Aus dem
Universitätsklinikum Düsseldorf
Institut für Diagnostische und Interventionelle Radiologie
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Funktionelle Beckenbildgebung

Kumulative Habilitationsschrift
zur Erlangung der venia legendi
für das Fach Radiologie
des Fachbereichs Medizin
der Heinrich-Heine-Universität Düsseldorf

vorgelegt von
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Abkürzungen

CO_2	Kohlendioxid
CT	Computertomographie
2D	zweidimensional
3D	dreidimensional
ESUR	Europäische Gesellschaft für Urogenitale Radiologie
ESGAR	Europäische Gesellschaft für Gastrointestinale und Abdominelle Radiologie
ICS	Internationale Kontinenz Gesellschaft
MRT	Magnetresonanztomographie
PET	Positronen-Emissions-Tomographie
trueFISP	Fast Imaging with Steady State Precession

I. Einleitende Worte

Die Magnetresonanztomographie (MRT) liefert überlagerungsfreie und objektiv beurteilbare Schnittbilder mit einer hohen Detailgenauigkeit und einem exzellenten Weichteilkontrast, weshalb die MRT die Schnittbildgebung der Wahl zur Darstellung der Beckenorgane ist [1]. Diese Vorteile der MRT wurden von gynäkologischer und urologischer Seite jedoch lange Jahre nur zögerlich als ergänzende Informationsquelle zur Therapieplanung bzw. zum Staging von Beckentumoren genutzt. Aufgrund einer Vielzahl an publizierten wissenschaftlichen Arbeiten, die sich u.a. mit der Staginggenauigkeit der MRT im Vergleich zu den klinisch durchgeführten Untersuchungen oder auch mit der technischen Weiterentwicklung zur dezidierten (Umfeld-) Diagnostik von Beckentumoren beschäftigten, wurde bei den gynäkologischen Tumoren insbesondere für das Zervix- und Endometriumkarzinom der ergänzende Mehrwert der MRT im klinischen Setting unterstrichen [2–5]. Auch bei den selteneren gynäkologischen Beckentumoren wie dem Vulva- und dem Vaginalkarzinom ist die Becken-MRT im therapeutischen Setting sinnvoll, was die Verankerung dieser Bildgebungsmodalität nicht nur in den aktuellen S3-Leitlinien des Zervix- und Endometriumkarzinomes, sondern auch in den aktuellen S2k-Leitlinien des Vulva- und Vaginalkarzinomes verdeutlicht [6–9].

In der onkologischen MR-Bildgebung der Beckenorgane hat sich zur Erhöhung der diagnostischen Genauigkeit die Kombination aus hochaufgelöster T2-gewichteter Sequenz, Diffusionswichtung und Kontrastmitteldynamik etabliert [10–12]. Die als funktionelle MRT zusammenfassbare Sequenzkombination kommt mittlerweile in der primären lokalen Ausbreitungsdiagnostik, in der Therapiekontrolle und in der Rezidivdiagnostik zum Einsatz [6, 7, 13]. Eine kürzlich veröffentlichte Übersichtsarbeit fasst den aktuellen Stand der Diagnostik und des Stagings gynäkologischer Beckentumore mittels MRT zusammen (**Alt CD**, Kubik-Huch R, Radiologie up2date 2017)[1].

Des Weiteren kann als funktionelle Schnittbildgebung die kontrastmittelgestützte Computertomographie (CT) und die Positronen-Emissions-Tomographie (PET) zur Anwendung kommen, deren Einsatz bei gynäkologischen Beckenmalignomen in einer 2-teiligen Übersichtsarbeit beleuchtet wurde (**Alt CD** et al., Strahlenther Onkol 2011 sowie Brocker KA, **Alt CD** et al., Strahlenther Onkol 2011) [14, 15]. Während für die gynäkologischen Beckentumore für das lokale Staging die funktionelle Becken-MRT empfohlen ist, wird für das Ovarialkarzinom, da es schon früh eine thorakale oder abdominelle Ausbreitung zeigen kann, die kontrastmittelgestützte CT empfohlen [16].

Innerhalb der eigenen wissenschaftlichen Arbeit bezüglich der Anwendung der MRT in der onkologischen Bildgebung wurde die funktionelle MRT in Zusammenarbeit mit der Gynäkologie zur Diagnostik des primären Zervix- und Endometriumkarzinomes [17–19], und in Zusammenarbeit mit der Urologie in Studien zum Prostatakarzinom eingesetzt [20–25].

Ein weiteres großes Gebiet der funktionellen MRT stellt die Diagnostik bei Beckenbodendysfunktionen dar. Neben morphologischen Sequenzen wird mittels cine-Sequenzen der Vorgang der Ausscheidung ohne Manipulation durch Untersuchungsinstrumente dokumentiert [26–29]. Diese objektive und reproduzierbare Darstellung der Interaktion der Beckenorgane und des Beckenbodens ist insbesondere bei komplexen Defekten oder in der Rezidiv-Situation relevant [30, 31].

Innerhalb der eigenen wissenschaftlichen Arbeit wurde die dynamische MRT in Zusammenarbeit mit der Gynäkologie (Bereiche Urogynäkologie und Geburtshilfe) und der Orthopädie (Bereich Paraplegiologie) eingesetzt.

Die funktionelle Beckenbildgebung bietet ein faszinierendes und breites Forschungsspektrum mit vielen Facetten und der Möglichkeit, mit unterschiedlichen klinischen Fachbereichen zusammenzuarbeiten. Von den beiden Schwerpunkten funktionelle onkologische Beckenbildgebung und funktionelle Bildgebung des Beckenbodens möchte ich im Folgenden den Fokus auf den wissenschaftlichen Fortschritt und die Praxisrelevanz der funktionellen Bildgebung des Beckenbodens legen.

II. Literaturangaben der zugrundeliegenden Forschungsarbeiten

1) **Alt CD**, Brocker KA, Lenz F, Sohn C, Kauczor HU, Hallscheidt P: MRI findings before and after prolapse surgery. **Acta Radiol** 2014;55(4):495-504. **Impact Factor 2013: 1.350**

2) **Alt CD**, Benner L, Mokry T, Lenz F, Hallscheidt P, Sohn C, Kauczor HU, Brocker KA: Five-year outcome after pelvic floor reconstructive surgery: evaluation using dynamic magnetic resonance imaging compared to clinical examination and quality-of-life questionnaire. **Acta Radiol** 2018;59(10):1264-1273. **Impact Factor 2018: 2.011**

3) **Alt CD**, Katzenberger SM, Hallscheidt P, Sohn C, Kauczor HU, Eickhoff SB, Brocker KA: Urethral length and bladder neck behavior: can dynamic magnetic resonance imaging give the same results as introital ultrasound? **Arch Gynecol Obstet** 2019 Mar;299(3):809-816. **Impact Factor 2018: 2.236**

4) **Alt CD**, Hampel F, Hallscheidt P, Sohn C, Schlehe B, Brocker KA: 3 T MRI-based measurements for the integrity of the female pelvic floor in 25 healthy nulliparous women. **Neurourol Urodyn** 2016;35(2):218-23. **Impact Factor 2016: 3.560**

5) **Alt CD**, Hampel F, Hallscheidt P, Sohn C, Schlehe B, Brocker KA: Early postpartum pelvic floor changes in primiparous women after vaginal delivery using 3T MRI. **Neurourol Urodyn** 2017;36:2064-2073. **Impact Factor 2017: 3.560**

6) El Sayed RF and **Alt CD**, Maccioni F, Meissnitzer M, Masselli G, Manganaro L, Vinci V, Weishaupt D; ESUR and ESGAR Pelvic Floor Working Group: Magnetic resonance imaging of pelvic floor dysfunction - joint recommendations of the ESUR and ESGAR Pelvic Floor Working Group. **Eur Radiol** 2017;27(5):2067-2085. **Impact Factor 2017: 3.967**

7) Putz C and **Alt CD**, Hensel C, Wagner B, Gantz S, Gerner HJ, Weidner N, Grenacher L: 3T MR-defecography-A feasibility study in sensorimotor complete spinal cord injured patients with neurogenic bowel dysfunction. **Eur J Radiol** 2017;91:15-21. **Impact Factor 2017: 2.462**

III. Kurze Zusammenfassung der Inhalte aus den Publikationen

1) Alt CD, Brocker KA, Lenz F, Sohn C, Kauczor HU, Hallscheidt P: MRI findings before and after prolapse surgery. Acta Radiol 2014 May;55(4):495-504. Impact Factor 2013: 1.350

In dieser Studie wurde der Einfluss der Beckenorganmobilität zur Beurteilung des Beckenorganvorfalles untersucht, da die gängige Gradeinteilung beim Beckenorganvorfall nach der maximalen Ausprägung eines Vorfalles bestimmt wird und aufgrund individueller physiologischer Pressvorgänge nicht zwingend dem subjektiven Beschwerdebild entspricht. Die Auswertung erfolgte an 80 Patientinnen vor und nach operativer Korrektur eines symptomatischen Beckenorganvorfalles. Die Beckenorganmobilität wird als Distanz der maximal gemessenen Organsenkung zur Referenzlinie im Vergleich zum Ruhewert definiert und ist damit individuell für jede Patientin bestimmbar. Die Auswertung präoperativ, und 4- bzw. 12 Wochen postoperativ zeigte eine signifikante Verbesserung postoperativ, also eine reduzierte Mobilität des operierten Organs, die mit dem klinischen Untersuchungsbefund korrelierte. Der erstmals durch uns definierte Parameter der „Beckenorganmobilität" liefert damit die Möglichkeit der Beurteilung des individuellen Beckenbodenverhaltens und ist losgelöst von einer starren Gradeinteilung.

2) Alt CD, Benner L, Mokry T, Lenz F, Hallscheidt P, Sohn C, Kauczor HU, Brocker KA: Five-year outcome after pelvic floor reconstructive surgery: evaluation using dynamic magnetic resonance imaging compared to clinical examination and quality-of-life questionnaire. Acta Radiol 2018;59(10):1264-1273. Impact Factor 2018: 2.011

In dieser Studie wurde das therapeutische Outcome nach operativer Korrektur eines symptomatischen Beckenorganvorfalles mittels dynamischer MRT im Vergleich zur klinisch urogynäkologischen Untersuchung und einem Lebensqualitäts-Fragebogen evaluiert. Untersuchungszeitpunkte waren präoperativ sowie 12 Wochen, 1 Jahr und 5 Jahre postoperativ. Bei 26 Patientinnen lagen alle drei Auswertungen zu allen Zeitpunkten vor. Die Ergebnisse der dynamischen MRT wichen am stärksten in der 5-Jahres-Kontrolle vom klinischen urogynäkologischen Untersuchungsbefund ab; die dynamische MRT diagnostizierte deutlich mehr Rezidiv- und neu aufgetretene Senkungszustände im hinteren Kompartiment (Enterozelen, Rektozelen) als die urogynäkologische Untersuchung. Die Auswertung des Parameters der

Beckenorganmobilität zeigte für die dynamische MRT nach 5 Jahren vergleichbare Werte zum präoperativen Befund – bis auf die Ergebnisse der Harnblase, die weiterhin ein sehr gutes postoperatives Outcome zeigte. Die MRT-Ergebnisse korrelierten mit dem subjektiven Empfinden der Patientinnen nach Auswertung der Lebensqualität-Fragebögen insbesondere hinsichtlich des hinteren Kompartimentes.

3) Alt CD, Katzenberger SM, Hallscheidt P, Sohn C, Kauczor HU, Eickhoff SB, Brocker KA: Urethral length and bladder neck behavior: can dynamic magnetic resonance imaging give the same results as introital ultrasound? Arch Gynecol Obstet 2019 Mar;299(3):809-816. Impact Factor 2018: 2.236

In dieser Studie wurden zwei Bildgebungsmodalitäten (Sonographie und dynamische MRT) hinsichtlich der Bestimmung der Harnröhrenlänge sowie des Nachweises spezifischer Veränderungen des Blasenhalses bei Senkungszuständen verglichen. Als Patientenkollektiv dienten Frauen, die sich aufgrund eines symptomatischen Senkungszustandes einer Operation mit alloplastischem Material (Netz, Bändchen) unterzogen hatten. Es wurden insgesamt 320 Bildserien von 40 Patientinnen (Sonographie und MRT, präoperativ und 12-Wochen postoperativ) ausgewertet. Während die Urethra bei allen Patientinnen im MRT sichtbar und damit messbar war, war bei fast ¼ der Patientinnen die Urethra auf den präoperativen Ultraschallbildern während des Pressens aufgrund einer ausgedehnten Blasensenkung nicht vollständig einsehbar und damit nicht valide messbar. Basierend auf den Patientinnen mit verfügbaren Messwerten in beiden Modalitäten ergab die Hochrechnung mittels bootstrap Analyse, dass die beiden Modalitäten hinsichtlich der Urethralänge vergleichbar sind mit einer mittleren intermodalen Messabweichung von 2-3 mm. Allerdings stimmt die in der dynamischen MRT gestellten Diagnose eines rotatorischen/vertikalen Blasenhalsdeszensus bzw. einer Trichterbildung nur mäßig mit der Sonographie überein, wenn man die Sonographie als Goldstandard verwendet.

4) Alt CD, Hampel F, Hallscheidt P, Sohn C, Schlehe B, Brocker KA: 3 T MRI-based measurements for the integrity of the female pelvic floor in 25 healthy nulliparous women. Neurourol Urodyn 2016 Feb;35(2):218-23. Impact Factor 2016: 3.560

In dieser Pilotstudie wurde bei 25 gesunden jungen Nullipara eine native MRT des Beckenbodens durchgeführt. Ziel war es, in einer zweidimensionalen (2D) MRT Parameter zu bestimmen, die in der Literatur als Indikatoren für die Intaktheit des Beckenbodens gelten, und sonst unter Verwendung des translabialen dreidimensionalen (3D) Ultraschalles oder von 3D-MRT-Modellen gemessen werden. Alle 10 gängigen Messparameter konnten in der 2D-MRT bestimmt werden. Drei Parametern zeigten eine anatomische Varianz, 6 Parameter waren vergleichbar zu den in den anderen Modalitäten erhobenen Messwerten, und bei einem Parameter konnten wir erstmals einen cut-off Wert für die MRT definieren. Vorteil der Machbarkeit der Messungen in einer 2D-MRT ist der geringere Zeitaufwand bei der Nachbearbeitung der Aufnahmen. Die erhobenen Messergebnisse können als Referenz für weitere MRT-Studien hinsichtlich der Beckenbodenintegrität dienen.

5) Alt CD, Hampel F, Hallscheidt P, Sohn C, Schlehe B, Brocker KA: Early postpartum pelvic floor changes in primiparous women after vaginal delivery using 3T MRI. Neurourol Urodyn 2017; 36:2064-2073. Impact Factor 2017: 3.560

In dieser Pilotstudie wurden 25 Primipara innerhalb 1 Woche nach zeitgerechter vaginaler Geburt mittels nativer MRT hinsichtlich morphologisch sichtbarer Veränderungen postpartal untersucht. Zudem wurden Messungen zur Beckenbodenintegrität durchgeführt und mit einer Kontrollgruppe (gesunde Nullipara, Daten aus der zuvor beschriebenen Pilotstudie) verglichen, die mit dem gleichen MRT-Protokoll untersucht worden sind. Wir konnten zeigen, dass bei allen Frauen sowohl oberflächliche als auch tiefer gelegene Strukturen (Bänder, Muskeln, Knochen) postpartale Veränderungen aufwiesen, hauptsächlich Ödem oder Hämatom. Die Messungen der Parameter zur Integrität des Beckenbodens wiesen signifikante Unterschiede zur Nullipara-Kontrollgruppe auf. Die MRT bietet damit insbesondere bei strukturellen Veränderungen tief im kleinen Becken oder im Knochen einen Vorteil gegenüber der üblicherweise direkt postpartal angewandten Perinealsonographie.

6) El Sayed RF and Alt CD, Maccioni F, Meissnitzer M, Masselli G, Manganaro L, Vinci V, Weishaupt D; ESUR and ESGAR Pelvic Floor Working Group: Magnetic resonance imaging of pelvic floor dysfunction - joint recommendations of the ESUR and ESGAR Pelvic Floor Working Group. Eur Radiol. 2017;27(5):2067-2085. Impact Factor 2017: 3.967

Dies sind die ersten publizierten Empfehlungen zur dynamischen MRT / MR-Defäkographie, die zum Ziel hat, die Indikationen, die Patientenvorbereitung, die Durchführung der MRT, die radiologische Befundung und die abschließende Bewertung zu standardisieren, um zum einen die Abläufe in der klinischen Praxis zu optimieren, zum anderen aber auch Studienergebnisse in der Literatur vergleichbar zu machen. Die Empfehlungen stützen sich auf Ergebnisse einer ausgedehnten Literaturrecherche zwischen 1993 und 2013 und einem Expertenkonsensus von Radiologen aus der Arbeitsgruppe Beckenboden unter der Schirmherrschaft der Europäischen Gesellschaft für Urogenitale Radiologie (ESUR) und der Europäischen Gesellschaft für Gastrointestinale und Abdominelle Radiologie (ESGAR). Mindestens 80% Übereinstimmung wurde als Konsens gewertet, welcher in 88% bei den insgesamt 82 zur Diskussion gestellten Positionen erreicht wurde.

7) Putz C and Alt CD, Hensel C, Wagner B, Gantz S, Gerner HJ, Weidner N, Grenacher L: 3T MR-defecography-A feasibility study in sensorimotor complete spinal cord injured patients with neurogenic bowel dysfunction. Eur J Radiol 2017;91:15-21. Impact Factor 2017: 2.462

Diese Machbarkeitsstudie befasste sich mit der Durchführung der dynamischen MRT bzw. MR-Defäkographie bei 20 Patient(inn)en mit komplettem sensomotorischem Querschnitt nach Trauma zur Detektion von Ausscheidungsstörungen. Da querschnittgelähmte Patient(inn)en nicht mehr willkürlich ihren Darm entleeren können, wurde nach der rektalen Füllung mit Ultraschallgel die Defäkation unter Zuhilfenahme von CO_2-Tabletten und einer digital-rektalen Stimulierung induziert. Darunter war bei allen Patienten eine Ausscheidung mit der funktionellen MRT dokumentierbar. Zur Auswertung der induzierten Ausscheidung wurden Standardparameter gemessen, die zur Bewertung einer obstruktiven Defäkationsstörung etabliert sind, und schließlich mit Literaturangaben nicht querschnittgelähmter asymptomatischer Personen verglichen. Wir konnten mit dieser Pilotstudie demonstrieren, wie eine MR-Defäkographie bei Querschnittgelähmten suffizient durchführbar ist und dass die MR-Defäkographie ergänzende Informationen hinsichtlich der Ausscheidungsstörungen geben kann, die für ein individuelles Therapiekonzept relevant sein können.

Diese Arbeit erhielt 2012 den Forschungspreis der Deutschsprachigen Medizinischen Gesellschaft für Paraplegie e.V.

IV. Grundlagen der Forschungsarbeiten

IV.1 Anatomie

Der Beckenboden ist ein komplexes System aus Muskulatur, Bändern und Faszien, der sich zwischen der Symphyse, den Schambeinästen und den Sitzbeinhöckern ausspannt und damit das kleine Becken verschließt. Die Beckenorgane liegen auf dem Beckenboden und werden durch einen aktiven und passiven Halteapparat im kleinen Becken fixiert [32, 33]. Eine Beschädigung dieses komplexen Halteapparates oder auch nur einzelner Komponenten (bspw. faszial, muskulär oder nerval) kann zu einer Beckenbodenfunktionsstörung führen, die sich als Beckenbodenschwäche, Beckenorganvorfall oder Inkontinenz manifestieren und die Lebensqualität beträchtlich einschränken kann. Von einer Beckenbodenfunktionsstörung sind Frauen häufiger betroffen als Männer [34]. Abhängig vom führenden Symptom werden die Patientinnen primär durch die Urologie (vorderes Kompartiment mit Harnblase und Urethra), die Urogynäkologie (vorderes und mittleres Kompartiment mit zusätzlich Uterus, Zervix und Vagina) oder die Proktologie (hinteres Kompartiment mit Rektum und Douglasraum) betreut.

