forceps delivery
Pelvic floor disorder					
Symptomatic pelvic organ prolapse	9% (61/666)	5% (11/245)	15% (100/669)	15% (43/289)	16% (51/325)
Urinary incontinence	48% (323/676)	39% (99/251)	49% (330/676)	51% (149/291)	47% (156/329)
Fecal incontinence	6% (41/671)	9% (22/246)	12% (82/677)	12% (36/292)	13% (42/329)
Number of pelvic floor disorder					
0	48% (313/651)	58% (139/241)	42% (275/657)	40% (114/282)	42% (134/321)
1	42% (276/651)	33% (80/241)	42% (276/657)	43% (120/282)	42% (134/321)
2	9% (57/651)	8% (20/241)	14% (93/657)	15% (42/282)	14% (46/321)
3	1% (5/651)	1% (2/241)	2% (13/657)	2% (6/282)	2% (7/321)

The prevalence of single PFDs and overlaps of two or three PFDs are presented in Figure 25. There was a large degree of overlap between symptoms of sPOP and UI, and of FI and UI: 60% (101/169) of women with sPOP had UI, 72% (100/139) of women with FI had UI. There was a lower degree of overlap between sPOP and FI, where 17-20% of women had both symptoms. Most women with UI (75% (543/724)) had not other symptoms. Among women with at least one PFD, 2% (20/822) had all three PFDs.

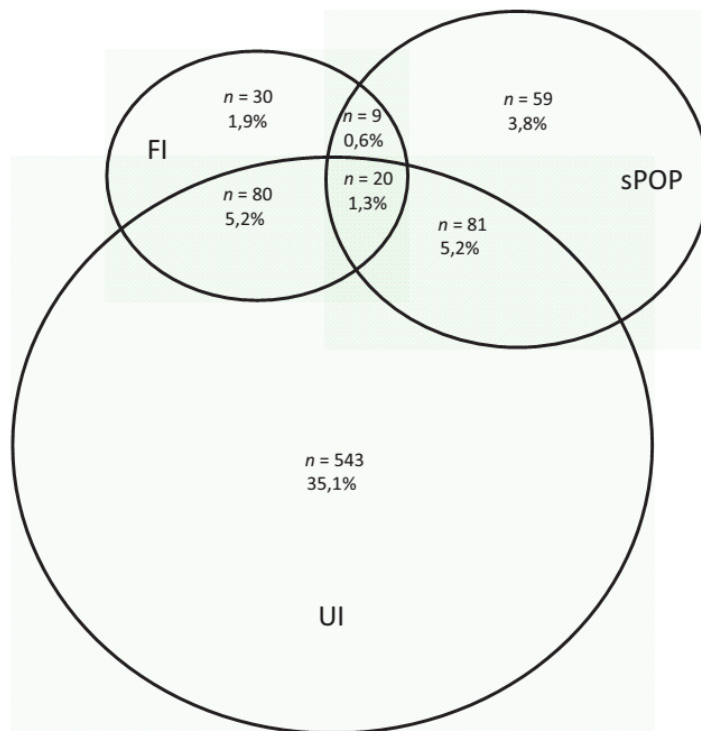


Figure 25 Prevalence of urinary incontinence (UI), fecal incontinence (FI) and symptomatic pelvic organ prolapse (sPOP) and overlap of symptoms among 1549 women who had responded to questions regarding all three pelvic floor disorders.

CD was associated with decreased risk for sPOP and UI compared to NVD. OVD was associated with higher prevalence of sPOP and FI compared to NVD. There was a higher prevalence of asymptomatic women in the CD group and higher prevalence of women with two PFDs in the OVD group when compared to NVD. There were no differences between FD and VD groups for any of the PFDs or number of disorders.

In addition to delivery mode, chronic coughing was a significant contributing risk factor for sPOP. BMI was a borderline significant risk factor for sPOP and statistically significant for UI. Also parity and the largest infant's birth weight were risk factors for UI, but parity did not remain significant in a multivariable logistic regression analysis and infant birth weight was only borderline significant. Smoking and OASIS were statistically significant risk factors for FI after multivariable logistic regression.

See Paper I for numeric details.

5.4 Supplementary analyses paper I

As a response to a “letter to the Editor”, a subgroup analysis was done to calculate the prevalence of different types of UI, Stress Urinary Incontinence (SUI) and Urge Urinary Incontinence (UUI) (Appendix IV)^{145, 146}:

For SUI the prevalence according to delivery group was: CD: 30% (77/256), NVD: 41% (280/688), OVD: 38% (262/688), FD: 37% (122/333) and VD: 41% (123/297). The differences between groups were similar as for the composite variable UI (UUI, + SUI + surgery).

For UUI the prevalence according to delivery group was: CD: 27% (68/256), NVD: 26% (176/678), OVD: 27% (187/682), FD: 26% (87/332) and VD: 30% (87/293). There were no statistically significant differences between the groups for urge urinary incontinence.

We originally planned to analyze differences between delivery groups in mean symptom score. The range is 0-100 for each subscale (POPDI, UDI, CRADI), and 0-300 for PFDI total. Data were not normally distributed and Mann Whitney-U test was therefore used. It was not possible to adjust for confounders. Table 12 and 13 present the mean, SD and Range for each subscale for delivery groups, and differences between groups. There was no significant difference in mean values for any of the scales comparing CD to NVD. The only significant differences between groups were mean POPDI and CRADI score which was higher after OVD compared to NVD, and this difference was also significant for the total PFDI-score. There was no significant difference in mean values for any of the scales comparing FD to VD. We observed that the highest upper border of the range, and close to maximal scores, were found in the CD group for POPDI, CRADI and PFDI total, but we have no information *why* one woman in the CD group had high scores.

Table 12 Comparison between Cesarean delivery (CD), normal vaginal delivery (NVD) and operative vaginal delivery (OVD) by Mann Whitney-U test for symptoms scores of pelvic floor disorder: Pelvic Organ Prolapse Distress (POPDI), ColoRectal-Anal Distress (CRADI), Urinary Distress (UDI) and total score for Pelvic Floor Distress (PFDI).

Scale	CD			NVD			OVD			CD vs NVD	OVD vs NVD
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	<i>p</i>	<i>p</i>
POPDI	2.5	7.4	0-96	2.4	6.0	0-83	2.7	5.0	0-50	0.22	0.02
CRADI	10.8	15.3	0-100	10.2	13.3	0-75	13.5	16.0	0-84	0.82	<0.01
UDI	9.4	14.3	0-75	10.1	13.9	0-79.2	11.5	15.3	0-75	0.10	0.19
PFDI-total	22.7	31.5	0-271	22.6	27.2	0-207	27.5	29.8	0-172	0.28	<0.01

Table 13 Comparison between forceps (FD) and vacuum delivery (VD) by Mann Whitney-U test for symptoms scores of pelvic floor disorder: Pelvic Organ Prolapse Distress (POPDI), ColoRectal-Anal Distress (CRADI), Urinary Distress (UDI) and total score for Pelvic Floor Distress (PFDI).

Scale	FD			VD			FD vs VD
	Mean	SD	Range	Mean	SD	Range	<i>p</i>
POPDI	2.9	4.9	0-35	2.8	5.4	0-50	0.83
CRADI	14.6	16.8	0-84	12.8	15.3	0-69	0.19
UDI	12.3	15.7	0-75	11.3	15.3	0-71	0.62
PFDI-total	29.8	31.2	0-160	26.6	29.4	0-172	0.19

5.5 Main results for women attending clinical examination

The prevalence of POP \geq stage 2 for all women examined was 45% (275/608) in one or more compartments. Among these women 28% (172/608) had POP \geq stage 2 in the anterior compartment, 5% (29/608) in the middle compartment and 25% (154/608) in the posterior compartment. POP stage 3 was found in 11 women (1.8%), 7 in the anterior compartment, 5 in the middle compartment and 1 in the posterior compartment. No women had POP stage 4.

In all, 607 ultrasound datasets of 6 volumes each were analyzed. One dataset had not been stored properly, and in one dataset there was an artefact making avulsion analysis impossible, but analysis of hiatal areas was possible. Levator avulsion was diagnosed in 18.6% (113/608) of the women, 56 (9.2%) were unilateral and 57 (9.4%) were bilateral. Fifty-three women were unable to perform a proper Valsalva maneuver without levator co-activation. The hiatal area on Valsalva was measured in 554 women. Mean hiatal area for the whole study population was: at rest 23.07 cm², SD 4.98, at contraction 15.90 cm², SD=4.73 and at Valsalva 34.32 cm², SD 10.27. Hiatal areas were normally distributed. A total of 164 women (30%) had Area > 40 cm². In all, 195/553 (35%) had levator avulsion or Area > 40 cm², and 79/553 (14%) had both levator avulsion and Area > 40 cm².

Due to technical problems with the perineometer, registrations were missing for 49 women. Perineometry was not available from 05.02.2014 through 11.02.2014, and for 8 women outside this time period the data were not stored properly. A total of 559 women were examined with perineometry. The mean vaginal squeeze pressure was 29.6 cm H₂O, (SD 19.7, Range 0-129). All women were examined with palpation, and the mean MOS was 3.1 (SD 1.3, Range 0-5). Perineometry and MOS data were not normally distributed.

5.6 Paper II

Main results

Cesarean delivery had decreased risk for prolapse stage 2 or surgery, levator avulsion and smaller hiatal areas compared to normal delivery.

Forceps had increased risk for prolapse stage 2 or surgery, levator avulsion and larger hiatal areas compared to vacuum and normal vaginal delivery.

There was no difference between vacuum and normal delivery.

Table 14 gives the prevalence for PFMT and POP according to delivery group. FD was associated with increased risk of POP \geq stage 2 or surgery when compared to VD and NVD and for POP \geq stage 3 compared to VD. FD also had a fourfold increased risk for avulsion injury when compared to both VD and NVD. The mean hiatal areas both at rest, contraction and Valsalva were significantly larger after FD than after VD and NVD. There were no statistically significant differences in prevalence of POP \geq stage 2 or surgery, levator avulsion or hiatal areas between VD and NVD. CD was associated with a decreased risk of POP \geq stage 2 or surgery, levator avulsion and hiatal areas were significantly smaller when compared to NVD.

The study was not powered to study differences between elective (n=23) and acute (n=78) CD, but there was no difference in POP prevalence (2/23 and 4/78) and hiatal areas were similar in the two CD subgroups as demonstrated in Table 15.

Age in 2013 was associated with increased risk of POP \geq stage 2 or surgery and with levator avulsion in a multivariable logistic regression model. Infant birth weight was associated with POP \geq stage 2 or surgery, avulsion and larger hiatal areas. The contributing effect of parity on POP \geq stage 2 or surgery disappeared after adjusting for other confounding variables in the multivariable regression model. BMI was a significant confounder only for hiatal area.

For numeric details, see Paper II.

Table 14 Prevalence for pelvic floor muscle trauma and pelvic organ prolapse (POP) according to delivery group.

	Forceps delivery N=159	Vacuum delivery N=131	Normal vaginal delivery N=217	Cesarean delivery N=101
POP anterior compartment				
≥ stage 2	60 (38%)	36 (28%)	72 (33%)	4 (4%)
≥ stage 3	4 (3%)	0 (0%)	3 (1%)	0 (0%)
POP mid compartment				
≥ stage 2	13 (8%)	6 (5%)	10 (5%)	0 (0%)
≥ stage 3	3 (2%)	0 (0%)	2 (1%)	0 (0%)
POP posterior compartment				
≥ stage 2	54 (34%)	42 (32%)	56 (26%)	2 (2%)
≥ stage 3	1 (0.6%)	0 (0%)	0 (0%)	0 (0%)
POP in any compartment				
≥ stage 2	97 (61%)	67 (51%)	105 (48%)	6 (6%)*
≥ stage 3	7 (4%)	0 (0%)	4 (12%)	0 (0%)
Previous prolapse surgery	8 (5%)	2 (2%)	5 (2%)	0 (0%)
-cured	3 (2%)	0 (0%)	2 (1%)	0 (0%)
-still POP ≥ stage 2	5 (3%)	2 (2%)	3 (1%)	0 (0%)
POP ≥ stage 2 or previous prolapse surgery	100 (63%)	67 (51%)	107 (49%)	6 (6%)*
Levator avulsion				
-Any	65 (41%)	19 (15%)	29 (13%)	0 (0%)
-unilateral	29 (18%)	10 (8%)	17 (8%)	0 (0%)
-bilateral	36 (23%)	9 (7%)	12 (6%)	0 (0%)
Hiatal area cm²				
-rest	25.17 (5.5)	22.64 (4.5)	23.30 (4.6)	19.85 (3.8)
-contraction	17.82 (5.4)	16.02 (4.3)	15.86 (4.3)	12.83 (3.2)
-Valsalva	38.81 (9.8)	34.27 (10.5)	34.52 (9.5)	26.50 (7.6)

*2/23 after acute and 4/78 after elective Cesarean delivery

Table 15 Mean hiatal areas in women after elective and acute Cesarean delivery (CD)

	Elective CD N= 78 Mean (SD)	Acute CD N= 23 Mean (SD)
Hiatal area cm²		
-rest	19.9 (3.4)	19.7 (4.9)
-contraction	12.7 (3.2)	13.3 (3.5)
-Valsalva	26.5 (7.3)	26.5 (8.6)

5.7 Paper III

Main results

Many women from the normal population had symptoms and signs of pelvic organ prolapse 15-24 years after first delivery.

Pelvic floor muscle trauma was associated with symptoms and signs of pelvic organ prolapse in women from the normal population.

Levator avulsion was more strongly associated with POP-Q \geq 2 than sPOP. Also levator hiatal Area > 40 cm² was more strongly associated with POP-Q \geq 2 than sPOP. Bilateral avulsion was a stronger risk factor than unilateral avulsion for POP \geq 2, and the presence of both avulsion and severe hiatal ballooning further increased the risk for prolapse. We found the strongest association for avulsion and Area > 40 cm² for mid compartment and anterior compartment prolapse and a weaker but significant association to posterior compartment prolapse. Levator avulsion and Area>40cm² were independently associated with POP-Q \geq 2 when entered simultaneously into the multivariable regression model. For sPOP only Area>40cm² remained an independent risk factor after entering all other factors into the model. POP-Q \geq 2 was a risk factor for sPOP. For numeric details, see Paper III.

We had decided to use POP-Q \geq 2 as indicative for clinically relevant prolapse in this study. By using other cut offs, the positive response to seeing or feeling a vaginal bulge would be more sensitive, see Table 16.

Table 16 Sensitivity of “seeing or feeling a vaginal bulge” depends on cut off used to define significant pelvic organ prolapse

Definition used	Proportion of prolapse detected by positive response to question	Sensitivity
POP-Q \geq 2	56/270	21%
POP-Q to the hymen	36/135	27%
POP-Q> 0.5cm beyond the hymen	11/21	52%
POP-Q> 1 cm beyond the hymen= grade 3	9/11	82%

In all, 227 of 544 women with complete dataset had no PFMT or POP-Q \geq 2 and were asymptomatic. Among these women, there were 79 (89%) of 89 women who had delivered exclusively by CD, 44 (38%) of 117 women delivered by VD, 71 (38%) of 188 women with NVD, and 33 (22%) of 150 delivered by FD. Differences between delivery groups were statistically significant ($p<0.01$), see Figure 26.

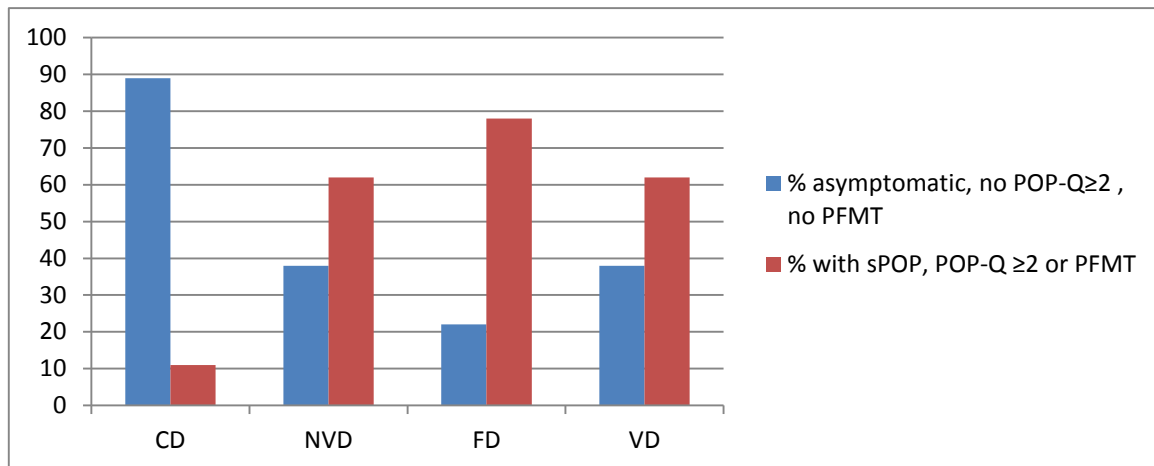


Figure 26 Symptoms and signs of pelvic organ prolapse (sPOP and POP-Q \geq 2) and pelvic floor muscle trauma (PFMT) present and absent according to delivery groups.