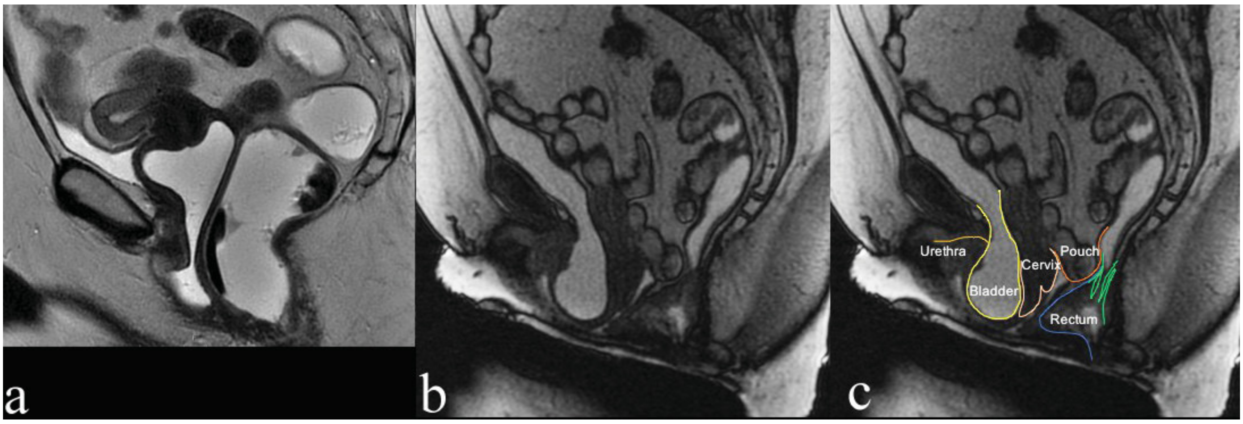
Da das kleine Becken mit dem Beckenboden jedoch als eine komplexe Einheit zu betrachten ist, ist ein symptomatischer Defekt in einem Kompartiment häufig mit weiteren Funktionsstörungen der anderen Kompartimente vergesellschaftet [35].

IV.2 Diagnostik

Abhängig von der primär führenden Symptomatik können unterschiedliche Funktionsbereiche in die Abklärung/Therapie der Beckenboden-Beschwerden eingebunden sein: die Urologie bei Beschwerden im vorderen Kompartiment (Harnblase, Urethra), die (Uro-)gynäkologie bei Beschwerden im mittleren und vorderen Kompartiment (Uterus, Vagina, Harnblase, Urethra), die Proktologie bei Beschwerden im hinteren Kompartiment (Rektum) oder auch die Internisten bei kompartiment-unabhängigen, häufig darmassoziierten, Beschwerden. Nicht selten finden sich jedoch kombinierte Defekte, so dass eine umfassende Diagnostik und Therapie einer Beckenbodendysfunktion fließend in urologische, gynäkologische, internistisch/ proktologische und radiologische Funktionsbereiche übergehen kann [34]. Jeder der genannten Fachbereiche bietet eine Basis- und Spezialdiagnostik an, wie z.B. die Urodynamik, die Uroflowmetrie, die Zysto-Urethrographie, den

Ultraschall, die Spekulumuntersuchung unter Valsalva-Manöver, die digital-rektale Untersuchung, die Endosonographie, oder die Rektoskopie. Von radiologischer Seite wurde jahrzehntelang die konventionelle Defäkographie als bildgebende Diagnostik angeboten [36–38].

In den letzten Jahren wurde die dynamische MRT in den Fokus zur Darstellung funktioneller Beckenbodendefekte gebracht, da sie als Schnittbildgebung den Vorteil hat, überlagerungsfrei und ohne manuelles Eingreifen oder technische Restriktionen objektiv beurteilbare Bilder aller Kompartimente im Gesamten zu generieren und den Beckenboden und die Beckenorgane zudem in ihrer Funktionalität zeigt, was für jeden Betrachter damit gleichermaßen beurteilbar ist [26–29, 39]. Dies ist insbesondere für eine primäre Therapieplanung bei komplexen Defekten oder auch in der umfassenden Beurteilung von Rezidiven bei bereits operativ versorgter Senkungsproblematik relevant [30, 31]. Von Bedeutung ist in diesem Zusammenhang auch die Entwicklung eines MR-sichtbaren Netzes, welches postoperativ in seiner Ausdehnung und Lage zu relevanten anatomischen Strukturen bewertet werden und damit beispielsweise bei postoperativen Komplikationen für eine präzisere Evaluation herangezogen werden kann [40–42].



MR-Defäkographie. a) sagittale Aufnahme in Ruhe mit rektaler und vaginaler Füllung. b) sagittale Aufnahme während der Ausscheidung. c) Farbliche Markierung der Defekte in allen drei Kompartimenten: Pulsionszystozele und hypermobile Urethra, Partialprolaps der Gebärmutter, Enterozele mit Tiefertreten von Dünndarmschlingen im Douglas-Pouch, Rektumdeszensus, Ausbildung einer kleinen vorderen Rektozele und einer Intussuszeption

V. Detaillierte Ausführung der Untersuchungen und Ergebnisse

1) Alt CD, Brocker KA, Lenz F, Sohn C, Kauczor HU, Hallscheidt P: MRI findings before and after prolapse surgery. Acta Radiol 2014 May;55(4):495-504. Impact Factor 2013: 1.350

Das therapeutische Outcome nach Beckenbodenchirurgie wird anhand eines standardisierten Grading-Systems der Internationalen Kontinenz Gesellschaft (ICS) evaluiert [43]. Die Gradeinteilung beruht auf Werten der maximalen Ausdehnung eines Beckenorganvorfalles, was aber gegebenenfalls nicht dem subjektiven Outcome der Patientin entspricht, da jede Frau eine eigene Physiologie während des Pressvorganges hat.

Ziel der Arbeit war die Evaluierung des Einflusses des Parameters der Beckenorganmobilität, gemessen in der dynamischen MRT bei Patientinnen vor und nach netzgestützter Beckenbodenchirurgie bei symptomatischem Beckenorganvorfall.

Die Messungen wurden an einem 1,5 Tesla Scanner (Siemens) auf einer parasagittalen T2 turbo spin echo Sequenz in Ruhe, auf einer parasagittalen T2 trueFISP single-shot Sequenz während des Kneifens und auf einer parasagittalen T2 trueFISP single-shot Sequenz unter maximalem Pressen durchgeführt. Die Patientinnen erhielten präoperativ, sowie 4 und 12 Wochen postoperativ eine dynamische MRT und eine urogynäkologische Untersuchung. Der Beckenorganvorfall wurde im MRT als Abstand des Referenzpunktes (Blasenhals, vordere Muttermundslippe, Pouch und Rektum) zur Referenzlinie (Pubococcygeallinie, Symphysenlängsachse) gemessen. Die Beckenorganmobilität wurde definiert als die Differenz zwischen gemessenem Ruhewert und maximalem Presswert für jeden einzelnen Referenzpunkt. Alle Patientinnen erhielten eine Defektrekonstruktion mittels Netzplastik. Die Operationen wurden von einem Operateur durchgeführt, der unterschiedliche Netzhersteller verwendete.

Es wurden 80 Patientinnen in die Studie eingeschlossen. Abhängig von der klinischen Diagnose bezüglich des symptomatischen Beckenorganvorfalles erhielten 51 Patientinnen ein vorderes Netz, 16 ein hinteres Netz und 13 ein kombiniertes Netz.

Die errechnete Beckenorganmobilität ging im operierten Kompartiment in den postoperativen Aufnahmen signifikant zurück ($p<0,001$). Zwischen der 4 Wochen und der 12 Wochen Kontrolle zeigten sich die Werte nicht signifikant unterschiedlich.

Auch die klinische Untersuchung zeigte in der 12 Wochen Kontrolle, wenn überhaupt, nur noch eine minimale und asymptomatische Beckenorgansenkung Grad 1.

Zusammenfassend stellt die dynamische MRT überlagerungsfrei die maximale Ausprägung eines Beckenorganvorfalles dar.

Wir konnten zeigen, dass die Bestimmung der Beckenorganmobilität das Therapieoutcome für jede Patientin individuell dokumentiert, losgelöst von einem allgemeinen Grading-System, welches nur auf einem maximalen Prolapswert beruht.

Table 2. Overall results of pelvic organ mobility preoperatively and at short-term follow-up (4 and 12 weeks) after reconstructive surgery using mesh repair in total study population, $n = 80$.

	△ B0	△ B4	△ B12	△ C0	△ C4	△ C12	△ P0	△ P4	△ P12	△ R0	△ R4	△ R12
MV (cm)	3.13	1.15	1.40	2.49	1.17	1.12	2.37	1.18	1.40	1.56	0.85	1.00
SD (cm)	±2.21	±0.96	±1.08	±2.28	±1.20	±1.26	±1.89	±1.50	±1.55	±1.27	±1.66	±1.20
Median (cm)	3.09	1.13	1.38	2.40	1.06	1.00	2.24	0.99	1.03	1.45	0.64	0.88
MVC	–	63%	55%	–	56%	58%	–	56%	54%	–	56%	39%
P value	–	5.66* e^{-11}	1.50* e^{-08}	–	1.25* e^{-07}	4.66* e^{-07}	–	4.01* e^{-06}	0.0001	–	0.001	0.0009
P value (12wk-4wk)	–	–	0.03	–	–	0.75	–	–	0.166	–	–	0.99
Total	80	80	80	80	80	80	80	80	80	80	80	80

4wk, 4 weeks; 12wk, 12 weeks; △, Difference at maximum strain minus at rest; B, bladder base; C, cervix; MVC, median value change to initial results (%); MV, mean value; P, pouch of Douglas; pre, preoperative; R, anterior rectal wall; SD, standard deviation.

Wiedergabe der Tabelle mit freundlicher Genehmigung von SAGE Pub [44]

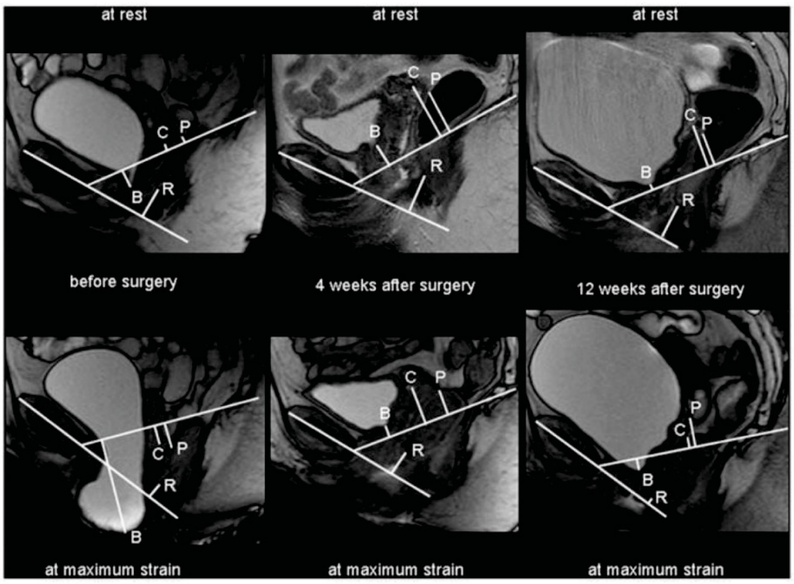


Fig. 3. Short-term follow-up results for anterior mesh repair in a 65-year-old woman presenting on clinical examination with grade II symptomatic cystocele and grade I uterine prolapse. Preoperative MRI at maximum strain showed severe cystocele, mild uterine prolapse, and a rectal descent, without falling below the MPL. Even with filled bladder, there was no significant cystocele at 12 weeks postoperatively, but better demarcation of the rectal descent, still without falling below the MPL. B, bladder base; C, cervix; MPL, midpubic line; P, pouch of Douglas; PCL, pubococcygeal line; R, anterior rectal wall.

Wiedergabe der Abbildung mit freundlicher Genehmigung von SAGE Pub [44]

2) Alt CD, Benner L, Mokry T, Lenz F, Hallscheidt P, Sohn C, Kauczor HU, Brocker KA: <u>Five-year outcome after pelvic floor reconstructive surgery: evaluation using dynamic magnetic resonance imaging compared to clinical examination and quality-of-life questionnaire.</u> Acta Radiol 2018;59(10):1264-1273. Impact Factor 2018: 2.011

Die dynamische MRT bildet das gesamte Becken während eines Valsalva-Manövers ab und hilft bei der Diagnose von posttherapeutischen Beckenboden-veränderungen nach Rekonstruktionschirurgie.

Ziel der Arbeit war die Evaluierung des therapeutischen Outcomes 5 Jahre nach
netzgestützter Beckenbodenchirurgie bei symptomatischem Beckenorganvorfall unter Verwendung der klinisch urogynäkologischen Untersuchung, der dynamischen MRT und einem standardisierten Lebensqualität-Fragebogen.

Die klinische Untersuchung, die dynamische MRT und der Fragebogen wurden präoperativ sowie postoperativ nach 12 Wochen, 1 Jahr und 5 Jahren durchgeführt bzw. von der Patientin ausgefüllt. In die Studie eingeschlossen wurden alle Frauen mit initial symptomatischem Beckenorganvorfall ≥ Grad 2. Die dynamische MRT wurde an einem 1,5 Tesla Scanner (Siemens) mit einem festgelegten Studienprotokoll gefahren, die Sequenzen für die Ausmessungen waren eine sagittale T2 turbo spin echo in Ruhe und eine sagittale T2 trueFISP unter maximalem Pressen. Es wurde zusätzlich die Beckenorganmobilität (Differenz zwischen Ruhe- und Presswert) für jeden Referenzpunkt bestimmt.

Es wurden 104 MRTs von 26 Patientinnen evaluiert. Die Ergebnisse der dynamischen MRT unterschieden sich zur klinischen Untersuchung vor allem beim Gesamtoutcome nach 5 Jahren, insbesondere aber im hinteren Kompartiment. Die dynamische MRT diagnostizierte deutlich mehr Rezidiv- und de-novo Organsenkungen im hinteren Kompartiment (n=17) als die klinische urogynäkologische Untersuchung (n=4). Die Werte für die Beckenorganmobilität glichen sich in der 5 Jahres Kontrolle den präoperativen Werten an, bis auf die Werte für die Blase. Die Beckenorganmobilität reflektierte die Ergebnisse des Fragebogens am besten hinsichtlich der Funktionsstörungen im hinteren Kompartiment.

Zusammenfassend zeigte sich in dieser Studie in allen Untersuchungsmodalitäten eine Tendenz zum Rezidiv- oder de-novo Beckenorganvorfall. Es wurde der Vorteil der dynamischen MRT hinsichtlich der objektiven und überlagerungsfreien Darstellung der Interaktion der Beckenorgane und des Beckenbodens während des Valsalva-Manövers verdeutlicht. Insgesamt korrelierte der Parameter der Beckenorganmobilität am besten mit dem persönlichen Eindruck der Patientinnen bezüglich ihrer Beckenbodenprobleme (Fragebogen-Ergebnisse).

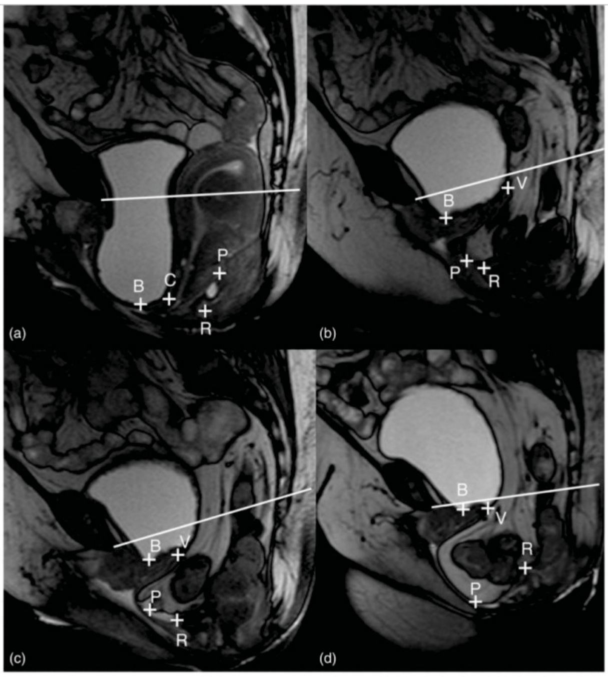


Fig. 3. A 41-year-old woman presenting with S-POP stage 3 for bladder and cervix, S-POP stage 0 enterocele, and S-POP stage 2 rectocele, who underwent anterior mesh repair with concomitant vaginal hysterectomy and MiniArc single-incision sling system by American Medical Systems. At the 12-week follow-up, clinical examination showed S-POP stage 0 for all compartments. At the one-year and five-year follow-ups, clinical examination diagnosed a recurrent rectocele S-POP stage 2, while all other compartments showed no descent. On dMRI, a multicompartment defect was initially diagnosed with grade 3 for bladder and grade 2 for cervix, pouch and rectum (a). At the 12-week follow-up (b), bladder descent grade 1 and vaginal vault grade 0 were diagnosed (enterocele and rectocele: grade 2). At the one-year and five-year follow-ups (c, d), the bladder and vaginal vault were diagnosed with grade 0, while the enterocele increased to grade 3 at the five-year follow-up with a stable grade 2 rectocele. The patient's QOL data support these results showing "general health perception" and "prolapse impact" mostly impaired before surgery, least impaired in the 12-week and one-year follow-ups, and recurrently impaired again in the five-year follow-up. B, bladder; C, cervix; P, pouch of Douglas; R, rectum; V, vaginal vault.

Wiedergabe der Abbildung mit freundlicher Genehmigung von SAGE Pub [45]

Table 2. S-POP stages gathered by clinical examination and POP grades gathered by dMRI are given for each reference point at all visits.

		CE (S-POP-stage)					dMRI (POP-grade)				*P* value* (pre surgery vs. FU)	
Reference point	Visit	0	1	2	3	4	0	1	2	3	CE	dMRI
Bladder	Pre surgery	5	2	3	15	1	10	2	8	6	–	–
	12 weeks	19	6	1	0	0	15	11	0	0	<0.001	0.001
	1 year	12	8	6	0	0	12	13	1	0	0.001	0.007
	5 years	9	7	9	1	0	6	14	6	0	0.005	0.161
Cervix/Vaginal vault	Pre surgery	12	3	3	6	2	16	4	5	1	–	–
	12 weeks	25	0	0	1	0	24	2	0	0	0.002	0.005
	1 year	26	0	0	0	0	25	1	0	0	0.001	0.007
	5 years	21	0	3	2	0	19	5	2	0	0.028	0.122
Pouch of Douglas	Pre surgery	13	3	0	9	1	7	8	11	0	–	–
	12 weeks	24	0	1	1	0	14	10	2	0	0.003	0.001
	1 year	18	6	2	0	0	11	12	3	0	0.012	0.005
	5 years	22	3	1	0	0	12	8	5	1	0.003	0.057
Rectum	Pre surgery	6	5	6	8	1	8	9	8	1	–	–
	12 weeks	20	5	0	1	0	1	12	12	1	0.001	0.029
	1 year	17	8	1	0	0	4	7	15	0	<0.001	0.104
	5 years	15	6	5	0	0	1	12	13	0	0.003	0.083

*Wilcoxon signed rank test using the individual not averaged POP stages/grades.
CE, clinical urogynecological examination; dMRI, dynamic magnetic resonance imaging; S-POP, simplified pelvic organ prolapse quantification system; POP, pelvic organ prolapse.

Wiedergabe der Tabelle mit freundlicher Genehmigung von SAGE Pub [45]

3) Alt CD, Katzenberger SM, Hallscheidt P, Sohn C, Kauczor HU, Eickhoff SB, Brocker KA: <u>Urethral length and bladder neck behavior: can dynamic magnetic resonance imaging give the same results as introital ultrasound?</u> Arch Gynecol Obstet 2019 Mar;299(3):809-816. Impact Factor 2018: 2.236

Die individuelle Länge der Urethra gilt neben einer Adipositas und vaginalen Geburten als wichtiger Faktor hinsichtlich des Therapieerfolges in der Behandlung der Stressharninkontinenz mit alloplastischem Material (insbesondere Bändchen) [46].

Um einen präoperativen Eindruck von Harnblase und Urethra zu bekommen, sollen Frauen in Ruhe und während des Valsalva-Manövers untersucht und die urethrale Länge bestimmt werden. Dies soll primär mit Ultraschall erfolgen, wobei es bisher keine Daten zum Vergleich unterschiedlicher Bildgebungsmodalitäten gibt, insbesondere Sonographie versus MRT [46].

Daher war das Ziel dieser Studie zwei Bildgebungsmodalitäten (Sonographie und dynamische MRT) hinsichtlich der Harnröhrenlänge sowie Nachweis spezifischer Veränderungen des Blasenhalses bei Senkungszuständen zu vergleichen. Als Patientenkollektiv dienten Frauen, die sich aufgrund eines symptomatischen Senkungszustandes einer Operation mit alloplastischem Material (Netz, Bändchen) unterzogen hatten. Es wurden insgesamt 320 Bildserien von 40 Patientinnen (Sonographie und MRT, präoperativ und 12-Wochen postoperativ) ausgewertet. Während die Urethra bei allen Patientinnen im MRT messbar war, war bei fast ¼ der Patientinnen die Urethra auf den präoperativen Ultraschallbildern während des Pressens nicht messbar aufgrund eines ausgedehnten Prolapses der Harnblase.