Figure 27 illustrates the association between PFMT, sPOP and POP-Q \geq 2 or 3 among 544 women with complete datasets. We found that most women with sPOP had PFMT and POP-Q \geq 2, but for 12 (17%) of 69 symptomatic women we did not find any PFMT or POP-Q \geq 2. Most women (209/263= 79%) with POP-Q \geq 2 were asymptomatic, and 2 (18%) of 11 women with POP-Q grade 3 were asymptomatic.

Figure 28 illustrates the correlation between POP-Q and levator avulsion and levator hiatal area $>40\text{cm}^2$ separately. Nineteen percent of women with Area $>40\text{cm}^2$ did not have POP-Q \geq 2, and 13% of women with avulsion did not have POP-Q \geq 2. All women with POP=3 had levator avulsion.

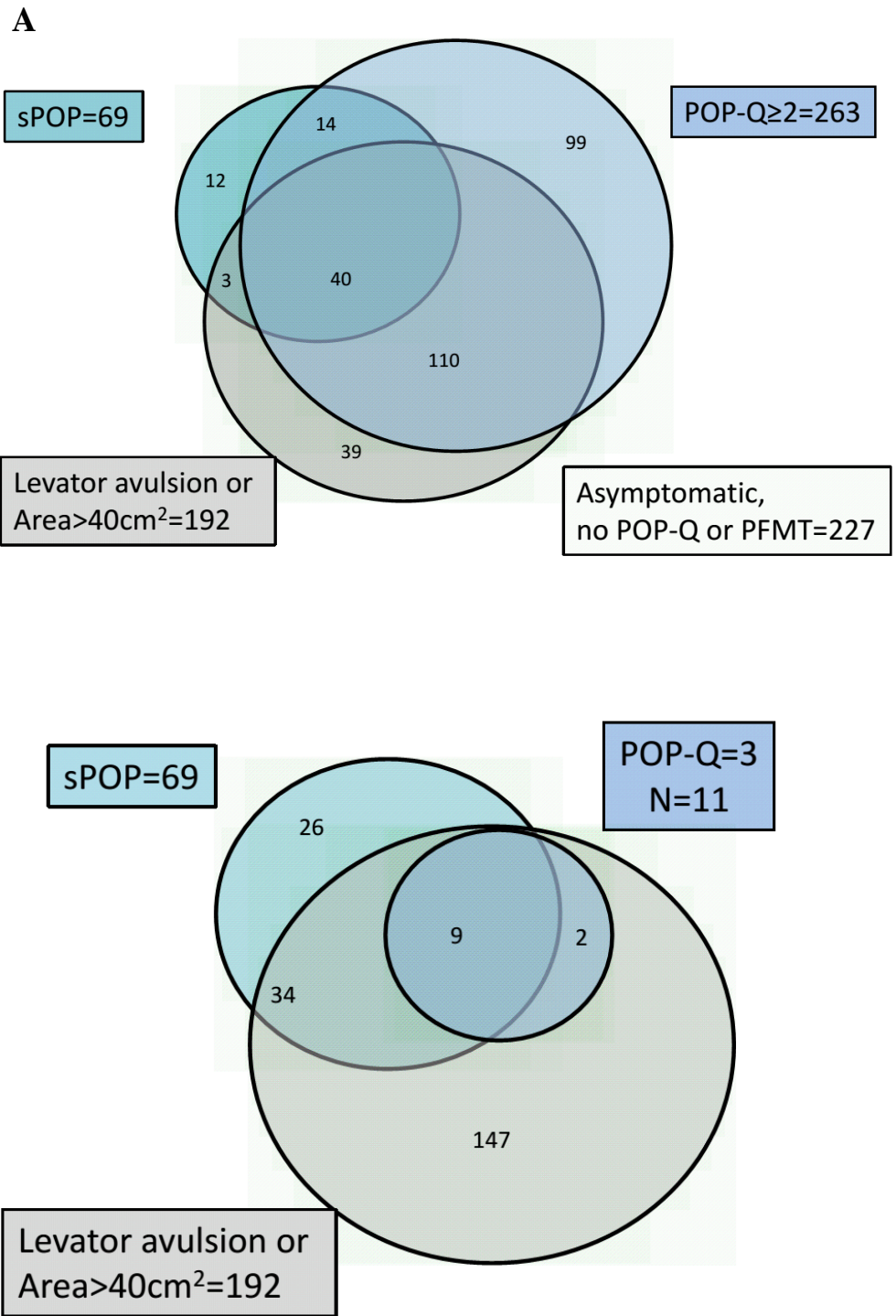
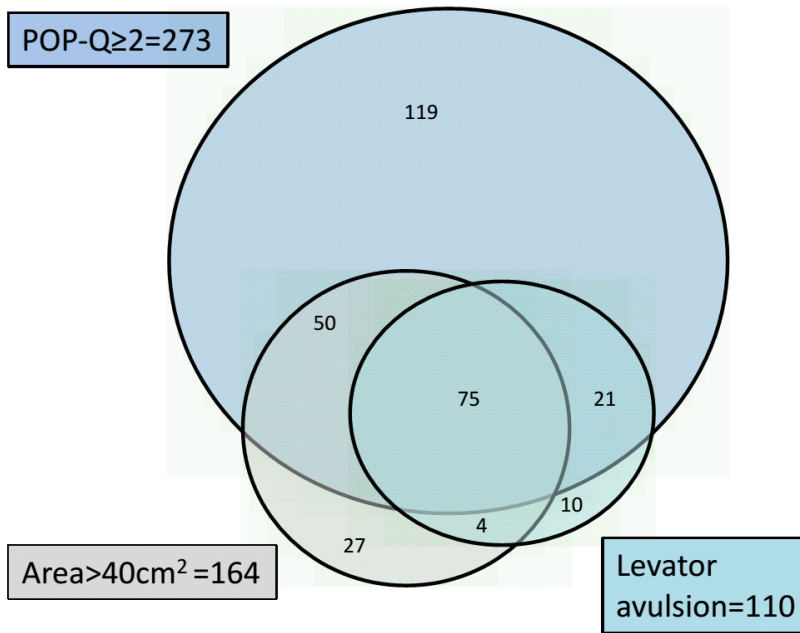


Figure 27

A) Correlation between pelvic organ prolapse grade 2 or larger (POP-Q \geq 2) and symptoms of pelvic organ prolapse (sPOP), pelvic floor muscle trauma (PFMT)

B) Correlation between pelvic organ prolapse grade 3 (POP-Q=3) and symptoms of pelvic organ prolapse (sPOP), pelvic floor muscle trauma (PFMT)

A



B

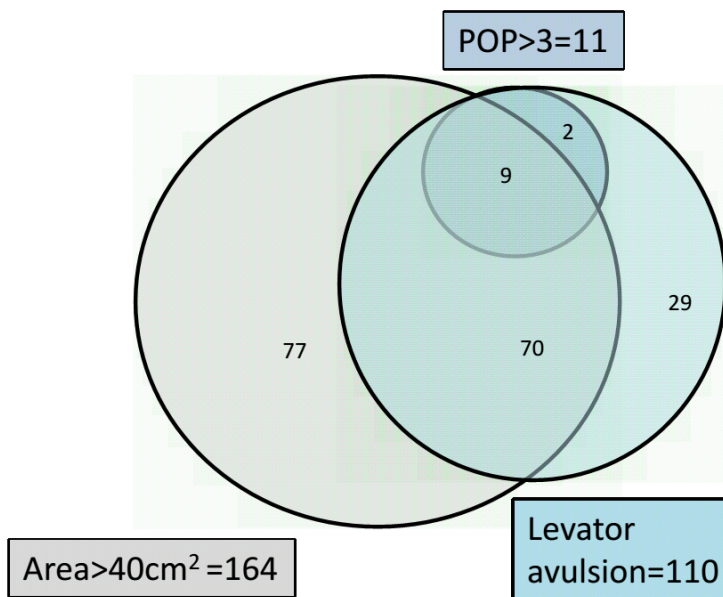


Figure 28

A) Correlation between pelvic organ prolapse grade 2 or larger (POP-Q ≥ 2) and levator avulsion and levator hiatal area > 40 cm²

B) Correlation between pelvic organ prolapse grade 3 (POP-Q = 3) and levator avulsion and levator hiatal area > 40 cm²

5.8 Paper IV

Main results

We found moderate to strong correlation between ultrasound measurements and palpation and perineometry.

The proportional change in levator hiatal anteroposterior diameter was the ultrasound measurement with strongest correlation to palpation and perineometry

We defined a contraction scale for ultrasound measurements based on the proportional change in levator anteroposterior diameter.

Values for different assessment methods for pelvic floor muscle contraction are presented in Table 17. Statistically significant correlations were found between all assessment methods. The strongest correlation was found between MOS and perineometry. The Spearman's rank correlation coefficient between ultrasound measurements and both MOS and perineometry is presented in Table 18. MOS had stronger correlation than perineometry to all ultrasound parameters, and the proportional change in hiatal AP diameter had the strongest correlation to MOS. Mean proportional change in the AP diameter with 95% CI in relation to mean MOS is presented in Table 19. Figure 29 presents the correlation between mean MOS and proportional change in AP diameter graphically.