Unter Verwendung einer bootstrap Analyse mit 500.000 Wiederholungen wurde anhand unserer Daten die Differenz der Abweichung zwischen den beiden Bildgebungsmodalitäten geschätzt. Im Mittel wird die Urethralänge in der dynamischen MRT kürzer gemessen auf den Ruhebildern vor und nach OP und postoperativ auf den Pressaufnahmen, wobei der Mittelwert im unteren Millimeterbereich liegt mit 1,6 – 3,1 mm. In den präoperativen Pressaufnahmen wird die Urethralänge im dynamischen MRT schätzungsweise um 0,2 mm im Mittel länger gemessen. Die Diagnose eines rotatorischen bzw. vertikalen Blasenhalsdeszensus oder einer Trichterbildung wurde von beiden Untersuchungsmodalitäten in unserem Kollektiv übereinstimmend in 67-74% getroffen, die Hochrechnung mittels bootstrap Analyse ergab etwas schlechtere Werte mit 50-72%. Da die Sonographie aktuell als

Goldstandard gilt, konnte nicht ermittelt werden, ob die dynamische MRT mit ihren Diagnosen richtig gelegen wäre bei negativem Sonographiebefund.

Mit der aktuellen Studie konnte erstmal gezeigt werden, dass die Messungen der urethralen Länge in der Sonographie und der dynamischen MRT vergleichbar sind. Die mittlere Messabweichung beträgt intermodal 2-3 mm. Die dynamische MRT zeigt Vorteile für die Bestimmung der Urethralänge im präoperativen Setting während des Valsalva-Manövers insbesondere bei ausgedehntem Organprolaps. Allerdings stimmt die in der dynamischen MRT gestellten Diagnose von Blasenhalsveränderungen nur mäßig mit der Sonographie überein, wenn man die Sonographie als Goldstandard verwendet.

4) Alt CD, Hampel F, Hallscheidt P, Sohn C, Schlehe B, Brocker KA: 3 T MRI-based measurements for the integrity of the female pelvic floor in 25 healthy nulliparous women. Neurourol Urodyn 2016 Feb;35(2):218-23. Impact Factor 2016: 3.560

In der Literatur werden insbesondere in der Sonographie verwendete Messparameter beschrieben, die einen Rückschluss auf die Integrität des Beckenbodens zulassen [47–51]. Einige Parameter wurden in Studien auch in 3D-MRT Modellen bestimmt [52].

Ziel dieser Arbeit war der Transfer dieser Messungen in 2D MRT Aufnahmen. 25 gesunde Nullipara wurden mit einem nativen Studienprotokoll in einem 3 Tesla Scanner (Siemens) untersucht. Die Messungen wurden auf T2 turbo spin echo Sequenzen durchgeführt. Es wurden folgende Parameter gemessen: Hiatuslänge, Hiatusbreite, Hiatusfläche, hiatale Zirkumferenz, Levatorfläche, maximale Muskeldicke des M. puborectalis, die Lücke zwischen Levatoransatz und Urethra (alle transferiert aus Ultraschallstudien), sowie die iliococcygeale Weite, der Abstand zwischen den beiden Ansatzstellen des M. puborectalis, und die Lücke zwischen Levator und Symphyse (alle transferiert aus 3D MRT Studien). Die Messergebnisse wurden mit Angaben aus der Literatur verglichen.

Es konnten alle Messparameter in 2D MRT Aufnahmen bestimmt werden. Die Ergebnisse für die Hiatuslänge, die Hiatusfläche, die Lücke zwischen Levatoransatz und Urethra und die Levatorfläche waren mit Werten aus der Literatur vergleichbar, während die hiatale Zirkumferenz, die Hiatusbreite und die maximale Muskeldicke anatomische Varianzen zeigte. Auch die Ergebnisse für die iliococcygeale Weite und die Lücke zwischen Levator und Symphyse waren mit der Literatur vergleichbar, aber auf 2D Aufnahmen schwierig zu bestimmen. Für die Weite der Muskelansatzpunkte des M. puborectalis wurde in dieser Studie ein cut off Wert erarbeitet.

Zusammenfassend konnten wir in dieser Studie zeigen, dass es möglich ist, mit 2D MRT Aufnahmen objektive Messungen zur Beckenbodenintegrität ohne eine aufwendige Nachbearbeitung durchzuführen. Die hier erhobenen Messwerte bei gesunden Nullipara können als Referenz für weitere Studien dienen.

Fig. 1. (**a**) Minimal hiatal area (HA) (whitened area), anteroposterior diameter (HAP), and laterolateral diameter (HLL) (black arrowed lines) were measured in the axial plane at the same slice. S, pubic symphysis; (**b**) The area surrounding the levator and hiatus (whitened area). The levator area (LA) was calculated by subtracting the hiatal area (measurement see Fig. 1a). S, pubic symphysis; (**c**) Maximum muscle thickness (MMT) measured bilaterally at the thickest point of the LAM sorrounding the rectum in the hiatal area (white tapered line). R, rectum.

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Fig. 3. The iliococcygeus width (IW) was measured bilaterally in the coronal plane on 2D images. A ledger line was drawn between the most lateral and the most inferior part of the puborectal sling at each side. Through the intersection of these ledger lines, a second vertical ledger line was drawn parallel to the longitudinal body axis. Finally, the most lateral point of the sling was connected to that vertical ledger line, defined as IW. IS, ischium.

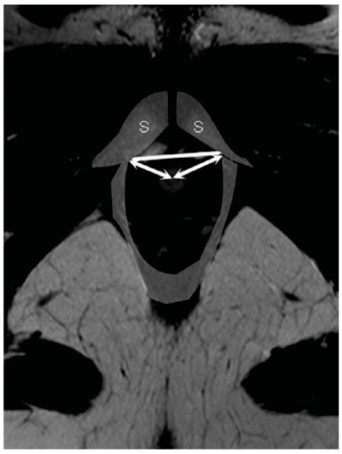

Fig. 2. Measurement of the levator urethra gap (LUG) was performed bilaterally as the distance between the middle of the urethra and the most inferior inner part of the LAM insertion at the os pubis in the plane of the hiatal area (white arrowed lines). S, pubic symphysis. The puborectalis attachment width (PAW) was measured in the axial plane as the distance between the most inferior visible bilateral insertions of the LAM at the os pubis (white tapered line).

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Fig. 4. Levator symphysis gap (LSG): It was measured in the transversal plane as the distance from the anterior-lateral part of the puborectal muscle to the most lateral part of the pubic symphysis still visible on the same transversal slice (white arrowed lines). S, pubic symphysis; PRS, puborectal sling.

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5) Alt CD, Hampel F, Hallscheidt P, Sohn C, Schlehe B, Brocker KA: <u>Early postpartum pelvic floor changes in primiparous women after vaginal delivery using 3T MRI.</u> Neurourol Urodyn 2017; 36:2064-2073. Impact Factor 2017: 3.560

Die vaginale Entbindung ist ein bekannter Risikofaktor für eine Verletzung des Levatormuskelkomplexes. Eine Verletzung des Levators kann starke Auswirkungen auf die aktive Stützfunktion des Beckenbodens haben und ist daher häufig assoziiert mit einem Beckenorganprolaps.

Ziel der vorliegenden Arbeit war die Detektion früher morphologischer Veränderungen im Becken nach vaginaler Entbindung bei Erstgebärenden mit MRT.

Die 3 Tesla MRT wurde mit einem nativen Studienprotokoll durchgeführt mit T2 turbo spin echo Sequenzen in 3 Ebenen, einer T1 Sequenz axial und einer fettgesättigten T2 Sequenz axial. Alle sichtbaren morphologischen Veränderungen wie Ödem, Hämatom, Einriss oder Abriss (muskulär oder ligamentär) wurden dokumentiert. Es wurden Messungen für die Intaktheit des Beckenbodens durchgeführt und mit unserer Kontrollgruppe von Nullipara verglichen [53].

25 Erstgebärende, die zeitgerecht vaginal entbunden haben, wurden in die Pilotstudie eingeschlossen und mit der MRT untersucht. Es wurden bei allen Frauen sowohl oberflächliche als auch tiefliegende morphologische Veränderungen detektiert. Die Messungen für die Beckenbodenintegrität zeigten einen signifikanten Unterschied zur Nullipara-Kontrollgruppe hinsichtlich der Hiatuslänge und -breite, der hiatalen Zirkumferenz, der Hiatusfläche, der maximalen Muskeldicke und der Lücke zwischen Levator und Symphyse.

Zusammenfassend konnten wir zeigen, dass die 2D 3 Tesla MRT im frühen postpartalen Setting einsetzbar ist und eine Vielzahl von morphologischen Veränderungen detektiert, die zum Teil mit der Sonographie nicht einsehbar sind.

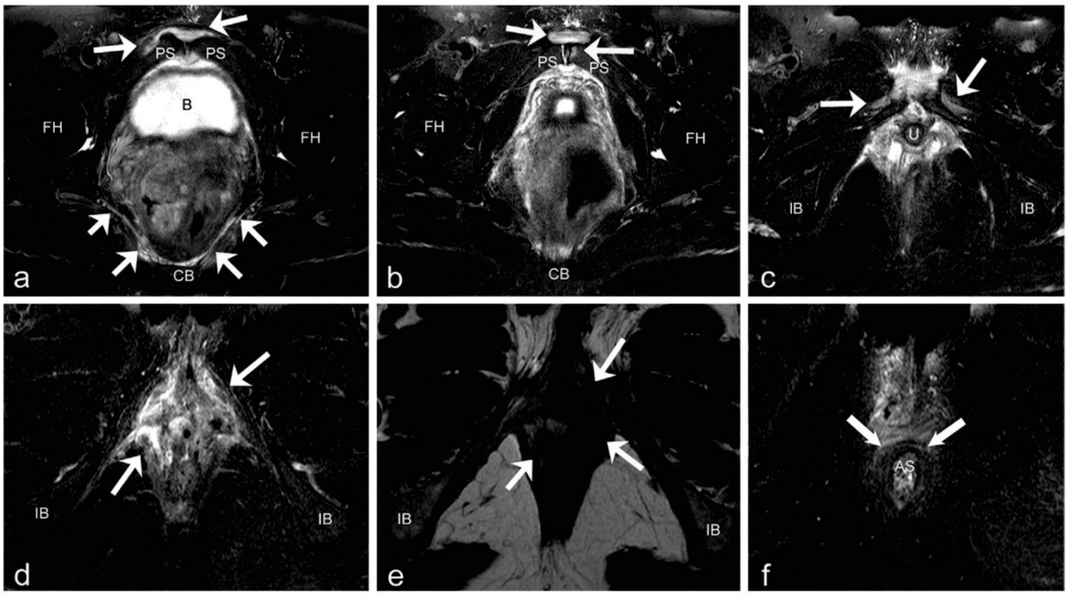

FIGURE 1 Postpartum changes in a woman who delivered vaginally at term without intrapartal epidural anesthesia. The birth weight of the baby was 3420 g, the neonates head circumference was 36 cm and the hiatal circumference was 16 cm. The second stage of labor was prolonged. Delivery was performed using vacuum extractor and mediolateral episiotomy. No labial or perineal tear was present clinically. On MRI on transverse plane from craniad to caudad, sacrouterine ligament, piriformis muscle and pubic symphysis superior ligament edema was visible (a, arrows), as well as pubic bone marrow and pubic symphysis edema (b, arrows), internal obturator muscle and pubovisceral insertion edema (c, arrows) and pubovisceral muscle edema and hematoma (d and e, arrows). The anal sphincter muscle is intact (f, arrows). After three years, she describes ongoing moderate symptoms for stress urinary incontinence and pubic symphysis pain. B, bladder; PS, pubic symphysis; FH, femoral head; IB, ischiatic bone; CB, coccygeal bone; U, urethra; AS, anal sphincter

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6) El Sayed RF and Alt CD, Maccioni F, Meissnitzer M, Masselli G, Manganaro L, Vinci V, Weishaupt D; ESUR and ESGAR Pelvic Floor Working Group: Magnetic resonance imaging of pelvic floor dysfunction - joint recommendations of the ESUR and ESGAR Pelvic Floor Working Group. Eur Radiol. 2017;27(5):2067-2085. Impact Factor 2017: 3.967

Vor dem Hintergrund, dass die Bevölkerung immer älter wird, die Inzidenz der Beckenbodenfunktionsstörungen steigt, und die Frage von Betroffenen nach einer suffizienten Therapie zur Erhöhung der Lebensqualität zunimmt, ist eine umfassende prätherapeutische Statuserhebung von großer Wichtigkeit, damit alle in die Funktionsstörung involvierten Strukturen erfasst werden, da sie das Therapieoutcome beeinflussen können.

Neben einer klinischen Untersuchung, einer Urodynamik und einem Ultraschall spielt die MRT eine zunehmende Rolle in der Beurteilung des Beckenbodens, insbesondere bei komplexen Defekten oder in der Rezidivsituation [55]. Denn die MRT liefert hochaufgelöste kontrastreiche Bilder der Weichteile des Beckens ohne Strahlenexposition, überlagerungsfrei, untersucherunabhängig und reproduzierbar [56, 57]. Sie bietet die Möglichkeit, in einer Untersuchung ein breites Spektrum an Defekten zu visualisieren, die in ihrer Gesamtheit für ein individuelles Therapiekonzept von Relevanz sind [35]. Die MRT kann außerdem zusätzliche und gegebenenfalls unerwartete Funktionsstörung diagnostizieren, die aktuell vielleicht unabhängig von der aktuellen Symptomatik sind, deren Vorhandensein jedoch die Entscheidungsfindung zu einer bestimmten operativen Technik in bis zu 42% beeinflussen können [30, 31].

Es sind in den letzten beiden Jahrzehnten zwar eine Vielzahl an Studien und Reviews zur MRT des Beckenbodens veröffentlicht worden, allerdings gab es bisher weder ein einheitliches Untersuchungsprotokoll noch ein standardisiertes Befundungsschema. Es war daher an der Zeit, Empfehlungen zu erarbeiten, die klare Richtlinien und minimale Anforderungen für die Durchführung einer State-of-the-Art MRT des Beckenbodens aussprach. Die Erarbeitung der Empfehlungen durchlief insgesamt 5 Schritte im Zeitraum zwischen 2010-2015 bis zur Festlegung der relevanten Aspekte, die in den Empfehlungen verankert und 2016 schließlich publiziert wurden.

Schritt 1 beinhaltete die Erstellung einer Datentabelle zur Abfrage technischer Details und der Vorbereitung/Durchführung der MRT in den Institutionen der Mitglieder aus der Arbeitsgruppe Beckenboden der ESUR/ESGAR.

Im Schritt 2 wurde nach Durchsicht der Mitglieder-Protokolle die Optimierung der Datentabelle hinsichtlich der abzufragenden relevanten Punkte durchgeführt und die Abfrage durch detaillierte Sequenzparameter ergänzt. Anschließend erfolgte innerhalb eines Präsenzmeetings die Diskussion und Verabschiedung der in der Datentabelle zu erhebenden Punkte mit Finalisierung der Datentabelle zur Anwendung bei der Literaturrecherche.

Schritt 3 beinhaltete die Literaturabfrage in PubMed zwischen 1993 und 2013. In die Literaturrecherche eingeschlossen wurden nur Originalarbeiten mit vollständiger Information zu Parametern und dem Untersuchungsprotokoll gemäß der erarbeiteten Datentabelle. Arbeiten, die zudem nicht in englischer Sprache verfasst waren, deren Studienkollektiv nicht Menschen waren oder in denen Informationen zur Durchführung der Untersuchung fehlten, wurden ausgeschlossen. Es erfüllten insgesamt 514 Arbeiten die Einschlusskriterien. Diese wurden thematisch in drei Gruppen entsprechend der Kompartimente/Zuweiser aufgeteilt: Urologie (160 Artikel), Gynäkologie (182 Artikel) und Proktologie (172 Artikel). Anhand der gruppenspezifischen Analyse wurde auf der Basis der sich daraus ergebenden Kernthemen im 4. Schritt ein Fragebogen erstellt, der zum Ziel hatte, die wichtigsten Informationen und Voraussetzungen zu definieren, die für eine standardisierte Durchführung und Befundung einer dynamischen MRT/MR-Defäkographie von Nöten sind. Der Fragebogen beinhaltete insgesamt 89 Fragen (binominale, multiple choice, numerische und offene Fragen), die dem Panel von 8 Experten zur Beantwortung zugesandt wurden. 82 von 89 Fragen wurden von allen 8 Experten vollständig beantwortet und flossen damit in die weitere Analyse ein. Die Daten wurden mittels deskriptiver Statistik ausgewertet und eine Übereinstimmung von mindestens 80% wurde als Konsens definiert.

Schritt 5: In einem zweiten Präsenzmeeting wurden die Fragen, die keinen Konsens erreicht hatten, in der Formulierung konkretisiert und optimiert und direkt erneut zur Abstimmung gestellt. Bei Fragen, die weiterhin keinen Konsens erreichen konnten, aber von einzelnen Experten als relevant angesehen wurden und in der Literatur durch Studienkohorten im Sinne eines Evidenzlevels 2 nach den sign Kriterien gestützt werden (www.sign.ac.uk), wurden ebenfalls in die Empfehlungen mit aufgenommen.

Die erarbeiteten Inhalte der Empfehlungen sind folgende:

Die Indikationen zur MRT des Beckenbodens, die die größte Übereinstimmung zwischen Expertenpanel und Literaturrecherche erlangten, sind die obstruktive Defäkationsstörung, die Rektozele, der rezidivierende Beckenorganvorfall, die Enterozele, und die dyssynerge Defäkation.

Die Patient(inn)envorbereitung und die Geräteanforderung verlangt eine umfassende Anamnese der Symptomatik, eine Untersuchung an einem mindestens 1,5 Tesla Scanner mit einer Phased-array-Spule und eine Patientenlagerung in Rückenlage mit angehobenen Knien, mit Platzierung der Spule tief auf das Becken [27, 58]. Des Weiteren sollen die Patient(inn)en eine Windel(hose) erhalten zur Steigerung der Compliance während der Untersuchung durch Reduzierung des Unbehagens, da der Enddarm mit ca. 200ml Ultraschallgel gefüllt wird, welches dann auf Kommando ausgeschieden werden muss. Die Harnblase sollte moderat gefüllt sein, so dass die Blase im Vorfeld ca. 2h nicht entleert werden sollte. Die Patient(inn)en müssen im Vorfeld über die anstehenden Kommandos Kneifen – Pressen – Ausscheiden informiert werden, wie diese richtig auszuführen sind. Eine orale oder intravenöse Kontrastierung ist nicht nötig.

Das empfohlene MR-Protokoll beinhaltet statische (hochaufgelöste T2-gewichte Sequenzen in 3 Ebenen) und dynamische Sequenzen (balanced state free precession Sequenz sagittal). Während die dynamischen Sequenzen beim Kneifen und Pressen einen Atemanhaltezyklus, also ca. 20sec, nicht überschreiten sollen, soll die Ausscheidungssequenz so lange gefahren/wiederholt werden, bis das Ultraschallgel aus dem Rektum ausgeschieden wurde (in der Regel über 2-3 Minuten). Es ist darauf zu achten, dass die Untersuchung diagnostisch verwertbar ist, dass also ein adäquater abdomineller Druckaufbau sichtbar ist (Bewegung der Darmschlingen und der Bauchwand) und es zu einer vollständigen Ausscheidung des Ultraschallgeles kommt, idealerweise 2/3 des Gels in den ersten 30 Sekunden.

In der Bildanalyse soll auf den statischen Aufnahmen nach strukturellen Auffälligkeiten gesucht und diese dokumentiert werden. Dazu zählen Verformungen/Einrisse/Abrisse der urethralen Ligamente, die Unterbrechung/Atrophie/Verletzung/Abtrennung am knöchernen Ansatzpunkt an der Symphyse der Puborektalisschlinge, sowie Verformung/Unterbrechung/Ausdünnung des M. iliococcygeus.

Ebenso sollen funktionelle Veränderungen in den dynamischen Aufnahmen dokumentiert werden. Dabei ist darauf zu achten, ob es zu einem Urinverlust während des Pressens kommt, wie beweglich die Urethra ist (hypermobil, horizontal, abknickend, gestaucht), wie die Form der Blase bei einer Senkung ist (breitbasig, sanduhrförmig), welchen Inhalt ein Prolaps des Douglas-Raumes aufweist (peritoneales Fett, Dünndarm, Dickdarm), ob eine Einstülpung der Darmschleimhaut intraluminal sichtbar ist (Intussuszeption), und wie sich der anorektale Winkel ändert im Vergleich zum Ruhewert (normalerweise spitzer beim Kneifen und stumpfer beim Pressen).

Des Weiteren werden Messungen zur Quantifizierung einer Beckenbodenfunktionsstörung durchgeführt, wobei die Pubococcygeallinie als Referenzlinie für den Referenzpunkt Blasenhals, vordere Muttermundslippe/ Vaginalstumpf, tiefster Punkt des Douglas-Raumes und anorektaler Übergang dienen soll. Die Messungen sollen orthogonal zur Referenzlinie erfolgen und sowohl auf einem Bild in Ruhe als auch unter maximalem Pressen durchgeführt werden. Die Distanz der beiden Werte pro Referenzpunkt soll als Beckenorganmobilität dokumentiert werden. Die gedachte Gerade durch die vordere Analwand gilt als Referenzlinie für den Referenzpunkt vordere Rektumwand. Zudem soll der anorektale Winkel in Ruhe, beim Kneifen und beim maximalen Pressen bestimmt werden, um eine individuelle Änderung des Winkels zu dokumentieren. Zuletzt wird die Messung der Hiatusweite und des Absinkens der Levatorebene zur Beckenbodenebene empfohlen, die je nach Ausprägung eine Beckenbodenschwäche dokumentiert.