Cut offs for proportional change in AP diameter according to a four point scale based on the proportions allocated to each category by palpation was: Proportional change in AP diameter < 7% corresponded to absent contractions, 7-18% corresponded to weak contractions, 18-35% corresponded to normal contractions, and >35% corresponded to strong contractions, see Table 20. When applying these cut offs, the correlation between palpation and proportional change in AP diameter remained good, and 65% of the contractions were allocated to the same category by the two methods; furthermore, for only two contractions a discrepancy of more than one category was found between the two methods.

Table 17 Results for different assessment methods for pelvic floor muscle contraction

Assessment method	Mean	SD	Range
Mean Modified Oxford Scale (n=608)	3.1	1.3	0-5
Perineometry (cm H ₂ O) (n=559)	29.6	19.7	0-129
Change in hiatal area (cm ²) (n=607)	7.2	3.2	0-21.1
Change in AP diameter (cm) (n=607)	1.6	0.7	0-3.4
Change in hiatal area (%) (n=607)	31.1	12.1	0-64.0
Change in AP diameter (%) (n=607)	24.4	9.8	0-50.9

Table 18 Spearman's correlation (r_s) between ultrasound measurements and Modified Oxford Scale and perineometry

	Mean Modified Oxford Scale (n=607)	Perineometry (n=558)
Change in hiatal area on ultrasound (cm ²)	0.54	0.46
(%)	0.67	0.60
Change in AP diameter on ultrasound (cm)	0.63	0.58
(%)	0.69	0.66

Table 19 Mean proportional change in the hiatal anteroposterior diameter with 95% confidence interval (CI) in relation to mean Modified oxford Scale

Mean Modified Oxford Scale	Number of women	Percent change in anteroposterior diameter		
		Mean	SD	95% CI
0	21	10.70	6.8	7.6-13.8
0.5	16	11.33	8.0	7.1-15.6
1	23	12.48	6.0	9.9-15.1
1.5	40	16.37	6.9	14.2-18.6
2	61	17.52	7.0	15.7-19.3
2.5	31	21.64	6.0	19.5-23.8
3	131	23.62	7.2	22.4-24.9
3.5	28	26.28	6.3	23.8-28.7
4	177	29.24	7.2	28.2-30.3
4.5	7	36.60	10.0	27.3-45.9
5	72	34.54	7.1	32.8-36.2

Table 20 Proposed contraction scale with cut offs for percent change in hiatal anteroposterior (AP) diameter on ultrasound

4 graded scale	Number (%) by palpation	Cut offs for %AP change
Absent	21 (3.5%)	<7%
Weak	140 (23%)	7- 18%
Normal	367 (60.5%)	18-35%
Strong	77 (13%)	>35%

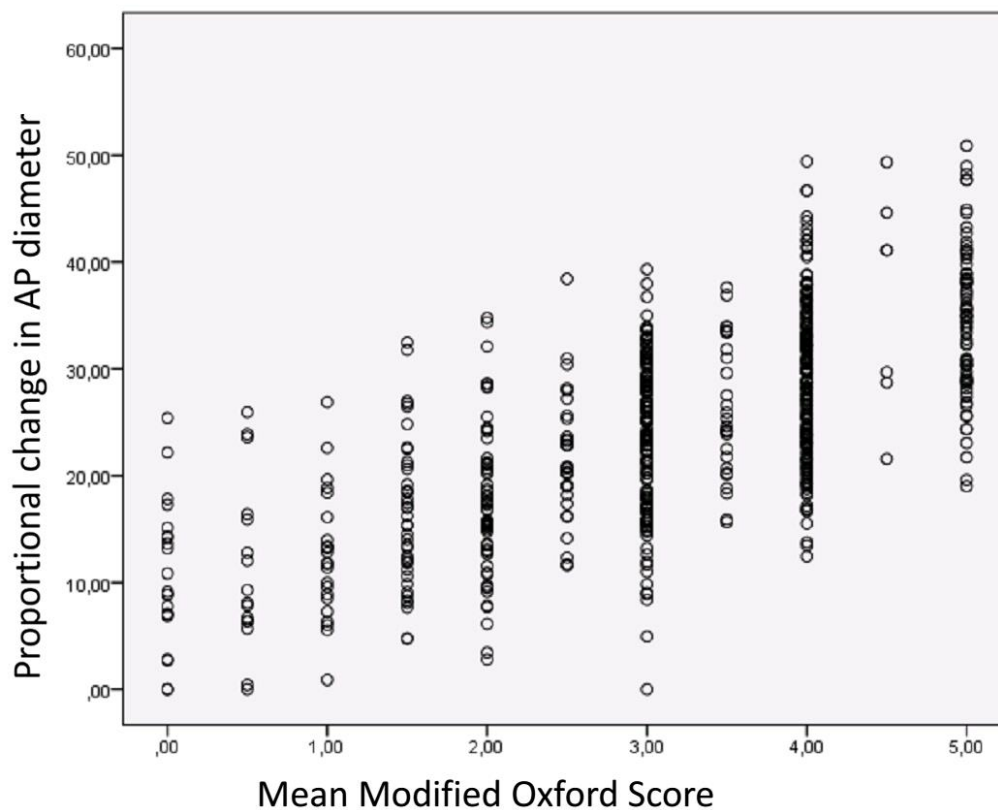


Figure 29 Correlation between the Mean Modified Oxford Scale (MOS) and proportional (percentage) change in antero-posterior (AP) diameter. From Volløyhaug et al 2015 Assessment of pelvic floor muscle contraction with palpation, perineometry and transperineal ultrasound: a cross-sectional study, with permission from John Wiley and Sons.

6 Discussion

6.1 Main strengths and weaknesses

Main strengths

The study had a long follow up of 15-24 years after first delivery.

Study participants were recruited from the normal population of parous women.

The doctors were equally trained in forceps and vacuum when the women delivered.

The response rate was similar for all delivery groups.

This is the hitherto largest study comparing forceps and vacuum for pelvic floor disorders, pelvic organ prolapse and pelvic floor muscle trauma.

Main weaknesses

The response rate was 53%, and the external validity is therefore not optimal

The cross sectional study design only permits to establish association, not causation

6.2 Methodological considerations

6.2.1 Study design

A weakness of this study was the cross-sectional study design. A cross-sectional study design can only find an association between delivery mode and PFD, PFMT and POP. The ideal would be to conduct a randomised study to establish causal inferences between delivery mode and PFD, POP and PFMT.

6.2.2 Bias regarding diagnostic criteria

A validated translation into Norwegian of questionnaires on sPOP, UI and FI was not available when the study was conducted. We chose a translation of the PFDI used by other Norwegian investigators, however not yet published. PFDI is not a screening questionnaire, but for the analyses we extracted five clearly formulated key questions and counted any positive response without calculation of scale scores. Counting any positive response as diagnostic for PFD without regard to severity of symptoms, may have contributed to the relatively high prevalence of PFD in our study population introducing a possible misclassification bias. The PFDI questionnaire was developed for use in patient populations, and this could explain why women in the present study had a low mean score on all three subscales, and why the scores were not normally distributed.

All women were examined in a standardized way by the same examiner applying uniform diagnostic criteria. The person who performed the examinations was blinded to all background data regarding delivery mode, parity and symptoms. The women were covered with a cloth to hide surgical scars on the abdomen, but in some women it was possible to see a scar after episiotomy. Episiotomy was routine for all OVDs and also frequent for NVDs in the period 1900-97. Seeing a scar implied that a woman did not belong to the CD group, but she could belong to any of the vaginal delivery groups.

The person who performed the examinations had long experience in examining women with POP according to the POP-Q criteria, and adequate training in pelvic floor ultrasound for assessment of hiatal areas and levator avulsion⁷⁰. Offline analysis of the ultrasound volumes was performed 6-14 months after the ultrasound scan, and the person who performed the analyses was blinded to clinical and demographical data.

The cut off of levator hiatal area $>40\text{cm}^2$ to define abnormal hiatal overdistension was chosen arbitrary on the basis of a previous publication⁷⁵, and not defined from the mean of this study population for determination of the 95th centile (54.9cm^2) or the mean plus two

standard deviations (51.9 cm²), which are definitions used to describe the normal range (https://en.wikipedia.org/wiki/Reference_range).

The levator-urethral gap was measured when doubt about avulsion diagnosis, and the measurement was used to compare the gap between the two sides ⁶⁹. We had the impression that women in this study population had a larger levator urethral gap than previously described even when the levator was intact, and the cut off of normality previously described (levator-urethral gap > 25 mm strongly associated with levator avulsion) was therefore not applied ⁶⁹.