Für die Einordnung der Messergebnisse wird eine Gradeinteilung empfohlen, die sich für die Referenzwerte der Beckenorgane entweder nach der 3er-Regel oder nach der 2er-Regel richtet. Für den schnellen Überblick während des Praxisalltages wurde eine Checkliste erarbeitet, die die relevanten Punkte für eine state-of-the-art MRT des Beckenbodens aufführt.

Table 2 Checklist for the recommended patients' preparation and MR-Imaging protocols

	Done	Concordance of experts *n*=8	Level of Evidence*	Reference
A Patients' preparation				
Equipment: preferable 1.5 T magnet and phased array coil	☐	100%	4	
Take patients' history of pelvic floor disorder	☐	100%	4	
Ask the patient to void 2h before the examination	☐	100%	4	
Train the patient on how to perform squeezing, straining and evacuation	☐	100%	4	
Use a diaper for protection	☐	100%	4	
Do rectal filling with ultrasonic gel	☐	100%	4	
Examine the patient in supine position with elevated knees on a high pillow	☐	100%	4	
B MR-imaging protocol				
1 Recommended static sequences				
T2-weighted TSE, FSE, RARE in sagittal, transverse and coronal plane	☐	100%	2	[15, 17]
2 Recommended dynamic SSFP or BSFP sequences in sagittal plane				
Straining phase	☐	100%	2	[17–19]
Evacuation phase	☐	100%	2	[16, 17, 19]
Squeezing phase	☐	88%	2	[17, 20]

BSFP balanced state free precession, *FSE* fast spin echo, *RARE* rapid acquisition with relaxation enhancement, *SSFP* steady state free precession, *TSE* turbo spin echo

* Level of evidence 2 = based on systematic reviews, case control or cohort studies; Level of evidence 4 = based on expert opinion (www.sign.ac.uk)

Table 4 Checklist for the recommended MRI reporting scheme

	Done	Concordance of experts *n*=8	Level of Evidence*	Reference
A Measurements				
1 Basic measurements for all compartments				
Determine PCL	☐	100%	2	[15, 24]
Determine organ-specific reference points	☐	100%	2	[25]
Measure the descent of reference points below the PCL	☐	100%	2	[15, 26]
2 Measurements for posterior compartment				
Measure the bulging of the anterior rectal wall at evacuation phase/straining phase	☐	100%	2	[15, 20]
Measure the ARA at rest - squeezing phase - straining phase/evacuation phase	☐	100%	2	[16, 27]
B Reporting				
1 Basic reporting for all compartments				
Report values above the PCL as negative and below as positive	☐	100%	2	[28]
Report pelvic organ mobility	☐	100%	2	[8, 25]
2 Reporting for anterior compartment				
Report loss of urine at straining phase	☐	88%	2	[15]
Report urethral mobility at straining phase	☐	88%	2	[29]
3 Reporting for middle compartment				
Report uterine descent	☐	100%	4	[15]
Report the content of a present enterocele	☐	100%	4	[15]
4 Reporting for posterior compartment				
Report presence of a rectal intussusception	☐	100%	2	[19, 30]
Evaluate time-effective rectal evacuation	☐	88%	2	[31]
Point out the change of ARA	☐	100%	4	
C Grading				
1 Anterior compartment				
Use the "rule-of-three' grading for cystocele	☐	100%	2	[32, 33]
Report cystocele as pathological starting from °II	☐	88%	4	[33]
2 Middle compartment				
Use the "rule-of-three' grading for uterine prolapse and enteroceles	☐	100%	2	[34, 35]
Report POP as pathological starting from °II	☐	88%	4	[35]
3 Posterior compartment				
Use the grading for Anorectal Junction descent (ARJ) starting at 3 cm below the PCL	☐	100%	2	[19, 36]
Report a rectocele as pathological starting from °II	☐	100%	2	[19, 20]
Use the "rule-of-two" grading for rectoceles	☐	88%	2	[16, 19]

PCL pubococcygeal line, *ARA* anorectal angle, *POP* pelvic organ prolapse, *ARJ* anorectal junction

* Level of evidence 2 = based on systematic reviews, case control or cohort studies; Level of evidence 4 = based on expert opinion (www.sign.ac.uk)

open access, Wiedergabe der Tabelle mit freundlicher Genehmigung von www.creativecommons.org [35]

Zusammenfassend wurden auf der Basis einer ausgedehnten Literaturrecherche und eines Expertenkonsensus in Zusammenarbeit zweier Fachgesellschaften (ESUR und ESGAR) erstmals Empfehlungen zur standardisierten Durchführung und Befundung der dynamischen MRT/MR-Defäkographie erarbeitet. Sie sollen als Leitfaden im klinischen Alltag genutzt werden und unter dem wissenschaftlichen Aspekt einer besseren Vergleichbarkeit von Studien dienen.

7) Putz C <u>and</u> Alt CD, Hensel C, Wagner B, Gantz S, Gerner HJ, Weidner N, Grenacher L: <u>3T MR-defecography-A feasibility study in sensorimotor complete spinal cord injured patients with neurogenic bowel dysfunction.</u> Eur J Radiol 2017;91:15-21. Impact Factor 2017: 2.462

Patienten mit einem Querschnitt entwickeln mit der Zeit eine neurogene Funktionsstörung des Darmes, da die zentrale Kontrolle fehlt. Diese Funktionsstörung stellt eine physische und psychische Belastung der Betroffenen mit z.T. starker Einschränkung der Lebensqualität dar. Das Darmmanagement hat daher eine sehr hohe Priorität.

Mit der vorliegenden Arbeit sollte untersucht werden, ob eine MR-Defäkographie bei Patienten mit komplettem Querschnitt möglich ist, da keine willkürliche Ausscheidung möglich ist, und ob die MRT möglicherweise Hinweise für Ursachen einer bestehenden Ausscheidungsstörung geben kann. Dazu wurden Parameter bestimmt, die zur Diagnose einer obstruktiven Defäkationsstörung in der Literatur etabliert sind .

In dieser prospektiven Single-Center-Machbarkeitsstudie wurden Patienten mit traumatisch bedingtem komplettem Querschnitt in einem konventionellen 3 Tesla Scanner untersucht. Die Patienten wurden in Linksseitenlage gelagert und die Ausscheidung mittels CO_2-Suppositorien und einer digito-rektalen Stimulation induziert. Darunter schieden alle Patienten das zuvor rektal applizierte Ultraschallgel aus. Der anorektale Winkel, die Senkung des anorektalen Überganges, die Hiatusweite und das Absenken der Levatorebene zur Beckenbodenebene wurden in einer sagittalen T2 turbo spin echo Sequenz in Ruhe und in einer sagittalen ultraschnellen T2 mit mehrfachen Messungen während der induzierten Defäkation bestimmt und mit Referenzwerten aus der Literatur von nicht querschnittgelähmten Patienten verglichen.

Die MR-Defäkographie liefert auswertbare Bildsequenzen der induzierten Defäkation bei Patienten mit komplettem Querschnitt, so dass wir Referenzwerte für dieses Patientenkollektiv erheben konnten. Die Messergebnisse der bestimmten Parameter unterschieden sich signifikant von Referenzwerten aus der Literatur von Nicht-Querschnittgelähmten.

Wir konnten in dieser Arbeit zeigen, dass es möglich ist, eine MR-Defäkographie bei querschnittgelähmten Patienten durchzuführen, die dabei helfen kann, neben neurogenen Ursachen auch mechanische Ursachen für eine bestehende Darmfunktionsstörung zu detektieren und das Therapiemanagement damit individuell anpassen zu können.

Diese Arbeit erhielt 2012 den Forschungspreis der Deutschsprachigen Medizinischen Gesellschaft für Paraplegie e.V.

Table 1
Patient preparation and performance of MR-defecography in our study cohort.

Patients' preparation	
1	Ask the patient to avoid rectal evacuation prior to the examination to increase the probability of defecation during MRI
2	Ask the patient to empty the bladder by catheterization right before the examination
3	Position the patient in left decubitus position on a gel mat with knees flexed for stable position and to avoid pressure sores
4	Perform digital rectal examination to assure that the patient has no obstruction
5	Do rectal filling with body temperatured ultrasonic gel using a rectal catheter connected with a bladder syringe
6	Insert two suppositories of Lecicarbon (CO_2) into the rectum to increase the stretching and to initiate defecation reflex
7	Repeat rectal filling and perform digital rectal stimulation if there is no evacuation after 15 min

MR-imaging protocol

	Sequence	Plane	TE (ms)	TR (ms)	FOV (mm)	Matrix	ST (mm)	
1	T2-weighted turbo-spin-echo	Transverse	89	5160	300	512 × 512	4	Static
2	T2-weighted turbo-spin-echo	Sagittal	89	3220	300	512 × 512	4	Static
3	Ultrafast T2-weighted single-slice-true-FISP	Midsagittal	1.54	3.51	400	320 × 256	6	Dynamic*

TE = time of echo; TR = time of repetition; ms = milliseconds; FOV = field of view; ST = slice thickness; mm = millimetre.
* 21 slices, time duration 0:13 s.

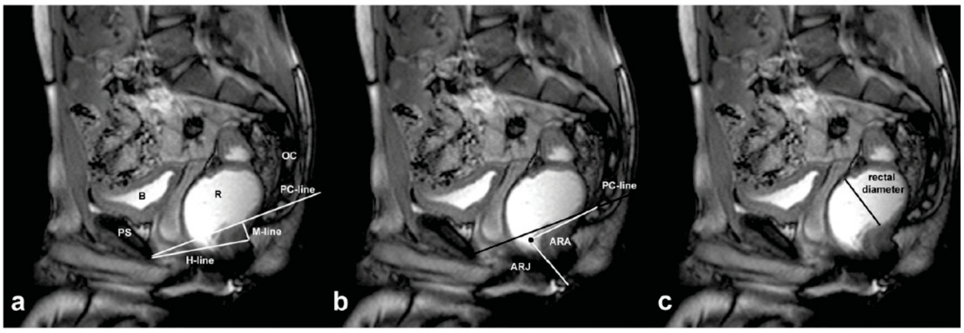

Fig. 1. Measurement parameters performed on the sagittal plane for evaluation of pelvic floor related dysfunction. Image after initial rectal filling with ultrasonic gel in a 19 year old man with sensorimotor complete paraplegia (neurological level of injury is T4), 3 years after injury. (a) The pubococcygeal line (PC-line) is drawn from the inferior border of the pubic symphysis (PS) to the last visible joint of os coccygeus (OC). The hiatal width is measured as the horizontal line (H-line) from the inferior border of the PS to the posterior aspect of the anorectal wall. From this endpoint, the M-Line is drawn perpendicular to the PC-Line to measure the descent of the hiatus to the level of the pelvic floor. B = bladder, R = rectum. (b) The anorectal angle (ARA) is measured between the tangent to the posterior rectal wall and the line through the central axis of the anal canal. The cross point is defined as the anorectal junction (ARJ) (black dot). (c) The rectal diameter was measured after complete rectal filling; alternatively, the sequence before the induced defecation process started was chosen.

Wiedergabe der Tabelle und Abbildung mit freundlicher Genehmigung von Elsevier [59]

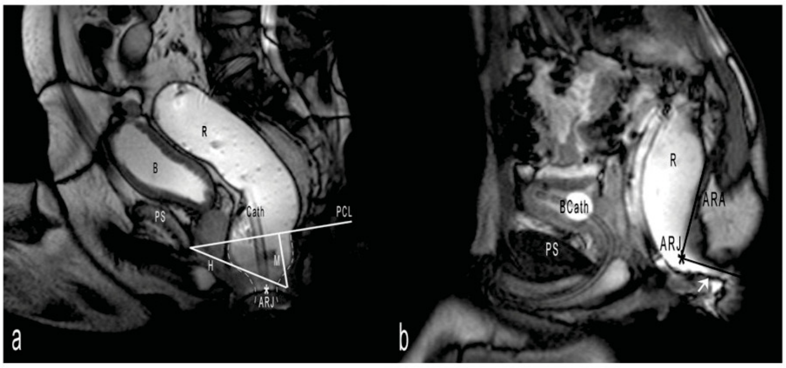

Fig. 2. Illustration of the induced evacuation phase in two SCI patients. (a) 60 year old male, paraplegia American Spinal Injury Association Impairment Scale grade A (AIS-A), neurological level of injury (NLI) is T2, time since injury is 40 years, suffering from severe neurogenic bowel dysfunction (NBD). The rectum was filled with 440 ml of ultrasound gel, the catheter remains in the rectal lumen, evacuation process was initiated after 35 repeated measurements. The rectum shape is sacciform (gray contour) and the anorectal junction (ARJ) (asterisk) is located 4.7 cm below the pubococcygeal line (PCL). Pelvic floor relaxation is present with widening of the hiatus (H) at 7.5 cm and hiatal descent (M) at 4.7 cm. B = bladder, PS = pubic symphysis, R = rectum, Cath = rectal catheter. (b) 24 year old male, paraplegia AIS-A, NLI T4, time since injury is 7 years, suffering from moderate NBD. The rectum was filled with 300 ml of ultrasound gel and evacuation phase started after 9 repeated measurements (arrow). The anorectal angle (ARA) became more obtuse at 124° during the evacuation phase, while ARA at rest was 105° in this patient (not shown). Pelvic floor relaxation grade 1 is present. There is no rectal descent, as the anorectal junction (ARJ) (asterisk) is close to the level of the distal edge of pubic symphysis. BCath = indwelling transurethral bladder catheter, R = rectum, ARA = anorectal angle.

Wiedergabe der Abbildung mit freundlicher Genehmigung von Elsevier [59]

VI. Diskussion

Die dynamische MRT ist in der Diagnostik einer Beckenbodendysfunktion eine ergänzende Bildgebungsmodalität, bei der es nicht so sehr auf die Diagnose der korrekten maximalen Ausprägung eines Beckenorganvorfalles in einem Kompartiment ankommt, sondern der Mehrwert insbesondere in der überlagerungsfreien und reproduzierbaren Darstellung des Zusammenspieles des Beckenbodens und der Beckenorgane im Valsalva-Manöver liegt, wobei die Komplexität der Defekte in den drei Kompartimenten verdeutlicht wird.

Anhand der Studienergebnisse aus unserer prospektiven Longitudinalstudie konnten wir das Potential der dynamischen MRT herausarbeiten, indem wir Frauen mit symptomatischen Senkungszuständen, die alle mittels netzgestützter Beckenbodenrekonstruktion operativ versorgt und präoperativ, 4 Wochen, 12 Wochen, 1 Jahr und 5 Jahre postoperativ sowohl urogynäkologisch als auch mittels dynamischer MRT untersucht wurden, sowie zusätzlich einen Fragebogen zur Lebensqualität ausgefüllt hatten, ausgewertet haben.

Der von uns eingeführte Parameter der Beckenorganmobilität (die Distanz, die ein Organ aus der Ruheposition bis in die maximale Ausprägung des Tiefertretens zurücklegt) liefert eine individuelle Beurteilung der Organsenkung unabhängig von einer Gradeinteilung, was dem Zuweiser therapierelevante Informationen über die Festigkeit des Halteapparates im Becken liefert. Zudem konnten wir in der 5-Jahres-Evaluation zeigen, dass gerade der Parameter der Beckenorganmobilität am besten mit dem subjektiven Eindruck der Patientinnen hinsichtlich bestehender Beckenboden- beschwerden postoperativ korreliert. Dass dieser Parameter in den aktuellen Empfehlungen der ESUR zur dynamischen MRT/MR-Defäkographie verankert ist, hebt die klinische Bedeutung noch einmal hervor [35].

Unser Patientenkollektiv konnte zudem erstmals die Frage nach der Vergleichbarkeit der Messung der Harnröhrenlänge im MRT zum standardmäßig durchgeführten Ultraschall beantworten, welche hinsichtlich des Therapieerfolges von alloplastischem Material, insbesondere für die korrekte Platzierung eines Bändchens, als relevant angesehen wird [46, 60]. Des Weiteren konnten interessante Aspekte bezüglich intermodaler Differenzen bei der Diagnose von Blasenhalsveränderungen erhoben werden, die in weiteren Studien zu beleuchten sind.

Als einer der Hauptrisikofaktoren für die Entstehung einer Beckenbodendysfunktion wird die vaginale Entbindung angesehen, da aufgrund des hiatalen Durchtritts des Kindskopfes insbesondere der Puborektalismuskel eine temporäre Überdehnung erfährt, die zu Einrissen oder Abrissen des Muskels führen kann [61–64]. Die primär verwendete Bildgebungsmodalität zur Beurteilung des Beckenbodens prä- und postpartal ist die schnell verfügbare und kosteneffiziente Perineal- und Introitussonographie, die allerdings stark abhängig von der Erfahrung des Untersuchers ist und technische Restriktionen bei der Beurteilung tiefer im Becken gelegener Strukturen hat [65]. Mittels hochaufgelöster MRT Sequenzen konnten wir erstmals oberflächliche und tiefe Veränderungen innerhalb 1 Woche nach vaginaler Entbindung überlagerungsfrei und unabhängig von der Lokalisation im Becken visualisieren, die über die erwarteten Veränderungen am Levator-ani Muskelkomplex, dem Damm und der Symphyse hinausgingen. Diese Studie diente damit der Statuserhebung der visuellen Möglichkeiten der postpartalen MRT, eine longitudinale Langzeitbeobachtung ist wünschenswert, inwieweit die Veränderungen persistieren oder Auswirkungen haben. Es ist denkbar, dass einige dieser Veränderungen ggf. zu einem späteren Zeitpunkt ursächlich für eine Beckenbodendysfunktion sein können und man durch Kenntnis der Veränderungen in Zukunft beispielsweise durch ein gezieltes Training eine Stabilisierung des Halteapparates bewirken kann, um Funktionsstörungen vorzubeugen. Auch hier regen unsere Ergebnisse zu weiteren Studien an.

Die Frage nach der Visualisierung von Beckenbodenveränderungen im dynamischen MRT stellte sich auch bei unserem Kollektiv der paraplegischen Patienten mit z.T. erheblichen Problemen beim Darmmanagement. Klinisch hätte es eine therapeutische Konsequenz, ob für die subjektiven Probleme beim Darmmanagement neben den bisher bekannten neurogenen Funktionsstörungen gegebenenfalls auch mechanische Ursachen verantwortlich sein könnten. Da die Patienten aufgrund des thorakalen Querschnitts jedoch nicht mehr aktiv den Ausscheidungsvorgang steuern können, musste der Defäkationsvorgang von außen herbeigeführt werden, um die diagnostischen Vorteile einer dynamischen MRT bzw. MR-Defäkographie bei diesem Patientenkollektiv nutzen zu können. Durch eine Optimierung der Patientenvorbereitung konnte die Ausscheidung des rektal applizierten Ultraschallgels bei allen Studienpatienten dokumentiert und die MRT hinsichtlich bekannter Messparameter zur Diagnose obstruktiver Defäkationsstörungen bei nicht paraplegischen Patienten ausgewertet werden.

Unsere Studie zur Machbarkeit der MR-Defäkographie bei paraplegischen Patienten legte den Grundstein für weitere klinische Studien zur objektiven Beurteilbarkeit der Darm- und Beckenbodenfunktion als klinisch relevante Basis für individuelle Therapiekonzepte in diesem sehr speziellen Patientenkollektiv und erhielt daher 2012 den Forschungspreis der Deutschsprachigen Medizinischen Gesellschaft für Paraplegie e.V.

VII. Zusammenfassung und Ausblick

Die dynamische MRT/MR-Defäkographie ist neben der onkologischen Beckenbildgebung eine der Hauptsäulen der funktionellen Beckenbildgebung. Sie dient der Visualisierung und Beurteilung von Beckenbodenfunktionsstörungen und zeigt objektiv und reproduzierbar die Interaktion des komplexen Beckenbodenhalteapparates und der Beckenorgane während der Ausscheidung, was insbesondere in Beckenbodenzentren, in denen verschiedene Fachbereiche in einer Konferenz ein individuelles Therapiekonzept erarbeiten, einen immer größeren Stellenwert einnimmt.

Die Wichtigkeit dieser Untersuchung wurde durch die Veröffentlichung europäischer Empfehlungen zur standardisierten Durchführung und Befundung der dynamischen MRT/MR-Defäkographie noch unterstrichen.

Des Weiteren steigt die Anzahl an Anforderungen für eine solche Untersuchung, da die Anzahl an Patient(inn)en mit einer symptomatischen Beckenbodendysfunktion zunimmt, die eine Verbesserung der Lebensqualität durch die Behebung der Funktionsstörung wünschen und damit eine dezidierte Diagnostik und eine individuelle Therapie verlangen.

Es ergeben sich daher eine Vielzahl weiterer Untersuchungsansätze an unterschiedlichen Patientenkollektiven, zu denen unsere Studienergebnisse, teilweise als Machbarkeits- bzw. Pilotstudien, anregen bzw. den Grundstein gelegt haben.