6.2.3 Selection bias

It has been demonstrated that symptomatic women are more prone to participate in studies ⁹¹. This could lead to an overestimation of the prevalence of symptoms. Only 53% of invited women responded to the questionnaire. Non-responders were significantly younger than responders, and therefore they probably had less symptoms than responders, as PFD increases with advancing age. More non-responders lived far from Trondheim in 2013 according to their postal code, which probably reflect that women living far from Trondheim are less interested in studies at Trondheim University Hospital. This should not lead to a biased prevalence estimate. In all, 72% of women invited for clinical examination were examined. Significantly more women with sPOP met for examination compared to the background population of questionnaire responders. The women who were examined were also slightly older in 2013 and at first delivery. Women who met for examination could be a selection of more obedient women or women with an occupation permitting them to take time off and come for the examination.

6.2.4 Internal validity

The response rate to the questionnaire was similar for all delivery groups, but slightly higher in the VD group compared to NVD and CD. There was no difference in participation rate between delivery groups in the clinical examination. Since the questionnaire response rate was similar in the four delivery groups and the proportion of women who met for examination was equal between groups, it is reasonable to believe that the comparison between delivery groups is valid.

6.2.5 External validity

Women in the study were predominantly white European, and the results should be interpreted with caution for diverse ethnic groups^{37, 38, 56, 59, 91, 120, 121, 147}. It is fair to assume that the prevalence of PFD, objective POP and PFMT could be over estimated due to the factors discussed under selection bias. All women in this study were parous, and one would expect a lower prevalence of PFD and POP, and no PFMT in nulliparous women.

6.2.6 Possible bias in disfavour of vacuum

Rotational forceps was not recommended at Trondheim University Hospital during 1990-97, and FD was only carried out for low or mid-cavity fetal head in occiput anterior or occiput posterior position. VD was allowed if the fetal head was at or below the spines and for all head positions. Higher stations and different positions may implicate higher risk of trauma and may have introduced bias in disfavour of VD. Another possible source of bias was better training and/or operative skills for FD. In 1980-1989 the FD:VD ratio was 3:1 at Trondheim University Hospital, whereas in 2000-2010 the FD:VD ratio was 1:8. Over a period of 15-20 years VD became the method of choice for OVD in this hospital. Theoretically doctors were better trained in FD than VD during 1990-97. Thus, both these possible biases would be towards more complications in the VD group.

6.3 Relation to other studies

6.3.1 Pelvic floor disorders in association to delivery mode

The present study is the hitherto largest epidemiological study addressing possible risk difference between FD and VD regarding PFD. The results support previous studies reporting that CD is associated with lower prevalence of PFD whereas OVD is associated with higher prevalence of PFD^{89, 90, 96-99}. No statistically significant association between sPOP, UI or FI and mode of operative vaginal delivery (FD and VD) was found. Since the confidence intervals were large, it is not possible to rule out a clinically relevant difference in favour of either FD or VD. The present findings contrast the results from a smaller study demonstrating that FD, and not VD, increased the odds of PFD compared to NVD 5-10 years after delivery¹⁰⁰ and a randomised study demonstrating higher prevalence of FI after FD compared to VD¹⁰¹. Other studies with short time interval after delivery have demonstrated increased risk of FI after FD compared to VD^{78, 101, 102}.

Since the present study was planned, there are some recent publications from Sweden addressing risk differences for PFD between primiparous women delivered by CD and vaginal delivery with a long follow up demonstrating increased risk of sPOP, UI and FI after vaginal delivery¹⁴⁸⁻¹⁵⁰. Women delivered by forceps were not represented in that population. We found that CD was not protective against FI, and this is supported by other studies^{50, 90, 110, 127}.

6.3.2 Pelvic floor muscle trauma and pelvic organ prolapse in association to delivery mode

The association between PFMT and delivery mode was established prior to the start of the present study, but only in patient populations and puerperal women^{72, 73, 133-137}. In this study the association was confirmed in women from a normal population. Prior to start of this study, there were only four studies distinguishing PFMT prevalence between FD and VD^{71, 73, 134, 138}. During 2014-15 five new studies focusing on the difference between FD and VD were published and summarised in a recent review¹⁵¹, see Table 19. The results from these studies are in concordance with our findings of increased prevalence of levator avulsion after FD when compared to VD and NVD, see Figure 30, even if most studies find an intermediate prevalence of levator avulsions after VD^{72, 73, 133-137, 152-156}. Our study is the second largest of similar studies, and we have a longer follow up after delivery than all previous studies, which

is important, as it has been demonstrated that levator trauma can heal within the first years after delivery¹⁵⁷. Another strength of the present study, not indicated in previous studies, is that doctors were equally trained in forceps and vacuum, and the procedures were performed for the same indications, and we can conclude that muscle trauma were method dependent, and not dependent on the indication for delivery or the doctors' skills, which could have been the case in previous studies.

Table 21 Prevalence of avulsion of the puborectalis muscle. The last two columns give odds ratios and confidence intervals for avulsion in forceps (FD) vs. normal vaginal delivery (NVD) and forceps compared with vacuum extraction delivery (VD). Modified after: Dietz 2015: Forceps: towards obsolescence or revival? With permission from John Wiley and Sons © 2015 Nordic Federation of Societies of Obstetrics and Gynecology

Author	Year	n	Follow up	% Full avulsion	FD vs NVD OR (95% CI)	FD vs VD OR (95% CI)
Dietz and Lanzarone	2005	50	4 months	36%; 4 FD only	–	–
Kearney et al.	2006	160	9–12 months	NVD 12%, VD 17%, FD 66%	15.3 (4.5–55)	10 (1.3–96)
Krofta et al.	2009	76	1 year	FD only, 64%	–	–
Shek et al.	2010	367	4 months	NVD 12%, VD 9%, FD 35%	4 (1.3–12.4)	5.6 (1.05–32.9)
Valsky et al.	2010	210	3	19%; no FD	–	–
Albrich et al.	2010	159	2–3 days	40%; one FD only	–	–
Kearney et al.	2010	157	>1 year	NVD 6% (8/129), FD 53% (20/38)	16.8 (5.9–49.4)	–
Cassado G et al.	2011	164	?	NVD 15%, FD 50%; no VD	10.3 (3–37.4)	–
Blasi et al.	2011	52	1	31%; no FD	–	–
Eisenberg et al.	2011	73	1 year	NVD 20%, VD 41%, FD 89%	32 (4.5–301)	11.4 (2–74)
Chan et al.	2012	339	2 months	NVD 15%, VD 33%, FD 71%	13.7 (3.6–56)	5 (1.2–22.8)
Van Delft et al.	2014	191	3 months	NVD 10%, VD 13%, FD 48%	8.4 (2.5–29.3)	5.9 (1.3–29.1)
Caudwell Hall et al.	2014	844	4.6 months	NVD 13%, VD 13%, FD 44%	5 (2.6–9.4)	5.3 (2.3–12.6)
Memon and Handa	2014	79	10 years	no NVD; VD 15%, FD 50%	–	5 (1.63–15.3)
Chung et al.	2014	289	2 months	no NVD; VD 17%, FD 40.5%	–	3.42 (1.6–7.3)
Durnea et al.	2014	202	1.8 years	NVD 6%, VD 18%, FD 55%	18.2 (5.3–67)	5.3 (1.6–18)

There has been less focus on differences in levator hiatal areas after different delivery modes^{30, 158, 159}. Larger increase after delivery and, in general, larger hiatal areas after FD than VD has been described, but the effect could be partly explained by a higher prevalence of levator avulsions in the FD group, as levator avulsion contributes to larger hiatal areas³⁰. Nevertheless, levator avulsions and larger levator hiatal areas have been described as independent risk factors for POP¹⁴⁰. We found significant differences in levator hiatal areas both at rest, contraction and Valsalva between CD and NVD, and between FD and NVD/VD. Women were only examined once, and many years after delivery, it was therefore not possible to assess any difference in hiatal area before and after delivery in our study population. There are several arguments for hiatal areas *not* being larger in the FD group *prior* to delivery: 1) FD was performed at similar indications as VD. 2) There was a higher prevalence of PFMT after FD than VD, despite the fact that infants in the vacuum group were significantly larger. 3) Some authors have found an association between smaller levator hiatal areas in pregnancy and the need for operative vaginal delivery and CD^{158, 160, 161}. We therefore assume that the larger hiatal areas seen in the FD after delivery is caused by the delivery method.

A plausible explanation is that PFMT is more likely to occur during FD due to a more traumatic effect of the blades of the forceps and the excessive traction force allowed, acting as a plough and causing more dilatation of the birth canal and more trauma to the levator ani muscles than the vacuum device, see Figure 30.