Zudem schlägt die objektiv beurteilbare funktionelle Beckenbildgebung eine Brücke zwischen den unterschiedlichen Fachbereichen und erhöht damit die interdisziplinäre Zusammenarbeit sowohl unter klinischen als auch unter wissenschaftlichen Gesichtspunkten.

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X. Anhang

Original Article

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MRI findings before and after prolapse surgery

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Abstract

Background: Therapeutical outcome after prolapse surgery is evaluated using a standardized grading system based on maximum prolapse extent, which might not provide the full picture of the patient's subjective outcome. We therefore applied an evaluation method, which is detached from a grading system.

Purpose: To evaluate the impact of pelvic organ mobility in dynamic magnetic resonance imaging (MRI) before and after mesh-repair surgery in patients with symptomatic pelvic organ prolapse.

Material and Methods: To obtain measurements, we performed parasagittal T2-weighted turbo spin echo sequence at rest (TR, 3460 ms; TE, 85 ms; matrix, 512; slice thickness [ST], 5 mm), parasagittal T2-weighted true fast imaging with steady-state precession (TrueFISP) single-shot sequence during straining (TR, 397.4 ms; TE, 1.5 ms; matrix, 256; ST, 8 mm), and parasagittal T2-weighted TrueFISP sequence at maximum strain (TR, 4.3 ms; TE, 2.15 ms; matrix, 256; ST, 5 mm) at 1.5 T MRI. Pelvic organ prolapse (anatomical landmarks: bladder, cervix, pouch, rectum) was measured perpendicularly with reference to the pubococcygeal and the midpubic line. Pelvic organ mobility was defined as the difference between the measured distance at rest and at maximum strain for each anatomical landmark. All patients underwent mesh-repair procedure. Eighty patients could be included in this short-term follow-up study. Due to the physical diagnosis of pelvic organ prolapse, 51 underwent anterior mesh repair, 16 underwent posterior mesh repair, and 13 underwent total mesh repair. Surgery was performed by one surgeon, using mesh implants from several manufacturers.

Results: Median values of maximum organ prolapse for bladder, cervix, pouch, and rectum preoperatively were 2.54 cm, 0.33 cm, 2.47 cm, and 0.32 cm, respectively, and 12 weeks postoperatively 0.87 cm, −1.79 cm, 1.49 cm, and 0.49 cm, respectively. Highly significant improvement ($P < 0.001$) of pelvic organ mobility was observed in the treated compartment at 4- and 12-week follow-up. Physical evaluation 12 weeks after mesh-repair showed an asymptomatic POP-Q stage I, if any.

Conclusion: Dynamic MRI is useful in visualizing the maximum extent of pelvic organ prolapse, as the evaluation of pelvic organ mobility documents the intraindividual therapeutic outcome detached from a grading system based on maximal prolapse values.

Keywords

Pelvic organ prolapse, dynamic MRI, mesh repair, pelvic organ mobility

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Introduction

Pelvic floor dysfunction, including pelvic organ prolapse (POP) and pelvic floor relaxation, is increasing in middle-aged and older women (1,2). It is often accompanied by a variety of symptoms, such as urinary, bowel, or sexual dysfunction. Findings such as cystocele, uterine prolapse, enterocele, and rectocele

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are frequently combined, as pelvic floor disorder is often complex. The aforementioned symptoms may greatly affect the patient's subjective quality of life (3,4).

Polypropylene meshes are being used increasingly frequently in reconstructive surgery of POP and are comparable to meshes that are successfully used in hernia surgery (5–7).

The therapeutic outcome after mesh-repair surgery is commonly assessed by physical examination or by intravaginal or perineal ultrasound (8). At present, ultrasound is the only method able to delineate the implanted mesh beneath the vaginal epithelium. However, the mesh position cannot be completely evaluated and the overall postoperative success of reconstructive surgery visualized, e.g. whether the sacrospinal ligament has been reached with a six-point mesh. Another imaging modality that can be considered to evaluate surgery outcome is magnetic resonance imaging (MRI), preferably dynamic (8–10). MRI can be used to gather indirect information about the supporting effects of mesh repair for POP before and after surgery. Dynamic MRI also provides an overview of the pelvis and the relationship between pelvic organs. Any defects can be shown in their entirety. To grade POP, the maximum descent of the pelvic organs needs to be detected at maximum strain. In contrast to clinical POP grading systems, such as POP-Q used by the International Continence Society (ICS), MRI defines POP with reference to the level of the pelvic floor and not to the introital area. This makes it difficult to compare clinical and radiological POP grading.

The present study focuses on the image results and was designed to search for a further possibility to evaluate therapeutical outcome in patients with pelvic organ prolapse after mesh repair surgery detached from a grading system based on maximal extent of POP, having in mind, that every patient has an individual physiology in straining.

Material and Methods

The research was conducted according to the Declaration of Helsinki as revised in 2008, and the study proposal was approved by the local ethics committee. The study was designed and performed as a prospective, controlled clinical trial. Women aged >18 years with symptomatic POP were examined by the Department of Gynecology and Obstetrics in our hospital. The ICS POP-Q scoring system was used for physical staging of POP and to establish the indication for mesh-repair surgery (POP-Q stage III or symptomatic lower stage) (11). All patients underwent a preoperative dynamic MRI examination, which had no influence on the indication for reconstructive surgery. Follow-up by dynamic MRI was performed at the same follow-up interval on physical re-evaluation.

Patient preparation

The patients were asked not to void their bladder 1 h before imaging to ensure a moderately filled bladder. A total of 20 mL sterile ultrasonic gel (Endosgel®, Farco-Pharma GmbH, Köln, Germany) was inserted into the vagina for better demarcation of the vaginal wall and the cervix. The women were carefully instructed by the physician on how to perform straining (Valsalva maneuver).

MRI examination

MRI was performed with a 1.5 T scanner (Magnetom Symphony, Siemens, Erlangen, Germany) preoperatively and 4 and 12 weeks after reconstructive surgery with patients laying in a supine position, the knees elevated on a high pillow to allow abdominal pressure to be exerted on the pelvic floor more easily.

A predefined protocol of sequences was performed in all patients, including the following to evaluate POP: mid-sagittal T2-weighted turbo spin echo sequence at rest (TR, 3460 ms; TE, 85 ms; FOV, 300 mm; matrix, 512; ST, 5 mm), mid-sagittal T2-weighted TrueFISP single-shot sequence during straining (TR, 397.4 ms; TE, 1.5 ms; FOV, 300; matrix, 256; ST, 8 mm), and mid-sagittal T2-weighted TrueFISP sequence at maximum strain (TR, 4.3 ms; TE, 2.15 ms; FOV, 330; matrix, 256; ST, 5 mm). The duration time of the dynamic single shot sequence with three slices and 15 repeating measurements as well as the sequence at maximum strain is about 18 s each. In addition, the protocol included high-resolution T2-weighted turbo spin echo (TR, 3460 ms; TE, 88 ms; FOV, 300; matrix, 512; ST, 6 mm) and T1-weighted fl2d (TR, 132 ms; TE, 4.76 ms; FOV, 380; matrix, 256; ST, 6 mm) sequence in an axial plane.

Image analysis

All MR images were interpreted by two radiologists (CDA and PH) experienced in the field of urogenital imaging with 4 and 16 years of experience in consensus reading. The observers were trained in measuring POP prior to the study. To measure POP, mid-sagittal sequences at rest and at maximum strain were used. In the TrueFISP single-shot sequence, patient compliance on abdominal pressure during straining was verified by small bowel movement and movement of the abdominal wall.

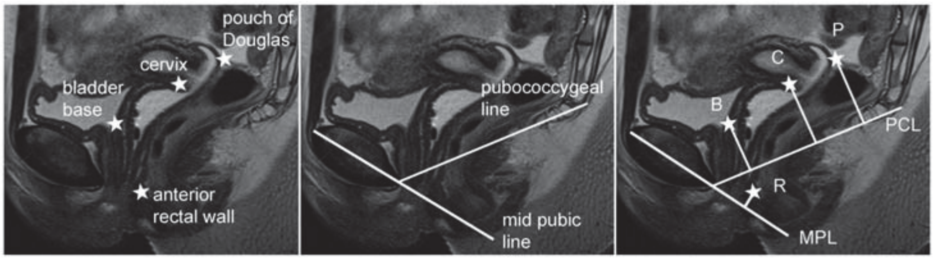

Fig. 1. Sagittal T2-weighted TSE sequences at rest demonstrating the measurement techniques used: (a) anatomical landmarks: bladder base, cervix, pouch of Douglas, anterior rectal wall; (b) lines of reference: pubococcygeal line, midpubic line; (c) measurement procedure: perpendicular line from each anatomical landmark to the respective line of reference. B, bladder base; C, cervix; MPL, midpubic line; P, pouch of Douglas; PCL, pubococcygeal line; R, anterior rectal wall.

Measurement methods

Measurements of all three examinations of a certain patient were performed in one session. Two lines of reference were used in our study to measure POP: The first was the pubococcygeal (PC) line, a straight line from the inferior part of the pubic symphysis to the last visible coccygeal joint, the second was the midpubic line (MPL), a straight line through the longitudinal axis of the pubic symphysis (8,9,12–17). There are four anatomical landmarks to measure POP by MRI, based on the ICS POP-Q criteria: the bladder neck (B), the anterior part of the cervix (C) or the vaginal vault after hysterectomy, the pouch of Douglas (P), and the anterior rectal wall (R) (Fig. 1) (1,11,12,14,16,18). The PCL is used for B, C, and P, while the MPL is used for R to reduce the number of false-positive rectoceles (1,12,19–22).

The perpendicular line from each anatomical landmark to the respective line of reference was drawn on a parasagittal plane at rest and at maximum strain (9). By definition, POP is present if the anatomical landmark falls below the line of reference during straining. Measured distances (cm) are positive if the landmark position is below the line of reference, and negative if the position is above it (Fig. 1). The differences between the measured distances at rest and at maximum strain for each antomical landmark (B, C, P, R) were calculated before and after surgery to define POM as an indicator for the therapeutic outcome.

Surgical treatment

In the Department of Gynecology and Obstetrics in our hospital, three types of mesh from different manufacturers were implanted: an anterior mesh if the symptomatic prolapse presented in the anterior compartment (cystocele, uterine prolapse), a posterior mesh for symptomatic prolapse of the posterior compartment (rectal descent), and a total or combined anterior/posterior mesh if all compartments were symptomatically involved in POP (including enteroceles). All women were treated by the same experienced pelvic floor surgeon (FL). The readers were not informed on the type of surgery performed in each patient.

Statistical analysis

Analysis was performed using descriptive statistics. The numerical differences of the anatomical landmark position at maximum strain and at rest were calculated for all three time points. The mean value of the numerical differences, the standard deviation, and the median value were calculated and Student's t-test was used to calculate P values between the three time points (Microsoft®Excel®, version 12.2.8). Statistical significance was defined as $P < 0.05$.

Results

Between February 2008 and August 2009, a total of 130 consecutive patients underwent preoperative dynamic MRI after giving written informed consent. Fifty patients were excluded from the study (Fig. 2). In total, 80 patients were included in this short-term follow-up study. The median age of the study population was 66 years (range, 41–87 years). Due to the physical diagnosis of POP, 64% underwent anterior mesh repair ($n = 51$), 20% posterior mesh repair ($n = 16$), and 16% total mesh repair ($n = 13$) (Table 1).

Measurement results for POP and POM

Total study population. Eighty patients underwent all three examinations and were included in the study. The median values of maximum bladder prolapse were 2.54 cm (preoperatively), 0.26 cm (at 4 weeks), and 0.87 cm (at 12 weeks); the median values of maximum uterine prolapse were 0.33 cm, −1.76 cm, and −1.79 cm, respectively; of maximum prolapse of the pouch of Douglas 2.47 cm, 1.03 cm, and 1.45 cm,

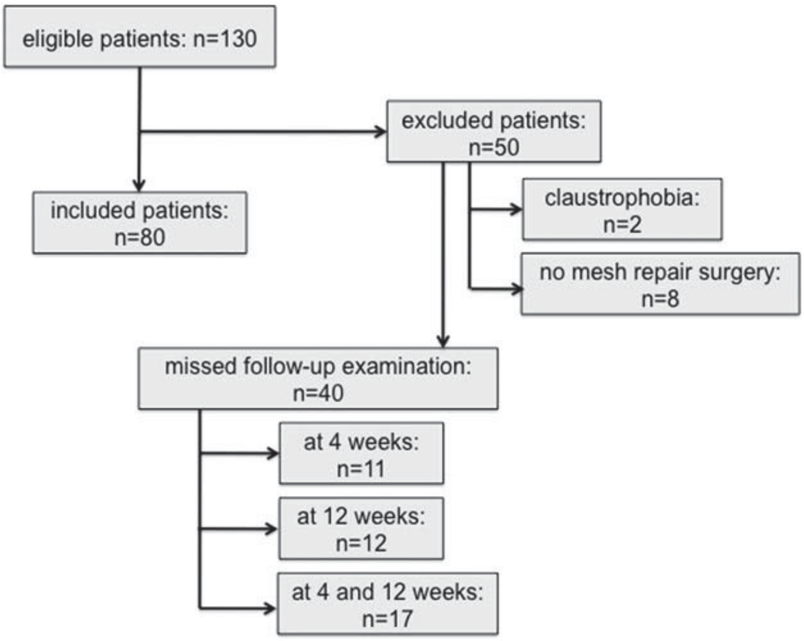

Fig. 2. Flowchart of the study population, including the reasons for exclusion.

Table 1. Patient population with symptomatic pelvic organ prolapse undergoing surgical mesh repair, $n = 80$.

		Gynecologic grading (ICS score)					
		0	I	II	III	IV	Total
Cystocele		14	11	18	32	5	80
Uterine prolapse		51	8	15	4	2	80
Enterocele		64	6	2	6	2	80
Rectocele		20	16	21	21	2	80
Anterior mesh repair	51						
Posterior mesh repair	16						
Total mesh repair	13						
Total	80						

ICS, International Continence Society.

respectively; and of maximum rectal prolapse 0.32 cm, −1.05 cm, and 0.49 cm, respectively.

For POM, the overall median value of preoperative bladder descent was 3.09 cm, of uterine descent 2.40 cm, of descent of the pouch of Douglas 2.24 cm, and of rectal descent 1.45 cm (Table 2).

There were very highly significant differences ($P \leq 0.0001$) between the 4-week follow-up and the initial examination as well as between the 12-week follow-up and the initial examination regarding POM of the anterior and middle compartment, and highly significant differences in the posterior compartment ($P \leq 0.001$). There were no significant differences between 4 and 12 weeks regarding the POM of all three compartments (Table 2).

Anterior mesh repair. A total of 51 patients underwent anterior mesh repair. The median values of maximum bladder prolapse were 3.59 cm (preoperatively), 0.26 cm (at 4 weeks), and 1.1 cm (at 12 weeks); the median values of maximum uterine prolapse were 0.33 cm, −2.35 cm, and −1.94 cm, respectively; of maximum prolapse of the pouch of Douglas 2.27 cm, 0.97 cm, and 1.45 cm, respectively; and of maximum rectal prolapse −0.02 cm, −0.93 cm, and −0.64 cm, respectively.

Table 2. Overall results of pelvic organ mobility preoperatively and at short-term follow-up (4 and 12 weeks) after reconstructive surgery using mesh repair in total study population, $n = 80$.

	△ B0	△ B4	△ B12	△ C0	△ C4	△ C12	△ P0	△ P4	△ P12	△ R0	△ R4	△ R12
MV (cm)	3.13	1.15	1.40	2.49	1.17	1.12	2.37	1.18	1.40	1.56	0.85	1.00
SD (cm)	±2.21	±0.96	±1.08	±2.28	±1.20	±1.26	±1.89	±1.50	±1.55	±1.27	±1.66	±1.20
Median (cm)	3.09	1.13	1.38	2.40	1.06	1.00	2.24	0.99	1.03	1.45	0.64	0.88
MVC	–	63%	55%	–	56%	58%	–	56%	54%	–	56%	39%
P value	–	5.66* e^{-11}	1.50* e^{-08}	–	1.25* e^{-07}	4.66* e^{-07}	–	4.01* e^{-06}	0.0001	–	0.001	0.0009
P value (12wk-4wk)	–	–	0.03	–	–	0.75	–	–	0.166	–	–	0.99
Total	80	80	80	80	80	80	80	80	80	80	80	80

4wk, 4 weeks; 12wk, 12 weeks; △, Difference at maximum strain minus at rest; B, bladder base; C, cervix; MVC, median value change to initial results (%); MV, mean value; P, pouch of Douglas; pre, preoperative; R, anterior rectal wall; SD, standard deviation.

Table 3. Overall results of pelvic organ mobility preoperatively and at short-term follow-up (4 and 12 weeks) after reconstructive surgery using anterior mesh repair, $n = 51$.

	△ B0	△ B4	△ B12	△ C0	△ C4	△ C12	△ P0	△ P4	△ P12	△ R0	△ R4	△ R12
MV (cm)	3.59	1.12	1.41	2.40	1.16	1.15	2.37	1.34	1.62	1.45	0.98	1.07
SD (cm)	±2.18	±0.90	±1.02	±2.47	±1.22	±1.19	±2.01	±1.47	±1.42	±1.15	±1.93	±1.01
Median (cm)	3.79	1.12	1.37	2.38	0.99	0.99	2.09	1.18	1.15	1.19	0.62	0.84
MVC	–	70%	64%	–	58%	58%	–	43%	44%	–	48%	29%
P value	–	1.75* e^{-09}	1.21* e^{-07}	–	0.0003	0.0007	–	0.0027	0.016	–	0.096	0.075
P value (12wk-4wk)	–	–	0.060	–	–	0.945	–	–	0.163	–	–	0.683
Total	51	51	51	51	51	51	51	51	51	51	51	51

4wk, 4 weeks; 12wk, 12 weeks; △, Difference at maximum strain minus at rest; B, bladder base; C, cervix; MVC, median value change to initial results (%); MV, mean value; P, pouch of Douglas; pre, preoperative; R, anterior rectal wall; SD, standard deviation.

Regarding POM before surgery, the median value of bladder descent on dynamic MRI was 3.79 cm, of uterine descent 2.38 cm, of descent of the pouch of Douglas 2.09 cm, and of rectal decent 1.19 cm. Four weeks after surgery, a decrease in organ descent was observed in all compartments, especially in the anterior one. After 12 weeks, the cervix and the pouch of Douglas were stable, while a slight increase in descent was observed in the bladder base and a moderate increase in the anterior rectal wall (Table 3, Fig. 3).

In terms of POM, there were very highly significant differences ($P \leq 0.0001$) in bladder descent 4 and 12 weeks after surgery, highly significant differences ($P \leq 0.001$) in uterine descent 4 and 12 weeks after mesh repair, and significant differences ($P < 0.05$) in descent of the pouch of Douglas 4 and 12 weeks after mesh repair. No significant differences were observed in rectal descent (Table 3).

Posterior mesh repair. A total of 16 patients underwent posterior mesh repair. The median values of maximum bladder prolapse were 0.135 cm (preoperatively), 0.42 cm (at 4 weeks), and 0.31 cm (at 12 weeks); the median values of maximum uterine prolapse were −0.29 cm, −0.96 cm, and −1.56 cm, respectively; of maximum prolapse of the pouch of Douglas 3.32 cm, 1.25 cm, and 1.90 cm, respectively; and of maximum rectal prolapse 0.38 cm, −1.11 cm, and −0.44 cm, respectively.

Regarding POM before surgery, the median value of bladder descent on dynamic MRI was 1.34 cm, of uterine descent 1.62 cm, of descent of the pouch of Douglas

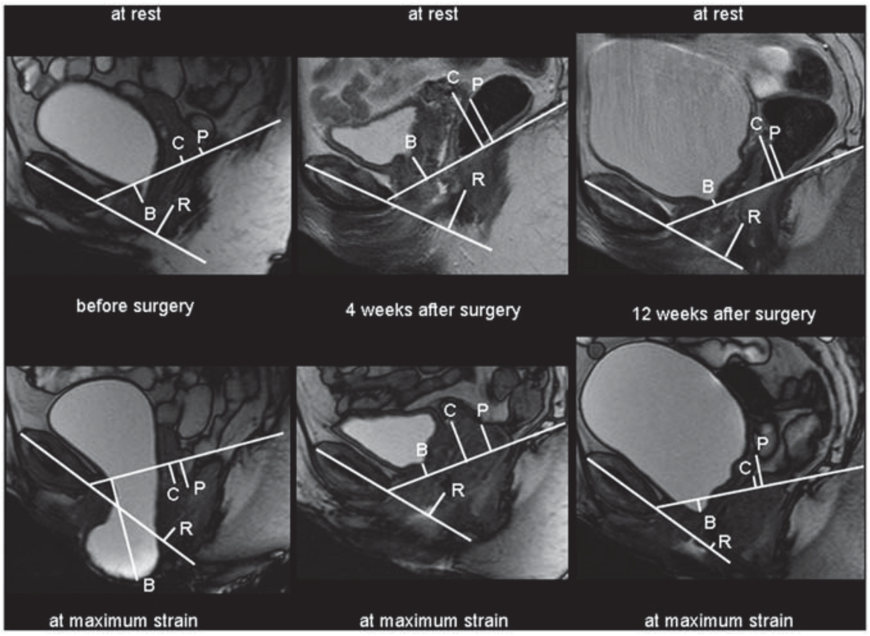

Fig. 3. Short-term follow-up results for anterior mesh repair in a 65-year-old woman presenting on clinical examination with grade II symptomatic cystocele and grade I uterine prolapse. Preoperative MRI at maximum strain showed severe cystocele, mild uterine prolapse, and a rectal descent, without falling below the MPL. Even with filled bladder, there was no significant cystocele at 12 weeks postoperatively, but better demarcation of the rectal descent, still without falling below the MPL. B, bladder base; C, cervix; MPL, midpubic line; P, pouch of Douglas; PCL, pubococcygeal line; R, anterior rectal wall.

Table 4. Overall results of pelvic organ mobility preoperatively and at short-term follow-up (4 and 12 weeks) after reconstructive surgery using posterior mesh repair, $n = 16$.

	Δ B0	Δ B4	Δ B12	Δ C0	Δ C4	Δ C12	Δ P0	Δ P4	Δ P12	Δ R0	Δ R4	Δ R12
MV (cm)	1.34	1.24	1.15	1.91	1.20	0.82	2.31	1.06	1.16	1.98	0.70	0.76
SD (cm)	±1.22	±1.25	±1.38	±1.64	±1.47	±1.54	±1.90	±1.42	±1.95	±1.53	±1.15	±1.73
Median (cm)	1.35	1.35	0.93	1.62	1.14	0.66	2.11	0.76	1.19	1.98	0.65	1.06
MVC	–	0%	31%	–	42%	59%	–	64%	44%	–	67%	46%
P value	–	0.769	0.60	–	0.0008	0.024	–	0.016	0.108	–	0.006	0.006
P value (12wk-4wk)	–	–	0.782	–	–	0.311	–	–	0.830	–	–	0.90
Total	16	16	16	16	16	16	16	16	16	16	16	16

4wk, 4 weeks; 12wk, 12 weeks; Δ, Difference at maximum strain minus at rest; B, bladder base; C, cervix; MVC, median value change to initial results (%); MV, mean value; P, pouch of Douglas; pre, preoperative; R, anterior rectal wall; SD, standard deviation.

2.11 cm, and of rectal decent 1.98 cm. Four weeks after surgery, a decrease in organ descent was observed in the middle and posterior compartment, with no changes in the anterior compartment. After 12 weeks, a decrease in organ descent was observed in the bladder base and cervix, while an increased descent of the pouch of Douglas and the anterior rectal wall was seen (Table 4, Fig. 4).

There were highly significant changes ($P \leq 0.001$) in uterine decent 4 weeks after surgery, and significant changes ($P \leq 0.01$) in rectal descent 4 and 12 weeks after mesh repair. No significant changes were seen in the anterior compartment or the pouch of Douglas, even between 4 and 12 weeks (Table 4).

Total mesh repair. A total of 13 patients underwent total mesh repair. The median values of maximum bladder prolapse were 2.49 cm (preoperatively), 0.26 cm (at 4 weeks), and 0.9 cm (at 12 weeks); the median values of maximum uterine prolapse were 0.78 cm, −1.59 cm,

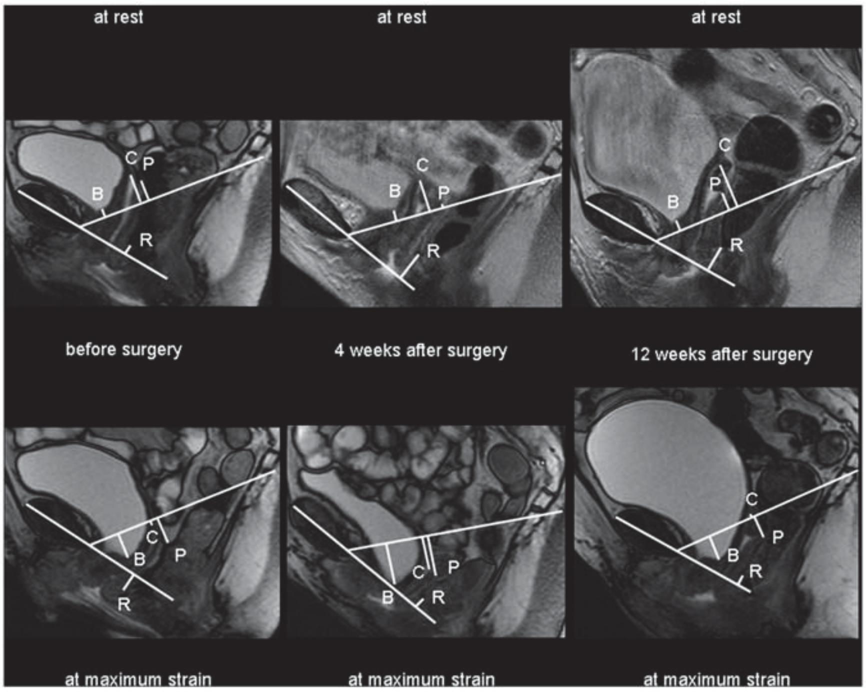

Fig. 4. Short-term follow-up results for posterior mesh repair in a 71-year-old woman presenting on clinical examination with grade III symptomatic rectocele and grade II cystocele. Preoperative MRI at maximum strain showed mild cystocele, moderate traction enterocele (passive descent of mesenteric fat without bowel loops), and mild rectal descent. Cystocele remained, while the posterior compartment did not show any prolapse 12 weeks postoperatively. B, bladder base; C, cervix; MPL, midpubic line; P, pouch of Douglas; PCL, pubococcygeal line; R, anterior rectal wall.

Table 5. Overall results of pelvic organ mobility preoperatively and at short-term follow-up (4 and 12 weeks) after reconstructive surgery using total mesh repair, $n = 13$.

	△ B0	△ B4	△ B12	△ C0	△ C4	△ C12	△ P0	△ P4	△ P12	△ R0	△ R4	△ R12
MV (cm)	3.54	1.15	1.70	3.53	1.14	1.37	2.43	0.68	0.84	1.44	0.52	0.98
SD (cm)	±2.30	±0.84	±0.88	±1.91	±0.81	±1.17	±1.43	±1.69	±1.43	±1.35	±0.87	±1.14
Median (cm)	3.32	1.03	1.53	3.01	1.06	1.66	2.83	0.45	0.61	1.37	0.65	1.24
MVC (%)	–	69%	54%	–	65%	45%	–	84%	78%	–	52%	9%
P value (4wk-pre)	–	0.0009	0.020	–	0.0004	0.0002	–	0.004	0.001	–	0.04	0.276
P value (12wk-4wk)	–	–	0.020	–	–	0.45	–	–	0.568	–	–	0.160
Total	13	13	13	13	13	13	13	13	13	13	13	13

4wk, 4 weeks; 12wk, 12 weeks; △, Difference at maximum strain minus at rest; B, bladder base; C, cervix; MVC, median value change to initial results (%); MV, mean value; P, pouch of Douglas; pre, preoperative; R, anterior rectal wall; SD, standard deviation.

and −1.71 cm, respectively; of maximum prolapse of the pouch of Douglas 2.08 cm, 1.08 cm, and 0.55 cm, respectively; and of maximum rectal prolapse 0.9 cm, −1.06 cm, and 0.29 cm, respectively.

Regarding POM before surgery, the median value of bladder descent on dynamic MRI was 3.32 cm, of uterine descent 3.01 cm, of descent of the pouch of Douglas 2.83 cm, and of rectal decent 1.37 cm. Four weeks after surgery, a decrease in organ descent was observed in all compartments. After 12 weeks, a severely increased descent was observed, especially for the anterior rectal wall (Table 5, Fig. 5).

There were highly significant differences ($P < 0.001$) 4 weeks after surgery for the anterior compartment and 4 and 12 weeks after mesh repair for uterine descent. Highly significant changes ($P < 0.01$) were observed

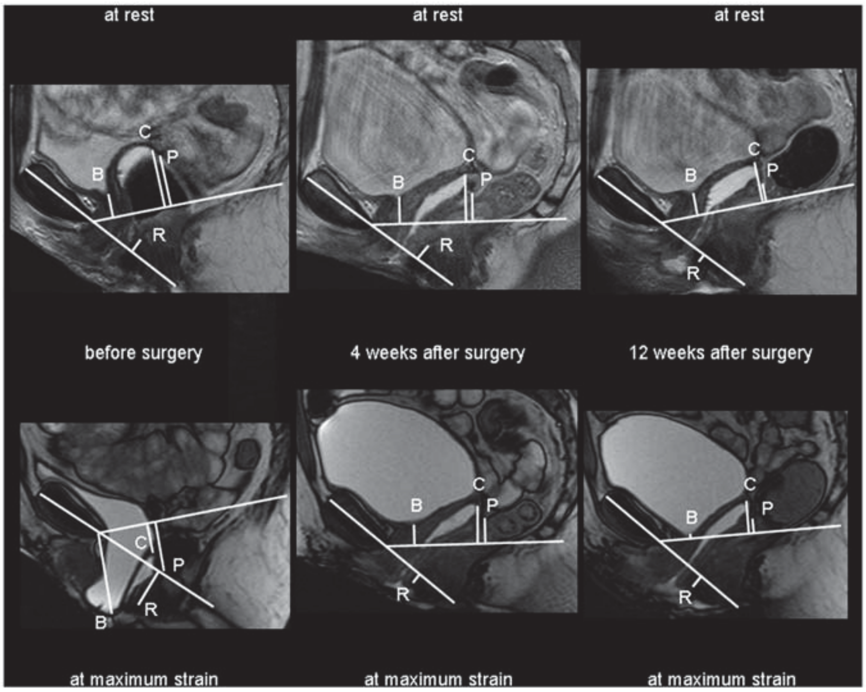

Fig. 5. Short-term follow-up results for total mesh repair in a 55-year-old woman presenting on clinical examination with grade II symptomatic rectocele and grade III cystocele. Preoperative dynamic MRI at maximum strain showed severe cystocele and mild rectal descent. At 12 weeks postoperatively, there was no pelvic organ prolapse in any of the three compartments. B, bladder base; C, cervix; MPL, midpubic line; P, pouch of Douglas; PCL, pubococcygeal line; R, anterior rectal wall.

4 and 12 weeks for descent of the pouch of Douglas. No significant changes were seen in the posterior compartment or between 4 and 12 weeks after surgery in any compartment (Table 5).

On physical evaluation after 4 and 12 weeks, all patients had asymptomatic POP-Q stage I descent, if any.

Discussion

Before planned surgical repair, a clear definition of all structures involved in POP is essential. In addition to clinical examinations, perineal ultrasound plays a major role in urogynecology (8,23). It is cost-effective and easily accessible, but evaluation depends on the physician's experience and is limited to a certain wave depth into the tissue; as a result, the whole extent of POP might not be seen (8). Thus dynamic MRI is an increasingly accessible cross-section imaging modality that can be used by a variety of disciplines (e.g. urogynecologists, urologists, surgeons) in a single patient. It offers the advantage of visualization of POP without overlapping, regardless of the extent of the prolapse or which compartment is involved (8,24–26).

POP can be evaluated using dynamic parasagittal TrueFISP sequences, while parasagittal and transversal turbo spin echo sequences are useful for static morphological evaluation; a predefined protocol with a minimum of sequences may therefore involve a scan time of about 15 min.

We chose to use the two aforementioned reference lines, as according to recent literature, the PCL is the most frequently used line and the MPL reduces the number of false-positive rectoceles. The four anatomical landmarks preferred for measurement are established and aligned to POP-Q landmarks (11–16,19–22).

So far, follow-up assessment after reconstructive surgery using dynamic MRI has been performed in only a few studies, although dynamic MRI may have the potential to visualize the therapeutic outcome after surgery and may determine re-prolapse at an earlier date (14,24,27). Nevertheless, in this study and in all the studies known to the authors that have been published in this field, the meshes themselves cannot be visualized by MRI. Thus only the indirect outcome of mesh support can be evaluated.

Due to the fact that dynamic MRI has several proposed grading systems by numerous authors yet none definite one, it was not the maximum extent of POP before and after mesh surgery that was to be evaluated and discussed in this study, but the mobility of the pelvic organs themselves (1,12,19,25). Every woman has a unique physiology in straining her pelvic floor muscles. Comparison of maximal straining values only and their integration into a grading system might not provide a full picture of the patient's subjective outcome of pelvic floor surgery. A question that needs to be discussed is whether the surgical outcome of each compartment can be seen individually for each patient just from the numerical changes in the difference between values at rest and at maximum strain without a clinical, subjective evaluation of the maximal measured numbers.

To the best of our knowledge, this is the first study to focus on evaluating POM.

While Siegmann et al. (14), Gufler et al. (24), Goodrich et al. (27), Woodfield et al. (28), Brocker et al. (29), and Rzepka et al. (30) compared the degree of organ prolapse on dynamic MRI before and after surgical repair to clinical examination or to the results of a standardized questionnaire, we focused on the images and evaluated the intraindividual POM before and after mesh repair regarding the changes in the numerical differences of the maximal extent during straining and the pelvic organ position at rest.

However, a comparison of our study with those of the above-mentioned authors is also only possible to a limited extent as they evaluated fewer patients. Studies involving a larger number of patients are rare.

Our results showed significant improvement of POM for the treated compartment after surgery, whereas, as expected, the untreated compartment did not show a significant improvement.

Our data on the maximum extent during straining at 3-month follow-up in 80 patients did not show any relevant POP in the untreated compartment, which is in contrast to the findings by Siegmann et al. (11) after evaluation of 15 patients in the same follow-up period. It should be mentioned that 40 patients had to be excluded from our study due to missing follow-up data. The reason for the reduced patient compliance might be dissatisfaction with the surgical result, which may have resulted in a bias.

Moreover, the surgical technique, the choice of mesh material, and the surgeon's experience may influence results. The fact that postoperative results showed significant differences compared with preoperative results, but no significant difference between 4 and 12 weeks, suggests good patient compliance on both examinations in terms of abdominal pressure. In addition, it is an indication for sufficient mesh support after reconstructive surgery without relevant re-prolapse of pelvic organs, which correlates with the results of physical examination at 3-month follow-up.

There are some limitations to our study. Due to a patient population with predominantly gynecological symptoms of pelvic floor dysfunction (anterior and middle compartment), the rectum (posterior compartment) was not opacified with gel, which may result in missed diagnosis e.g. intussusception. Retrospectively, there was no added value to the 4-week follow-up with MRI compared to the 12-week follow-up, at which point the patients are allowed to undergo normal physical work again. Therefore, the 12-week follow-up alone may be sufficient as a predictor for short-term therapeutic outcome. The comparison of newly developed symptomatic prolapse in the untreated compartment to the report of prolapse in the untreated compartment as visualized on the preoperative MRI was not evaluated in this short-term follow-up study. Also the impact of dynamic MRI for the management of patients with pelvic organ prolapse compared to 3D ultrasound or clinical examination alone was not outlined in this study.

In conclusion, dynamic MRI is useful in evaluating POP, providing an overview of the entire pelvis and visualizing the maximum extent of POP during straining.

Evaluation of POM before and after mesh support may be a promising method to evaluate the intraindividual therapeutic outcome in every woman with her own straining physiology, detached from a grading system based on maximal prolapse values.

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Original Article

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Five-year outcome after pelvic floor reconstructive surgery: evaluation using dynamic magnetic resonance imaging compared to clinical examination and quality-of-life questionnaire

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Abstract

Background: Dynamic magnetic resonance imaging (dMRI) captures the entire pelvis during Valsalva maneuver and helps diagnosing pelvic floor changes after reconstructive surgery.

Purpose: To evaluate therapeutic outcome five years after reconstructive surgery using clinical examination, dMRI, and quality-of-life (QOL) questionnaire.

Material and Methods: Clinical examination, dMRI, and QOL questionnaire were conducted before surgery and in the follow-ups at 12 weeks, one year, and five years in women with pelvic organ prolapse (POP) stage $\geq$2. dMRI was performed at 1.5-T using a predefined protocol including sagittal T2-weighted (T2W) sequence at rest and sagittal T2W true-FISP sequence at maximum strain for metric POP measurements (reference points = bladder, cervix, pouch, rectum). Pelvic organ mobility (POM) was defined as the difference of the metric measurement at maximum strain and at rest.

Results: Twenty-six women with 104 MRI examinations were available for analysis. dMRI results mostly differ to clinical examination regarding the overall five-year outcome and the posterior compartment in particular. dMRI diagnosed substantially more patients with recurrent or de novo POP in the posterior compartment ($n = 17$) compared to clinical examination ($n = 4$). POM after five years aligns to preoperative status except for the bladder. POM reflects best the QOL results regarding defecation disorders.

Conclusion: A tendency for recurrent and de novo POP was seen in all diagnostic modalities applied. dMRI objectively visualizes the interaction of the pelvic organs and the pelvic floor after reconstructive surgery and POM correlated best with the women's personal impression on pelvic floor complaints.

Keywords

Dynamic magnetic resonance imaging, pelvic organ prolapse, pelvic organ mobility, quality-of-life questionnaire, vaginal mesh repair

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Introduction

Pelvic organ prolapse (POP) represents a major public health issue. Women with this disorder can suffer from a severely decreased quality of life (QOL), such as physical, emotional, and social distress often making surgical interventions unavoidable (1). While there are a number of classic surgeries known and well-practiced in urogynecology (e.g. vaginal or abdominal hysterectomy, colporrhaphy, or sacrocolpopexy), the past decade in urogynecological surgery was influenced by the use of alloplastic material when aiming for pelvic floor reconstruction (2,3). Yet, the use of mesh material in surgical POP treatment remains highly controversial (4). Heterogeneous outcome results regarding prolapse recurrences, mesh erosions, or dyspareunia have been presented by numerous study groups often evaluating clinical results within themselves or, when applying an imaging tool, with ultrasound (US) (5). Pelvic floor US, for example, has rapidly been optimized in its visualization technique over the past years (e.g. three- and four-dimensional (3D/4D) US technique) with revealing a great amount of detail (6–8). However, it still has its limits as it cannot visualize all compartments at once, every so often being handicapped in complex prolapse situations and it is dependent on the experience and handling technique of its applicant (8). Dynamic magnetic resonance imaging (dMRI) is well-known to be able to capture the entire pelvis and its organs during Valsalva maneuver, allowing an objective view on pelvic organ interactions using a standardized protocol according to the current recommendations of the European Society of Urogenital Radiology and the European Society of Gastrointestinal and Abdominal Radiology (9). Because dMRI could play a role in the comprehensive evaluation of the postoperative pelvic floor after reconstructive surgery, we evaluated the medium-term follow-up results five years after vaginal mesh repair gained from clinical urogynecological examination (clinical examination), dynamic magnetic resonance imaging (dMRI), and prolapse quality-of-life (P-QOL) questionnaire. We present the surgical outcome evaluated by clinical examination as standard urogynecological procedure and focused on the evaluation of metric dMRI results compared to clinical examination and P-QOL.

Material and Methods

Study population

Between January 2008 and October 2009, 130 women were enrolled and registered into a prospective database as they received vaginal mesh repair due to a stage 3 or 4 or a symptomatic stage 2 prolapse according to the simplified pelvic organ prolapse quantification system (S-POP) (10,11). Institutional review board approval was obtained (IRB-number: S-473/2007. Amendment retrieved October 30th, 2012) and all women gave written informed consent. Due to the diagnosis made by clinical examination, an anterior, posterior, or combined anterior/posterior mesh repair was applied to repair POP (12). The patients were initially scheduled for five visits for clinical examination and dMRI, before and four times after surgery (at four weeks, 12 weeks, one year, and five years). At all visits, they were also asked to reply a validated QOL questionnaire that contains 34 questions, of which 18 questions concern the major symptoms of POP and 16 are grouped in nine domains related to particular aspects of life (12,13). Clinical examination included Graves speculum examination in the lithotomy position and documentation of POP during Valsalva maneuver (12). Recurrence was defined as S-POP $\geq$ stage 2 in women with the initial diagnosis of S-POP $\geq$ stage 2 regarding the same reference point. De novo POP was defined as S-POP $\geq$ stage 2 in women with initial S-POP stage 0 or 1 regarding the same reference point. dMRI was performed at 1.5-T (Magnetom Symphony, Siemens Medical Solutions, Erlangen, Germany) using a predefined protocol including a T2-weighted (T2W) high-resolution sequence in sagittal plane for morphologic information and measurements at rest and a T2W true-FISP sequence in sagittal plane during straining and at maximum strain for metric POP measurements (14). Evaluation of the validated P-QOL questionnaire was performed to assess the impact of vaginal mesh repair surgery on patients' QoL (13,15). Subgroups of this database were previously analyzed and reported (12,14). In these, we concluded that there was no added value to the four-week follow-up with MRI compared to the 12-week follow-up (12,14). Based on this, we did not include the four-week data into this mid-term follow-up evaluation. Patients were eligible for this analysis of longitudinal mid-term follow-up results after vaginal mesh repair if the pre-surgical examination, as well as the 12-week, one-year, and five-year postsurgical examination triad (clinical examination, dMRI, and QOL questionnaire), was available.