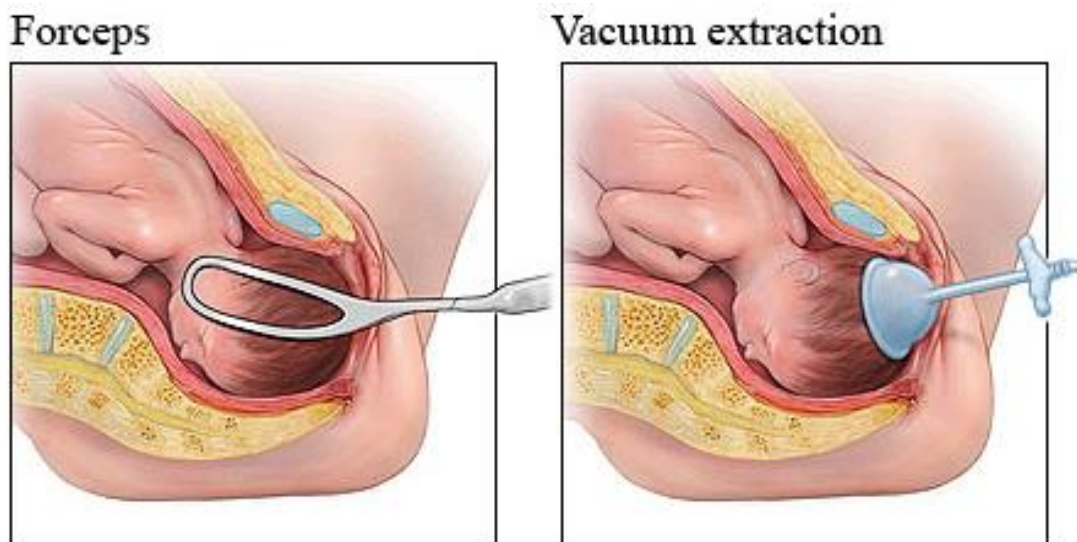


Figure 30 Forceps delivery and vacuum delivery.

From:

https://myhealth.alberta.ca/health/_layouts/15/healthwise/media/medical/hw/h9991588_001.jpg

Over all, we found larger hiatal areas compared to previous studies for all delivery groups^{75, 158}. This could be explained by ethnical differences. Women examined were mainly of Norwegian (Caucasian) ethnic origin. Other authors have recently found significant differences in hiatal biometry between women of different ethnic origins¹⁶². We found similar hiatal areas as other researchers from Norway¹⁶³. Another explanation is that women were examined many years after their first delivery, and hiatal dimensions could increase over time.

Studies comparing anatomical POP prevalence after FD and VD are sparse and the results are conflicting. One study demonstrated that FD, and not VD, was associated with higher prevalence of POP compared to NVD¹⁰⁰ whereas another study has found a protective effect of FD¹¹⁹. Both studies had a shorter follow up (5-10 and 12 years) than the present study, and the number of OVDs was smaller in the first study (VD: 49, FD: 76) and similar in the second (VD: 190, FD: 392), with larger proportion of FD than VD in both studies. One previous study has demonstrated an association between prolapse surgery and FD, when compared to NVD, but no women with VD were included¹⁶⁴. We found higher prevalence of prolapse surgery after FD (5.2%) than VD (1.6%), but because of small numbers we were not able to demonstrate a statistically significant difference between FD and VD for prolapse surgery alone.

6.3.3 Association between pelvic floor muscle trauma and symptoms and signs of pelvic organ prolapse

Previous studies on association between PFMT and POP have been conducted in urogynecological patient populations or among women a few months after delivery^{23, 68, 75, 133, 139-143, 165, 166}. The analyses in the present study confirmed a similar association between sPOP, POP-Q \geq 2 and PFMT also in women from a normal population many years after delivery. Levator avulsions and larger levator hiatal areas have been described as independent risk factors for POP¹⁴⁰, and we reproduced this independent association in women from the normal population in Paper III, see also Table 22. Similar to previous studies we found that PFMT had strong association with anterior and mid compartment prolapse, and a weaker association with posterior compartment prolapse^{68, 139-141, 165, 167}

The overlap between PFMT, sPOP and POP-Q \geq 2 was not complete. A discrepancy between symptoms and signs of POP was also found in other studies. Mouritsen et al investigated the association between mechanical, bladder, bowel and sexual problems to POP

symptoms and signs, and found that symptoms had little relation to prolapse in a specific compartment or to POP-Q value ⁴³. Glazener et al found a discrepancy between sPOP and objective measurement of POP ¹¹⁹. They concluded that sPOP and objective prolapse are associated with different risk factors, and that symptoms are not necessarily related to the anatomical changes of POP. Similar to our findings Tan et al found that the proportion of women feeling a vaginal bulge increases with increasing prolapse grade ⁶⁰.

6.3.4 Other factors' association to pelvic floor disorders, pelvic organ prolapse and pelvic floor muscle trauma

The contribution of other risk factors than mode of delivery to sPOP, UI, FI, POP-Q_{≥ 2} and PFMT found in the present study is summarised in Table 22.

Table 22 Risk factors for symptomatic pelvic organ prolapse (sPOP), urinary incontinence (UI), fecal incontinence (FI), pelvic organ prolapse grade 2 (POP-Q_{≥ 2}) and pelvic floor muscle trauma (PFMT). Crude and adjusted odds ratio (cOR, aOR,) and unadjusted and adjusted mean difference (aMD, aMD) with 95% confidence intervals (CI). Data from paper I*, II** and III***.

Condition	Significant studied one by one cOR or uMD, 95%CI	Significant after multiple logistic regression aOR or aMD, 95% CI
sPOP	Coughing 2.59 (1.42-4.73)*	Coughing 2.33 (1.22-4.48)* BMI 1.03 (1.00-1.07)* Area >40 cm ² 2.33 (1.27- 4.31)***
UI	Parity 1.14 (1.01-1.28)* BMI 1.09 (1.07-1.12)* Infant birth weight 1.04 (1.02-1.06)*	BMI 1.09 (1.06-1.12)* Infant birth weight 1.02 (1.00-1.04)*
FI	OASIS 2.07 (1.08-3.94)* Smoking 2.17 (1.48-3.17)*	OASIS 2.62 (1.27-5.42)* Smoking 2.10 (1.35-3.26)*
POP-Q _{≥ 2}	Parity 1.29 (1.06–1.58)* Infant birth weight 1.04 (1.01–1.07)*	Age 1.05 (1.01–1.09)* Infant birth weight 1.05 (1.01–1.09)* Levator avulsion 4.08 (2.17-7.69)*** Area >40 cm ² 3.32 (2.02-5.43)***
PFMT		
Avulsion	Age 1.05 (1.00–1.09)** Infant birth weight 1.04 (1.01–1.07)** Parity 1.29 (1.06–1.58)**	Age 1.08 (1.02–1.13)** Infant birth weight 1.06 (1.01–1.12)**
Area on Valsalva	BMI uMD 0.24 (0.06–0.43)** Infant birth weight uMD 0.32 (0.15–0.48)**	BMI aMD 0.23 (0.05–0.41)** Infant birth weight aMD 0.28 (0.11–0.45)**

6.3.5.1 Other risk factors for symptomatic and anatomic pelvic organ prolapse

Parity has previously been described as a stronger risk factor for POP than for UI^{114, 118}. In the present study parity was not a significant risk factor for sPOP, and the contributing effect of parity on POP-Q_{≥ 2} disappeared in the multivariable regression model. A study from 1997 on a large cohort of women followed up for at least two decades found increasing risk of sPOP with increasing parity¹¹⁸. Multiparous women were compared to nulliparous women, and delivery mode and infant birth weight were not studied. We found that women delivered by CD had lower parity than women after vaginal deliveries. This is supported by other studies⁹⁸, and it is well known that infant birth weight increases with parity¹⁶⁸. The effect of parity found previously could therefore be explained partly by delivery modes associated to high (NVD) and low (CD) parity, and increasing infant birth weight associated with higher parity. Another study found a five-fold increased risk for prolapse symptoms after multiple vaginal births, but the largest step was found between nulliparity and primiparity¹²⁰, and with less effect of parity in women delivered by CD. An increasing risk for sPOP with increasing parity was also found in a recent study after correcting for delivery mode, but not infant birth weight, and the largest step was found between nulliparous and primiparous women¹⁶⁹. Less than doubled risk between primiparous and multiparous women (18% vs 32%) has been found previously³⁷. Tegerstedt et al also found an effect of parity and a non significant effect of infant birth weight on sPOP⁸⁹. Samuelsson found an effect of parity and high infant birth weight on anatomical prolapse⁵⁵. The effect of high infant birth weight has also been found by Swift et al⁵⁶, and more recently in a Swedish study of primiparous women¹⁴⁹. We also found that increasing birth weight was a risk factor for POP-Q_{≥ 2}. The effect of high infant birth weight could be via PFMT, see Paragraph 6.3.5.4.