MR measurements

To define POP on dMRI, the maximum organ descent was measured at maximum strain in reference to the pubococcygeal line (PCL) using the bladder neck (B), the anterior cervical lip or vaginal vault after hysterectomy (C), and the pouch of Douglas (P) as reference points, according to the ESUR recommendations (9). The measurement of the extent of an anterior rectal wall bulge (R) was performed according to a line drawn through the anterior wall of the anal canal (9). Metric measurements (in cm) are positive if the position of the reference point is below the PCL and negative if the position is above it (9,14). While clinical terminology defines S-POP stages, dMRI terminology defines POP grades (9,10). We used the grading system recommended by the ESUR (9). Recurrence was defined as POP grade ≥ 2 using the same criteria as defined for clinical examination. We additionally evaluated the therapeutic outcome detached from a grading system by analyzing the pelvic organ mobility (POM), which is defined as the difference of the metric measurement at maximum strain to the measurement at rest for each reference point (9,14). MR measurements were performed in consensus reading by readers with up to nine years of experience in pelvic floor MRI.

Statistical analysis

Wilcoxon signed rank tests were used to compare both the POP stages by clinical examination and the POP grades by dMRI of the different post-surgical visits to the preoperative status. In addition, POM and maximum organ descent derived by dMRI was compared between preoperative and post-surgical visits using t-tests. ANOVA was used to compare QOL domains between pre- and post-surgical visits. Continuous variables are presented as mean $\pm$ standard deviation. Distributions of stages/grades are described by absolute frequencies. Due to the explorative character of the study we did not adjust for multiplicity. Statistical analyses were performed using R, version 3.2.3 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Twenty-six patients fulfilled the request of a complete examination triad at all visits during a five-year post-surgical period; therefore, 104 MRI examinations were available for analysis (Fig. 1). The mean age of this study cohort was 64 ± 10 years (range = 41–81 years). Mean body mass index (BMI) was 28.06 ± 6.43 kg/m^2.

Clinical urogynecological examination results

The S-POP stages derived by clinical examination changed significantly at the 12-week follow-up for all reference points and stayed significantly improved at the one-year as well as at the five-year follow-up (Tables 1 and 2). However, a recurrence was diagnosed at the five-year follow-up in 38% of patients (10/26),

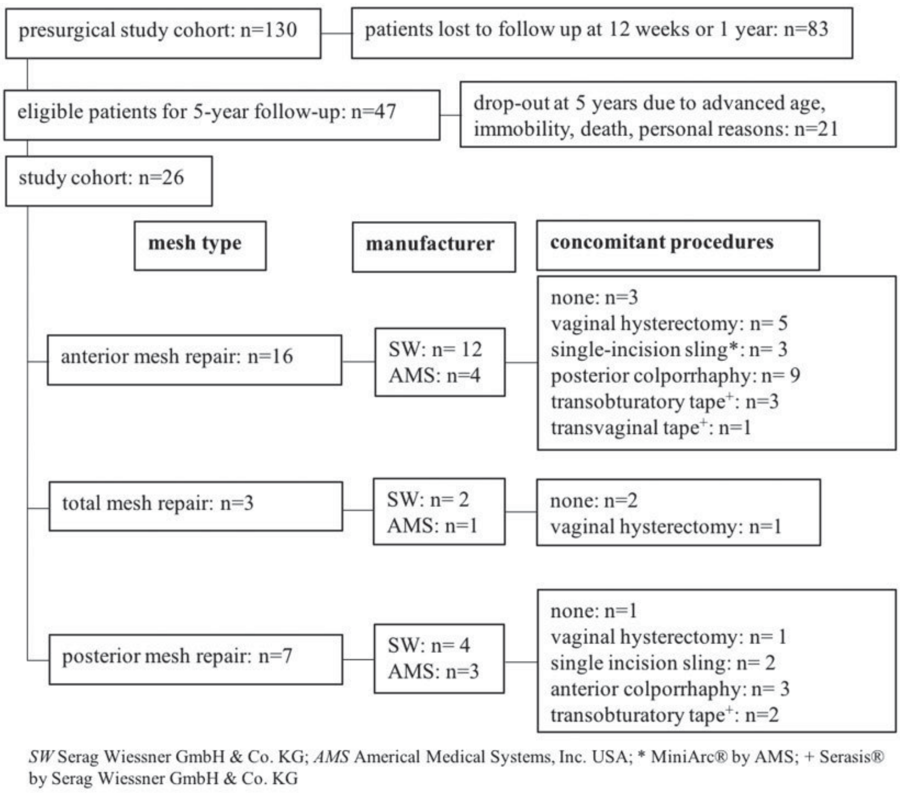


Fig. 1. Flowchart of the study cohort including mesh repair procedure.

Table 1. Urogynecological S-POP stage before surgery and five years after surgery.

Patient no.*	Bladder			Cervix/vaginal vault			Pouch of Douglas			Rectum		
	Pre	5-year FU		Pre	5-year FU		Pre	5-year FU		Pre	5-year FU	
1	3	0		2	0		3	0		0	0	
2	3	0		0	0		0	2	d-n	0	1	
3	3	2	r	0	0		0	1		0	1	
4	4	1		4	0		4	0		4	0	
5	0	2	d-n	4	2	r	0	0		0	2	d-n
6	3	0		3	0		0	0		2	2	r
7	3	2	r	3	0		0	0		2	0	
8	3	0		2	0		0	0		2	0	
9	2	2	r	3	0		1	0		1	0	
10	3	0		3	0		3	0		0	0	
11	3	1		1	0		0	0		1	2	d-n
12	3	2	r	1	3	d-n	3	0		1	1	
13	3	0		0	0		0	0		2	0	
14	3	2	r	0	0		0	0		1	1	
15	3	1		0	0		0	0		2	2	r
16	3	1		0	3	d-n	0	0		0	0	
17	3	1		0	0		3	1		3	0	
18	2	3	r	3	2	r	1	1		1	0	
19	3	0		3	0		3	0		2	0	
20	0	0		0	0		1	0		3	0	
21	1	2	d-n	1	0		3	0		3	0	
22	2	0		0	0		0	0		3	0	
23	0	1		0	0		3	0		3	1	
24	1	1		2	0		0	0		3	0	
25	0	2	d-n	0	0		3	0		3	1	
26	0	2	d-n	0	2	d-n	3	0		3	2	r

*Anterior mesh repair (patients 1–16), total mesh repair (patients 17–19), posterior mesh repair (patients 20–26).
Pre, before surgery; S-POP, simplified pelvic organ prolapse quantification system; FU, follow-up; r, recurrent POP; d-n, de novo POP.

with one compartment involved in 90% and two compartments involved in 10%. De novo POP was diagnosed in 31% of patients (8/26), with one compartment involved in 75% and two compartments involved in 22% (Table 1). Three patients were diagnosed with a combination of recurrent and de novo POP (Table 1).

MRI results

The mean values of maximum organ descent improved statistically significantly at the 12-week and one-year follow-up, except for the measurements of rectal wall bulges (R) (Fig. 2). At the five-year follow-up, however, the measured values were approximately equal to the preoperative status; moreover, the mean values for rectal wall bulges were even worse than at the beginning (Fig. 2). The results regarding the POP grade distribution derived by dMRI also showed statistically significant improvement at the 12-week follow-up for all reference points and at the one-year follow-up except for rectoceles (Table 2). At the five-year follow-up, the POP grade distribution was no longer significantly improved for all reference points compared to the preoperative status (Table 2).

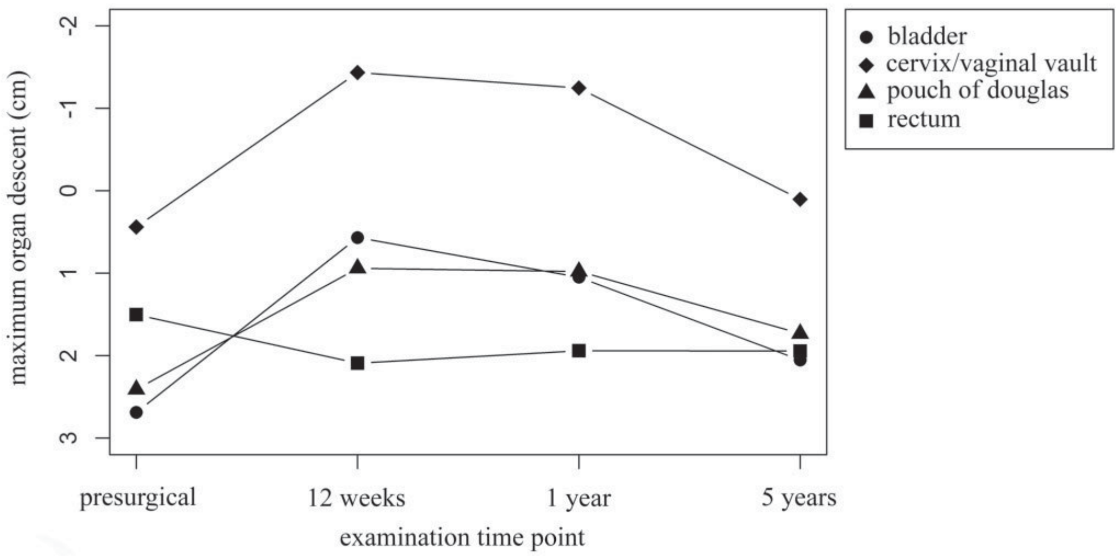
A recurrence was diagnosed at the five-year follow-up in 38% of patients (10/26), with one compartment involved in 70% and two compartments involved in 30%. De novo POP was diagnosed in 46% of patients (12/26), with one compartment involved in 83% and two compartments involved in 17%. Five patients were diagnosed by dMRI with a combination of recurrent and de novo POP.

Focusing on the five-year follow-up, clinical examination diagnosed slightly more patients with recurrent or de novo POP in the anterior and middle compartment (symptomatic cystocele or uterine prolapse)

Table 2. S-POP stages gathered by clinical examination and POP grades gathered by dMRI are given for each reference point at all visits.

		CE (S-POP-stage)					dMRI (POP-grade)				*P* value* (pre surgery vs. FU)	
Reference point	Visit	0	1	2	3	4	0	1	2	3	CE	dMRI
Bladder	Pre surgery	5	2	3	15	1	10	2	8	6	–	–
	12 weeks	19	6	1	0	0	15	11	0	0	<0.001	0.001
	1 year	12	8	6	0	0	12	13	1	0	0.001	0.007
	5 years	9	7	9	1	0	6	14	6	0	0.005	0.161
Cervix/Vaginal vault	Pre surgery	12	3	3	6	2	16	4	5	1	–	–
	12 weeks	25	0	0	1	0	24	2	0	0	0.002	0.005
	1 year	26	0	0	0	0	25	1	0	0	0.001	0.007
	5 years	21	0	3	2	0	19	5	2	0	0.028	0.122
Pouch of Douglas	Pre surgery	13	3	0	9	1	7	8	11	0	–	–
	12 weeks	24	0	1	1	0	14	10	2	0	0.003	0.001
	1 year	18	6	2	0	0	11	12	3	0	0.012	0.005
	5 years	22	3	1	0	0	12	8	5	1	0.003	0.057
Rectum	Pre surgery	6	5	6	8	1	8	9	8	1	–	–
	12 weeks	20	5	0	1	0	1	12	12	1	0.001	0.029
	1 year	17	8	1	0	0	4	7	15	0	<0.001	0.104
	5 years	15	6	5	0	0	1	12	13	0	0.003	0.083

*Wilcoxon signed rank test using the individual not averaged POP stages/grades.
CE, clinical urogynecological examination; dMRI, dynamic magnetic resonance imaging; S-POP, simplified pelvic organ prolapse quantification system; POP, pelvic organ prolapse.



	presurgical		12 weeks			1 year			5 years		
Maximum organ descent	mean (cm)	SD (cm)	mean (cm)	SD (cm)	p-value*	mean (cm)	SD (cm)	p-value*	mean (cm)	SD (cm)	p-value*
Bladder	2.69	±3.29	0.57	±1.15	0.001	1.05	±1.27	0.014	2.05	±1.29	0.236
Cervix / Vaginal vault	0.44	±3.35	-1.43	±1.47	0.002	-1.25	±1.44	0.007	0.10	±1.90	0.445
Pouch of Douglas	2.41	±2.12	0.94	±1.43	<0.001	0.98	±1.83	<0.001	1.73	±2.26	0.133
Rectum	1.50	±1.38	2.09	±0.93	0.036	1.94	±0.91	0.09	1.94	±0.88	0.143

SD standard deviation ; * student's t-test , compared to presurgical results; the values at the y-axis correspond to the maximum descent according to the reference line with positive values below

Fig. 2. Development of pelvic organ decent over time assessed with dMRI.

compared to dMRI (n = 9 vs. n = 8). However, dMRI diagnosed substantially more patients with recurrent or de novo POP in the posterior compartment (symptomatic enterocele or rectocele) compared to clinical examination (n = 17 vs. n = 4), including five patients with persistent POP at all examination time points. Three of them were evaluated as stage 0 by clinical examination, one was diagnosed as recurrent rectocele stage 2, and one was diagnosed as asymptomatic rectocele stage 1 (Fig. 3). Additionally, dMRI diagnosed three times more often recurrent multicompartment defects and slightly more one-compartment de novo POP as clinical examination did.

Regarding the results for POM measurements at the different time points, POM of the bladder showed the largest correction at 12 weeks postoperatively and stayed significantly improved at all examination time points, even if the mean value slightly increased again (Fig. 4). POM of the cervix/vaginal vault showed a similar trend; however, the mean value was statistically

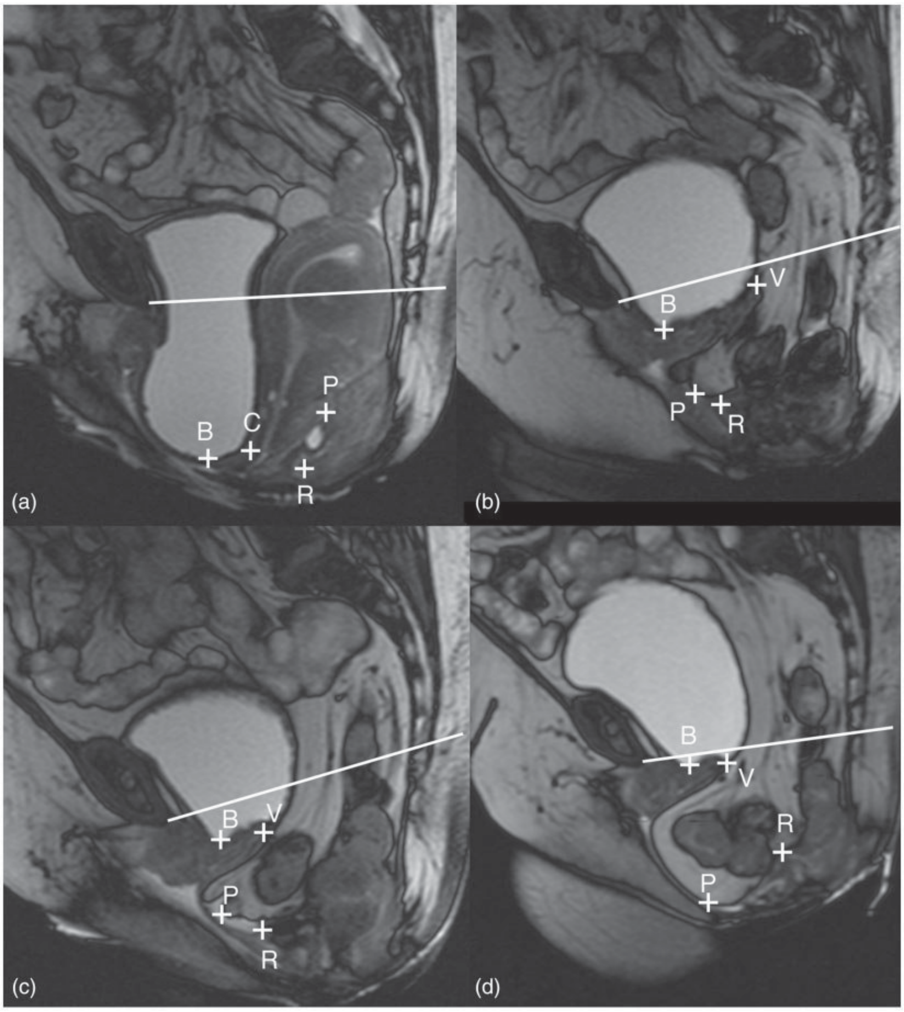
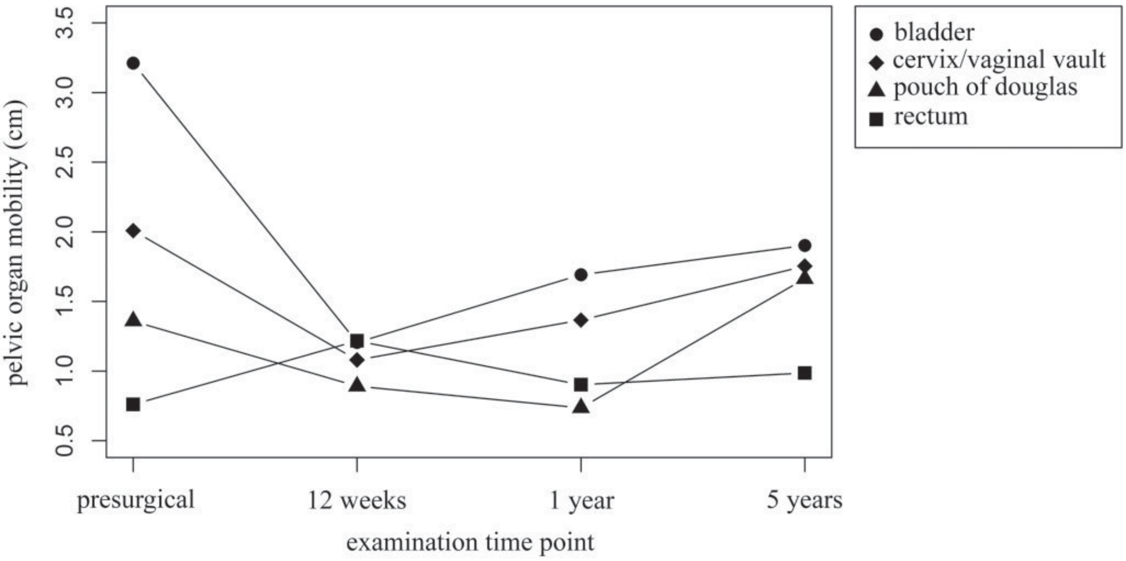


Fig. 3. A 41-year-old woman presenting with S-POP stage 3 for bladder and cervix, S-POP stage 0 enterocele, and S-POP stage 2 rectocele, who underwent anterior mesh repair with concomitant vaginal hysterectomy and MiniArc single-incision sling system by American Medical Systems. At the 12-week follow-up, clinical examination showed S-POP stage 0 for all compartments. At the one-year and five-year follow-ups, clinical examination diagnosed a recurrent rectocele S-POP stage 2, while all other compartments showed no descent. On dMRI, a multicompartment defect was initially diagnosed with grade 3 for bladder and grade 2 for cervix, pouch and rectum (a). At the 12-week follow-up (b), bladder descent grade 1 and vaginal vault grade 0 were diagnosed (enterocele and rectocele: grade 2). At the one-year and five-year follow-ups (c, d), the bladder and vaginal vault were diagnosed with grade 0, while the enterocele increased to grade 3 at the five-year follow-up with a stable grade 2 rectocele. The patient's QOL data support these results showing "general health perception" and "prolapse impact" mostly impaired before surgery, least impaired in the 12-week and one-year follow-ups, and recurrently impaired again in the five-year follow-up. B, bladder; C, cervix; P, pouch of Douglas; R, rectum; V, vaginal vault.



	presurgical		12 weeks			1 year			5 years		
POM	mean (cm)	SD (cm)	mean (cm)	SD (cm)	p-value*	mean (cm)	SD (cm)	p-value*	mean (cm)	SD (cm)	p-value*
Bladder	3.21	±2.47	1.21	±1.12	<0.001	1.69	±1.05	0.004	1.9	±1.57	0.021
Cervix / Vaginal vault	2.01	±2.49	1.08	±1.49	0.023	1.37	±1.24	0.178	1.75	±1.45	0.476
Pouch of Douglas	1.36	±1.47	0.89	±1.25	0.119	0.74	±1.64	0.056	1.66	±1.32	0.486
Rectum	0.76	±1.22	1.22	±1.00	0.177	0.9	±0.97	0.639	0.99	±1.04	0.528

SD standard deviation ; * student's t-test , compared to presurgical results

Fig. 4. Development of pelvic organ mobility over time assessed with dMRI.

significant improved only at the 12-week follow-up. POM of the pouch of Douglas was reduced at the 12-week and one-year follow-ups, increasing again at the five-year follow-up, with an even worse result than preoperatively. On the contrary, POM of the rectum worsened at the 12-week follow-up and slightly improved at the one-year and five-year follow-ups (Fig. 4).