Obesity is an established risk factor for prolapse^{52, 56}. We found a borderline significant association between increasing BMI and sPOP, but no effect on POP-Q_{≥ 2}. Recently, the effect of obesity on sPOP has been confirmed by Gyhagen et al¹⁴⁹. Lonnee-Hoffmann found that obesity was a risk factor for prolapse surgery¹⁷⁰ and that asthma was a non significant risk factor for prolapse surgery. Chronic coughing more than doubled the odds for sPOP in our study. Both obesity and chronic coughing increase the intraabdominal pressure, which may contribute to a sensation of downward descent of the pelvic organs. Both conditions also increase the load on the pelvic floor and cause chronic strain, stretching and weakening the muscles, nerves and connective tissue, and may contribute to pelvic organ descent over time.

We found that age was associated with POP-Q \geq 2, in concordance with strong evidence from previous studies^{52, 90, 98, 99}, and supported by recent publications^{147, 170, 171}.

6.3.5.2 Other risk factors for urinary incontinence

Increasing BMI was the strongest risk factor for UI in addition to delivery mode in the present study. This is in concordance with previous studies that have described obesity as a strong risk factor for UI^{37, 38, 92, 105}. The exact mechanism of the obesity-UI association is unknown, but could be similar to POP. Excess body weight increases abdominal pressure, which in turn increases bladder pressure and urethral mobility, causing SUI and also affecting detrusor instability causing UUI¹⁰⁵.

We found an effect of parity, as described by other investigators^{38, 96, 114}, but this effect disappeared in a multivariable logistic regression analysis, whereas increasing infant birth weight remained a borderline significant risk factor for UI.

We were not able to reproduce the effect of age described in previous studies^{37, 51, 115}. This could be explained by the age distribution of study participants, with a normal distribution around the mean of 47.3 years, with 90% women between 40 and 56 years.

6.3.5.3 Other risk factors for fecal incontinence

The strongest risk factor for FI in our study population was OASIS at first delivery. Several previous studies have found similar results^{81, 102, 129, 130, 172-176}. A protective effect of mediolateral episiotomy on FI has been suggested in previous studies¹⁵⁰, whereas others have demonstrated an association between high rates of routine episiotomy and anal incontinence⁸⁸. Women with OVD in our study had a high rate of episiotomy, but meaningful analysis of this was not possible due to unreliable data.

An effect of smoking on FI has been found previously¹⁷⁷ and again in our study. Cigarette smoking may directly influence gastrointestinal motility, but may also be linked to other confounding factors such as educational level, physical activity, and alcohol consumption not controlled for in the present study.

6.3.5.4 Other risk factors for pelvic floor muscle trauma

Increasing age was associated with levator avulsion, probably reflecting that older age at delivery is associated with less elastic musculature. Higher prevalence of levator avulsion with increasing age has been described previously^{134, 136}.

Increasing infant birth weight was associated with both avulsion and larger hiatal areas. A similar effect of increasing infant birth weight on PFMT has also been described previously⁷³. Larger babies are associated with more tissue injury and could also help explain the effect of larger babies on UI and POP-Q \geq 2. We found no contributing effect of indication for OVD (prolonged 2nd stage of labor or fetal distress) epidural or perineal tears, and data on oxytocin augmentation and episiotomy was not available. It seems plausible that women with prolonged second stage of delivery could have a relative fetomaternal disproportion, and thus be more prone to levator trauma. An effect of prolonged second stage of delivery as indication for OVD, epidural or perineal tears has been described by other authors^{72, 73, 134}.

Main findings regarding other risk factors

We found that body mass index, infant birth weight and age are the most important risk factors, in addition to delivery mode, for pelvic floor disorders and pelvic floor muscle trauma in our study.

Obstetric anal sphincter injury was an isolated risk factor for fecal incontinence.

The effect of parity may be less important than previously assumed, when taking delivery mode and infant birth weight into account.

6.3.6 Association between ultrasound measurements, palpation and perineometry

In most previous studies, palpation and perineometry have been tested against each other^{8, 33}. Two previous studies examined palpation and perineometry against ultrasound measurements^{28, 29}, and found a stronger correlation between palpation and ultrasound than between perineometry and ultrasound measurements ($r_s=0.58$ vs $r_s=0.43$ and $r_s=0.62$ vs $r_s=0.52$). We also found a stronger correlation between palpation and ultrasound measurements than between perineometry and ultrasound measurements. Both studies, however, found a weaker correlation between assessment methods than we found in the present study, and this could be caused by other ultrasound measurements, bladder neck displacement, used in previous studies.

A publication from 2015 used measurements of the hiatal area and AP diameter at rest and at maximum contraction, and expressed differences in measurements as percentages ¹⁴⁴. This study included 459 pregnant or puerperal women, and the MOS on the weaker side was compared to changes in area and AP diameter. We used the average MOS and found a stronger correlation between the MOS and the proportional change in AP diameter ($r_s = 0.69$ in the present study versus $r_s = 0.51$ in the previous study) ¹⁴⁴. This could imply that average MOS is a better estimate of pelvic floor muscle contraction than MOS on the weaker side. On the other hand we found identical correlations between ultrasound measurements and MOS when we used either the strongest or the weakest side to calculate the correlation. Thus, the difference between these studies may be explained by a single examiner performing all palpations in our study. In the present study we found a greater proportional change in hiatal dimensions during pelvic floor muscle contractions than reported in other studies ^{25, 144}. This may be explained by different populations in the other studies.

6.4 Possible explanations and implications

6.4.1 Paper I

Explanations:

The increased risk of PFD after OVD may be due to a relative fetal maternal disproportion causing the need for OVD, or due to the mechanical effect of the forceps and vacuum devices on the pelvic floor connective tissue, muscles and nerves.

Implications:

It is recommended to avoid OVD in general, because OVD is associated with more PFD than NVD.

6.4.2 Paper II

Explanations:

The hiatal areas were larger and there was more levator avulsion and POP-Q ≥ 2 after FD, despite the fact that infants in the VD group were significantly larger. A possible explanation is that PFMT is more likely to occur during FD due to a traumatic effect of the blades of the forceps and the traction force allowed.

Implications:

It is recommended to choose VD in a delivery situation where both methods could be an option, because FD is associated with more PFMT and POP-Q ≥ 2 than VD.

6.4.3 Paper III

Explanations:

Intact pelvic floor muscle anatomy is important for pelvic floor function. Trauma to pelvic floor muscles cause disturbed support of the pelvic organs and is associated with anatomical POP-Q ≥ 2 , in particular of the anterior vaginal wall and of the uterus/mid compartment. PFMT is also associated with sPOP.

Implications:

It is recommended to avoid delivery modes that cause PFMT because PFMT is a risk factor for sPOP and POP-Q ≥ 2 .

6.4.4 Paper IV

Explanations:

We found a good, but not perfect, correlation between different modes of assessment of pelvic floor contraction. Digital palpation depends on the experience of the examiner. Perineometry

measures intravaginal pressure and is influenced by increased intraabdominal pressure which may be increased by a concomitant Valsalva maneuver.

Implications:

Ultrasound could be a new tool to assess and quantify pelvic floor muscle contraction. Ultrasound is easy to perform, and it is possible to perform the measurements off line. Measurement of levator hiatus AP diameter is an objective measure that is less prone to interrater bias than palpation, and ultrasound measurements are not influenced by increased intraabdominal pressure, as created by a concomitant Valsalva maneuver.

6.4.5 Elective Cesarean delivery to prevent pelvic floor disorders?

Explanations:

Women had significantly less PFMT and POP-Q ≥ 2 after CD compared to vaginal deliveries, and CD was associated with a decreased risk of UI and sPOP when analysing the yes/no-response to these questions. When analysing the mean symptom scores, however, there was no difference between CD and NVD for any of the sub scores or total PFDI score. A possible explanation to this is the increased risk of PFD introduced by the pregnancy per se, and also that women in the CD group could have more PFD prior to delivery. CD would not protect against already present symptoms. A weakness of our study is that we did not know the indication for elective CD.

Implications:

Cesarean section will have a limited preventive effect on pelvic floor dysfunction at a population level^{50, 119}. On the other hand, PFD caused by PFMT could be prevented by CD.

6.4.6 Associations of delivery mode to other maternal and neonatal conditions

We did not study any other effects of delivery mode on maternal or child health. Other authors have described increased maternal and neonatal morbidity after planned CD compared to planned NVD¹⁷⁸⁻¹⁸⁰. It has also been suggested that VD may be associated to more neonatal morbidity than FD, mainly cephalhematoma^{181, 182}, and no difference in morbidity was found at 5 years follow up between children delivered by FD and VD in a recent publication¹⁸³.

6.4.7 Discrepancy between anatomical prolapse and symptoms of prolapse

There was no complete overlap between symptoms and signs of POP in the present study. We used POP-Q \geq 2 as diagnostic for anatomical relevant prolapse. This definition is widely used by other authors. One could, however question whether POP-Q \geq 2 is clinically relevant, as only 21% of the women with POP \geq 2 in this study stated they could see or feel a vaginal bulge. This indicates that POP-Q \geq 2 is not necessarily a pathological finding. However, lower grades of prolapse can progress over time and lead to prolapse symptoms¹⁸⁴. In our study population only a few women had prolapse beyond the level of the hymen, and it is difficult to draw conclusions when the numbers are small. However we found a clear tendency towards more symptoms as prolapses extended beyond the hymen. Despite this, only half the women with prolapses 0.5-1 cm beyond the hymen were symptomatic, and 82% of women with prolapses >1 cm beyond the hymen were symptomatic, as defined by seeing or feeling a vaginal bulge. This finding supports that only *symptomatic* prolapse needs treatment. However, other prolapse related symptoms, such as urinary tract and bowel dysfunction, should also be kept in mind in the clinical evaluation of patients.

6.4.8 Discrepancy between symptoms and signs of prolapse after forceps and vacuum deliveries

In Paper I we concluded that there was no difference in sPOP after FD compared to VD, but in paper II we found more PFMT and POP-Q \geq 2 after FD compared to VD. An important question is: "Why do women have more PFMT and POP-Q>2 after FD than VD, but still do not experience more sPOP?"

One explanation could be that symptomatic and anatomical prolapse are different conditions, with different risk factors. Another explanation is that prolapse symptoms can develop over time. The mean age of women participating in this study was 47-48 years, whereas mean age at first prolapse surgery at Trondheim University Hospital is currently 63 years (own, unpublished data). Women were examined on average 28 years after their first delivery. Thomas et al have demonstrated an average latency of 33.5 years between the first delivery and prolapse surgery in women with avulsion¹⁸⁵.

6.5 What does this study add?

Main new findings

There was no difference in prevalence of pelvic floor disorders between forceps and vacuum deliveries 15-23 years after delivery

There was more pelvic floor muscle trauma and anatomical pelvic organ prolapse after forceps than after vacuum deliveries 16-24 years after delivery

The association between pelvic floor muscle trauma and symptoms and signs of pelvic organ prolapse was confirmed in women from a normal population.

There was a moderate to strong correlation between palpation, perineometry, and ultrasound assessment of pelvic floor muscle contractions.

We have defined a four-point contraction scale using the proportional change in levator hiatus anteroposterior diameter on ultrasound, which can form the basis for a validation of a contraction scale for ultrasound measurements.

7 Conclusions

We found that PFD was associated with mode of delivery. CD was associated with decreased risk of UI and sPOP 15-23 years after delivery compared to NVD. OVD was associated with increased risk of FI and sPOP compared to NVD. We found no difference between FD and VD for any PFD.

We found that CD was associated with decreased risk of PFMT and POP-Q compared to NVD 16-24 years after delivery. VD had similar risk to NVD, whereas FD had increased risk for PFMT and POP-Q ≥ 2 compared to NVD and VD.

Furthermore we found that PFMT was a risk factor for symptoms and signs of POP in women from a normal population.

Pelvic floor ultrasound can be used to assess pelvic floor muscle contraction, and we found a strong association between proportional change in levator hiatal AP diameter between rest and contraction measured by ultrasound and digital assessment of pelvic floor muscle contraction using the MOS.

8 Future perspectives

8.1 Research questions that can be studied in this study population

8.1.1 Data from existing data set

The questionnaire contained one question on sexuality. We also acquired ultrasound volumes of the anal sphincters. These data in combination with presented data will give the possibility to answer the following questions:

- Are PFMT and muscle contraction associated with sexual dysfunction?
- Are PFD and POP-Q ≥ 2 associated with sexual dysfunction?
- Is muscle contraction associated with PFMT?
- Are symptoms of UI, AI and sPOP related to PFMC in general or UI in particular?
- Is muscle contraction related to delivery mode? And can this provide a possible explanation to why women have more PFMT and POP-Q after FD than VD but not experience more PFD?
- Are persistent sphincter defects on ultrasound associated with FI and delivery mode?
- Are OASIS associated with delivery mode and FI?

8.1.2 Supplemental information from patient records

Other analyses could be done with supplemental information from patient records are:

- Is PFMT associated with obstetrician's experience (trainee, consultant)?
- Is PFMT associated with primary or secondary FD and VD?

8.1.2 Follow up study

We plan to conduct a follow up study of women included in the present study 10-15 years from now. The most important question is whether differences between delivery groups will become larger or smaller with advancing age? Some authors suggest that there is no progress of POP over time¹⁸⁶⁻¹⁸⁸, whereas other studies have demonstrated a progression of POP with need for surgery¹⁸⁴. FI has increasing prevalence with age^{49, 50}. UI also becomes more frequent with advancing age, and in addition, UI has peak prevalence around menopause⁵¹. We found differences in PFMT and POP-Q between FD and VD, but no differences in symptoms of UI, FI or sPOP. It has been postulated that there is a mean time interval of 34

years between the initial PFMT and the need for prolapse surgery¹⁸⁵. Thus, important future research questions are:

- 1) Will differences in PFD symptoms between delivery groups increase?
- 2) Will there be a progression in grade of anatomical POP?

8.2 Designing new studies

8.2.1 Is a randomized study feasible?

The ideal study design to determine causality between delivery mode and pelvic floor disorders is a randomized controlled trial. We are aware of two previous studies examining differences in OASIS between FD and VD^{101, 181}. Randomization between different delivery modes is probably not possible because doctors in different countries tend to have preferences in operative delivery mode. Doctors need to be equally well trained in FD and VD before randomization. Another disadvantage of a randomized study is the long follow up period needed to investigate the long term consequences of the delivery mode.

8.2.2 Comparison of pelvic floor muscle trauma and pelvic organ prolapse to women from a patient population

At Trondheim University Hospital there is a local quality registry for women undergoing prolapse surgery. These data are limited to a simplified questionnaire of pre- and postoperative symptoms, a simple grading of prolapse in each compartment (grade 1-4), and questions regarding patient satisfaction and surgery related complications. We plan to conduct a study of women undergoing surgery during a 12 month period. Women will be asked similar questions prior to surgery and after 6 months. They will be examined in a standardized way including pelvic floor ultrasound. This study will improve the quality of the registry. We will also collect data that enable us to compare results from women from the normal population with the patient population.

8.2.3 Validation study of ultrasound scale for pelvic floor muscle contraction

We have proposed an ultrasound derived four graded contraction scale, which corresponds to the MOS. Further studies are needed to determine the most suitable ultrasound measurement (bladder neck descent, different angles, absolute and proportional changes in levator hiatus area and diameters) and if 2D could be used instead of 3D/4D ultrasound. Validation in

different populations is needed in order to determine validated cutoffs for an ultrasound scale for pelvic floor muscle contraction. We have planned to validate the ultrasound scale in three different groups:

- 1) Women planned for prolapse surgery
- 2) Women planned for incontinence surgery
- 3) Pregnant women.

Women will be assessed prior to surgery/ delivery, and six months after surgery/ delivery.

6.2.5 Is hiatal anatomy different for Norwegian women?

Are levator hiatal areas larger in Norwegian/Nordic women? Which cut offs are valid for the levator urethral gap for assesment levator avulsion in Norwegian/ Nordic women?

Most studies in the ultrasound field come from patient populations in Australia, and definitions used for diagnosing levator avulsions and levator hiatal ballooning are established in these populations, that differ ethnically from Norwegian or Nordic populations. There is a growing number of publications from China and European countries. A multicenter Nordic study is warranted.

9 Bibliography

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Errata

1) Correction regarding selection of potential study participants:

Paper I:

“We included all primiparous women with OVD or CD during 1990-97, and all primiparous women with NVD from January 1st to July 1st of each calendar year, to include a similar number of women with NVD stratified by year of first delivery.”

Paper II

“...In that study we had invited all primiparous women with forceps, vacuum or Cesarean delivery during 1990-97 and all primiparous women with normal vaginal delivery from January 1st to July 1st of each calendar year...”

The correct statement in both papers is: “...and 130 consecutive women with normal vaginal delivery (NVD) from January 1st to March or April each calendar year...”

For the years 1996 and 1997 a sampling error occurred, and women with normal vaginal delivery after March or April were invited to participate up to a total of 130 women per year.

2) Correction in thesis regarding the use of “mean” for symptom scores

Paragraph 5.4:

“There was no significant difference in mean values for any of the scales comparing CD to NVD”. The word “mean” should be deleted

“The only significant differences between groups were mean POPDI and CRADI score....”. Should be: “The only significant differences between groups were the POPDI and CRADI scores”

Paragraph 6.4.5:

“When analyzing the mean symptom scores...” should be: “When comparing the symptom scores....”

Papers

Paper I

Paper II

Paper III

Paper IV

Appendices

I Study participant information

II Questionnaire

III Clinical examinations

IV Letter to editor and Authors' reply