Symptom and QOL evaluation

Regarding the evaluation of the questionnaire for the presence of urinary symptoms, minor improvement was seen at the five-year follow-up with 18 of the initial 24 women stating they have remaining urinary symptoms. Regarding the evaluation of the questionnaire for the presence of defecation symptoms, no relevant changes were seen at the five-year follow-up with all 21 women stating they have remaining defecation problems. Six women assessed their remaining defecation problems as "being severe." Of those, four were diagnosed with a de novo rectocele (75% by dMRI, 25% by clinical examination), one was diagnosed with a recurrent rectocele by dMRI, and one patient presented with only a stage/grade 1 rectocele. However, six of the eight QOL domains evaluated by P-QOL showed significant improvement (general health perception, prolapse impact, role limitations, physical limitations, social limitations, and emotions) (Table 3). Compared to the pre-surgical results, the scores are lowest (QOL increased) at 12 weeks after surgery and slightly increase up to 20–60% of the pre-surgical score results at the five-year follow-up (QOL decreased), while social limitations showed the most constant improvement over time (Table 3).

Discussion

Clinical examination is the standard urogynecologic POP staging technique and enables the physician an unneglectable personal and haptic impression on patients' pelvic organ behavior. However, dMRI has proven to be a useful addition where clinical examination has technical limits and may determine POP recurrence at an earlier date (12,14,16). By using the cine function, dMRI has the advantage of giving an objective visual impression of the interaction of the pelvic floor and the pelvic organs during straining without the influence of clinical examination tools and specula. It is more observer-independent due to the use of a standardized and predefined protocol and it also helps to gain knowledge of pelvic floor mechanisms and facilitates the diagnosis of complex disorders (9,14,16–19).

Table 3. Pre- and post-surgical QOL results gathered with the German P-QOL questionnaire.*

	Pre surgery	12 weeks	1 year	5 years	*P* value
General health perception	58 ± 24.7	29.8 ± 15	29.7 ± 13.6	34.1 ± 14.5	<0.001
Prolapse impact	84.1 ± 19.4	20.1 ± 29.5	25 ± 28.6	36.4 ± 30.8	<0.001
Role limitations	70.1 ± 22.5	14.4 ± 26.1	23.3 ± 26.3	20.2 ± 23.9	<0.001
Physical limitations	71.8 ± 23.8	10.8 ± 23.4	14.9 ± 22.8	20.1 ± 25.2	<0.001
Social limitations	50.9 ± 30.8	7.9 ± 20.7	8.6 ± 17.2	8.2 ± 14.8	<0.001
Personal relationship	59.6 ± 36.1	15.4 ± 30	16.7 ± 19.2	35.5 ± 34.5	0.062
Emotions	35.3 ± 32	7.9 ± 24.1	13.2 ± 22.3	10.5 ± 18.7	0.006
Sleep/Energy	51.4 ± 28.8	25.4 ± 24.4	20 ± 23.3	38.1 ± 25.4	0.078

The eight quality-of-life life domains are presented as mean ± SD comparison using ANOVA; the lower the score, the better the QOL.
*P-QOL questionnaire according to Lenz et al. and Digesu et al. [13,15].

We set out to assess postsurgical pelvic floor behavior in a medium-term follow-up of five years after vaginal mesh repair by applying dMRI in comparison to clinical examination and P-QOL questionnaire results. The following facts were observed over the course of this mid-term follow-up sample size study: (i) recurrent and de novo POP was diagnosed by clinical examination as well as by dMRI; (ii) dMRI results mostly differ to clinical examination results regarding the overall five-year outcome and the posterior compartment in particular; (iii) POM after five years aligns to preoperative status except for the bladder staying significantly improved; (iv) dMRI results best reflect the gathered QOL results regarding defecation disorders; (v) the examination triad of clinical examination, dMRI, and QOL questionnaire offers a holistic view of pelvic floor behavior.

In general, our study cohort is comparable to those of other studies in terms of BMI, age, and surgical data (5,20,21). For this analysis, the 12-week follow-up results served to monitor the anatomical cure rate of the reconstructive surgery performed. Focusing on the five-year follow-up, the total number of diagnosed recurrent or de novo cystoceles were comparable regarding clinical examination and dMRI results. However, dMRI diagnosed four times more often recurrent or de novo POP in the posterior compartment compared to clinical examination. In particular, five patients presented with persistent POP over the time on dMRI, being undetected in four patients and diagnosed as recurrent rectocele in one patient by clinical examination. In our study cohort, anterior mesh repair was mostly performed and we observed that the untreated posterior compartment had more hiatal space to descend during post-surgical straining. Regarding dMRI evaluation, POM pointed this out clearer than POP grade did. However, this did not generally result in clinical POP diagnosis at the time of evaluation.

The QOL outcome evaluated with the P-QOL questionnaire also worsened post surgery and thereby underlines the impression gathered by clinical examination and dMRI of accumulated recurrent or de novo POP occurring at the five-year follow-up. However, the subjective impression of the therapeutic outcome remains considerably improved for the treated woman herself at the five-year follow-up compared to pre-surgical results. This led to the presumption that the POP stage gained clinically or the metric measurements gained by imaging tools might best not be solely used to evaluate the outcome after vaginal mesh repair but to include the QOL evaluation in clinical routine to get a comprehensive impression of the individual pelvic floor disorder (1,15,22). Additionally, POM should be evaluated if dMRI is performed, as these results reflected best the gathered QOL results regarding defecation disorders in our study cohort.

Physicians might be encouraged to apply all three diagnostic modalities in their clinical routine, if possible, to gain a holistic view on pelvic floor behavior pre surgery and after vaginal mesh repair. In the pre-surgical setting, studies could show that dMRI led to changes of the surgical therapy plan in 61% of patients with POP and in 67% in patients with symptomatic posterior compartment defect in particular (23,24). Focusing on the posterior compartment, the differentiation between a rectocele or an enterocele or the clear identification of the content of a large enterocele can be challenging during clinical examination alone, but easily done by dMRI. If an enterocele is not recognized in pre-surgical therapy planning, this might have a direct consequence in the therapeutic outcome, e.g. persistent impairment of QOL or re-surgery (25–27). In the post-surgical setting, the examination triad helps to identify those suffering from ongoing pelvic floor disorders. It has the potential to raise awareness of persistent, recurrent, or de novo disorders of the primarily asymptomatic and initially untreated compartment.

Additionally, the treated compartment can be followed up and compared to the subjective patients' impression in order to detect recurrent or persistent POP. Early detection of recurrent or de novo POP before being finally symptomatic might help educate women on the potential future behavior of their pelvic organs. Furthermore, it provides the physician the ability to focus on appropriate therapeutic options (e.g. risk factor reduction, more intensive pelvic floor muscle training) going forward.

Our study has some limitations. We are aware that a substantial number of patients of the pre-surgical study cohort (80%) was lost to follow-up for age-related or personal reasons over the five-year period, which resulted in a higher drop-out rate than Maher et al. gathered in a Cochrane Systematic Review with rates up to 53% (28). However, longitudinal mid-term follow-up studies after vaginal mesh repair are scarce and we could at least analyze 55% of the eligible five-year patients of our cohort. Due to the small sample size, no statistical subgroup analysis was performed for the different meshes used. Pelvic floor US was not part of the initial study design and was therefore not available for analysis. Besides the advantages of functional cross-sectional imaging of the pelvic floor, dMRI is more time-consuming and costly compared to other evaluation methods such as clinical examination or US limiting a widespread clinical application. However, the additional costs may individually be taken into consideration, e.g. in cases of complex pelvic floor disorders including posterior compartment defects or in symptomatic cases with influence on QOL without clear clinical findings.

In conclusion, an overall good anatomical outcome and patient satisfaction with a tendency for recurrent or de novo POP was seen in all three diagnostic modalities applied. Yet, if interpreted alone, clinical examination, dMRI, and QOL evaluation might mislead the observer in evaluating the therapeutic outcome. The combination of the three mentioned evaluation tools, however, enables a holistic view on the pelvic floor behavior after vaginal mesh repair. Focusing on dMRI, it objectively visualizes the interaction of the pelvic organs and the pelvic floor after reconstructive surgery. In particular, the evaluation of POM seems to correlate best with women's personal impression on pelvic floor complaints.

Declaration of Conflicting Interests

The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: KAB and FL received speaking honoraria by the company Serag Wiessner GmbH & Co. KG (Naila, Germany); FL received speaking honoraria by American Medical Systems, USA, and C. R. BARD GmbH, Karlsruhe, Germany. No money of speaking honoraria was used to fund this trial. KAB received research funding by Serag Wiessner GmbH & Co. KG (Naila, Germany) in the past, of which no money was used to perform this trial.

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Urethral length and bladder neck behavior: can dynamic magnetic resonance imaging give the same results as introital ultrasound?

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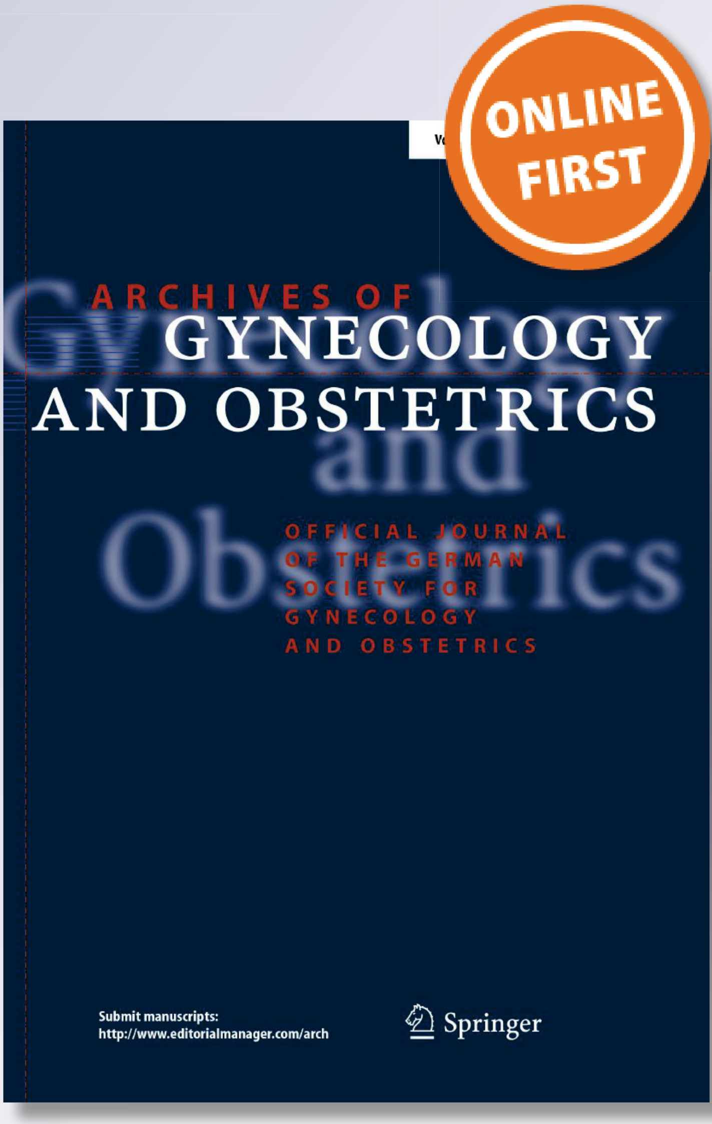

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GENERAL GYNECOLOGY

Urethral length and bladder neck behavior: can dynamic magnetic resonance imaging give the same results as introital ultrasound?

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Abstract

Purpose To compare dynamic magnetic resonance imaging (dMRI) and introital ultrasound results with regard to urethral length measurements and the evaluation of bladder neck changes.

Methods Retrospective analyses of urethral length measurements and detection of bladder neck changes (rotated/vertical bladder neck descent, urethral funneling) were conducted in women—scheduled for surgical treatment with alloplastic material—who had undergone introital ultrasound and dMRI presurgery and 3 months postsurgery. Measurement differences between both imaging modalities were evaluated by assessing the confidence interval for the difference in means between the datasets using bootstrap analysis.

Results Based on data from 40 patients (320 image series), the urethra could be clearly measured on every pre- and postsurgical dMRI dataset but not on preoperative ultrasound images in nine women during Valsalva maneuver due to a large cystocele. The estimation of the mean difference distribution based on 500,000 bootstrap resamples indicated that the urethral length was measured shorter by dMRI pre- and postsurgery at rest and postsurgery during Valsalva maneuver (median 1.6–3.1 mm) but longer by dMRI (median 0.2 mm) during Valsalva maneuver presurgery. Rotated/vertical bladder neck descent and urethral funneling diagnoses showed concordance of 67–74% in the direct comparison of patients; the estimation of the concordance indicated poorer outcomes with 50–72%.

Conclusions Metric information on urethral length from dMRI is comparable to that from introital ultrasound. dMRI is more advantageous in cases with an extended organ prolapse. At present, dMRI does not give the same diagnosis on bladder neck changes as introital ultrasound does.

Keywords Introital ultrasound · Dynamic magnetic resonance imaging · Urethral length measurement · Bladder neck descent · Urethral funneling

Introduction

Pelvic floor dysfunction (PFD) is a widespread health issue with a high socioeconomic impact and is a steadily growing concern in women of increasing age [1, 2]. Due to an increasing demand for remedying therapeutic options, surgical procedures utilizing alloplastic material to treat pelvic organ prolapse (POP) or stress urinary incontinence have been introduced in the past decade [3–6].

To provide an individually suitable therapeutic management system for each patient, a presurgical overview of the pelvic floor and the entire pelvis to visualize all disorders leading to PFD has played an increasing role. In addition to a urogynecological examination, including an introital ultrasound, dynamic magnetic resonance imaging (dMRI) serves as an objective diagnostic imaging tool to supplement the clinical data in selecting surgical candidates and in planning repairs [7–9].

Focusing on the anterior compartment, the individual length of the urethra, together with obesity and vaginal deliveries, is an important factor for the therapeutic success of treating stress urinary incontinence using urethral sling procedures [10]. The optimal sling location is reported to be in the high pressure zone between 53 and 72% of the total urethral length, varying between 19 and 45 mm [10,

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11]. Incorrect sling placement (e.g., particularly close to the bladder neck) is reported to be associated with persistent or recurrent incontinence [10, 12, 13]. Gaining a presurgical impression of the anterior compartment and the urethral behavior under the Valsalva maneuver, in addition to measuring the urethral length, therefore, seems crucial, and Pomian et al. [10] proposed the use of ultrasound. They also stated that there are no data comparing the different methods of urethral length measurement, e.g., ultrasound and MRI [10].

The aim of this study was to directly compare dMRI and introital ultrasound with each other in women at rest and during the Valsalva maneuver before and after pelvic floor surgery. The focus was on the urethral length measurement and the detection of bladder neck changes, particularly rotated or vertical bladder neck descent and urethral funneling.

Materials and methods

Between January 2008 and July 2012 women with symptomatic POP and/or stress urinary incontinence who were scheduled for surgical treatment with alloplastic material were included in a prospective longitudinal clinical single-center study database for the evaluation of PFD pre- and postsurgery with dMRI after they had given their written informed consent. The study was approved by the institutional review board (trial number: S-473/2007) with an approved amendment dated October 30th, 2012.

For the intermodal comparison of urethral length measurement and bladder neck changes, we retrospectively evaluated all women from the abovementioned database who had undergone an introital ultrasound in addition to clinical urogynecological examination and dMRI pre- and 3-months postsurgery. The time interval between ultrasound, which was performed directly after clinical examination, and dMRI was a maximum of 1 week in the preoperative setting and a maximum of several hours in the follow-up care. On the available image datasets, we focused on measurement of the total urethral length and on evaluating the urethral and bladder neck changes that were associated with the given pelvic floor disorder before and after surgery; specifically, we focused on rotated and vertical bladder neck descent and urethral funneling [14–16].

Ultrasound performance

An introital two-dimensional (2D) ultrasound was performed during the clinical urogynecological examination at rest and during the Valsalva maneuver with a moderately filled bladder, which is known to be more efficient for diagnosing bladder neck disorders, especially funneling, and this was achieved by asking the patient not to void 1 h before the examination [17]. The examination was performed by an experienced gynecologist with greater than 5 years of specialization in urogynecology using a vaginal probe (Voluson e, General Electric, USA, E8C-RS, 4.0–10.0 MHz, fixed angle), which was placed in the vaginal introitus at the level of the external urethral orifice [18]. The ultrasound image evaluation within this trial was performed at a later time by the same urogynecologist by the measurement of the total length of the urethra along its long axis from the internal urethral orifice into the bladder to the most peripheral part inside the hypoechogenic part of the urethra [19, 20], and documentation of the presence of a rotated or vertical bladder neck descent or urethral funneling on the pre- and post-surgical images (Figs. 1, 2).

MRI performance

The dMRI procedure was also performed with a moderately filled bladder by asking the patient not to void 1 h before the dMRI examination. Before the examination, the patients were instructed on how to correctly perform the Valsalva maneuver. The dMRI was performed with a 1.5 Tesla scanner (Magnetom Symphony, Siemens, Erlangen, Germany) with patients lying in supine position, knees elevated on a high pillow, following a predefined sequence protocol including T2- and T1-weighted sequences in sagittal or axial plane [8]. Vaginal opacification was not mandatory. For this study, T2-weighted high-resolution images in the sagittal

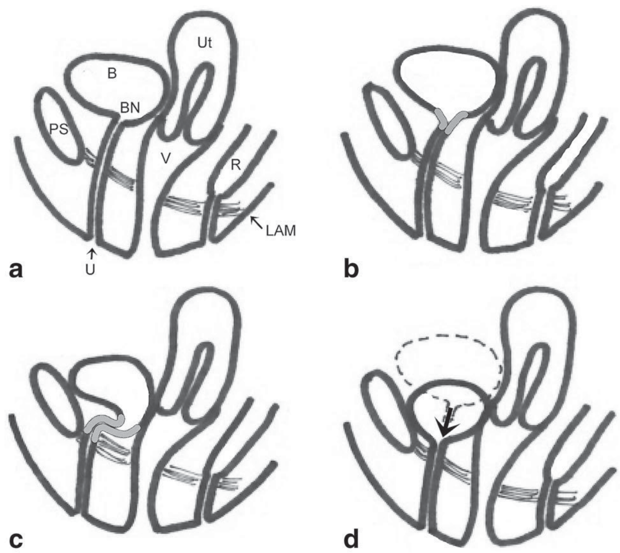

Fig. 1 Schematic drawing of the evaluated pathologies compared to a normal appearance: **a** normal anatomy; *B* bladder, *BN* bladder neck, *V* vagina, *Ut* uterus, *PS* pubic symphysis, *U* urethra, *R* rectum, *LAM* levator ani muscle complex; **b** urethral funneling; **c** rotated bladder neck descent; **d** vertical bladder neck descent

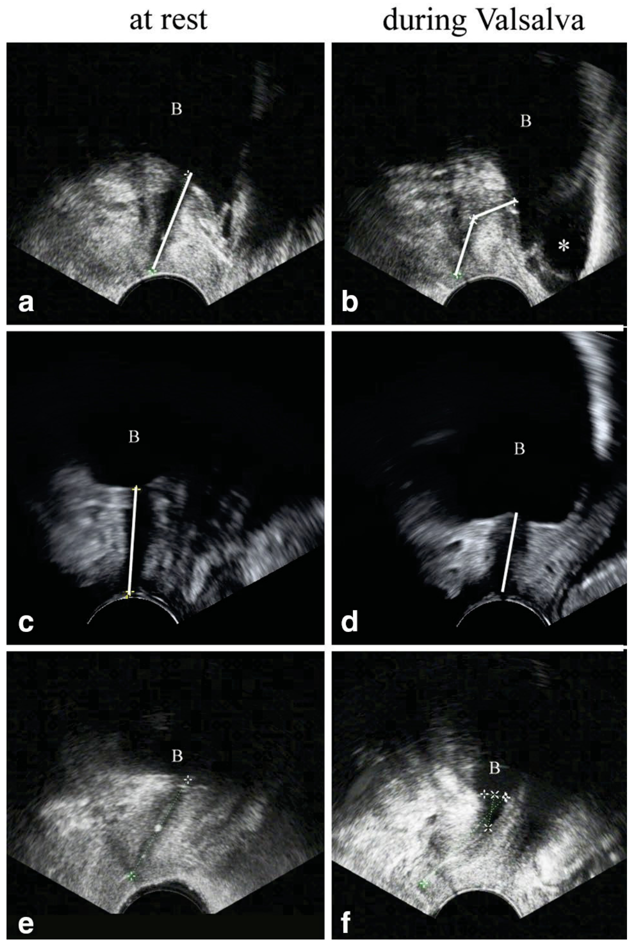

Fig. 2 Images gained from introital ultrasound in three different women. Image quality varies due to default settings the US investigator used for documentation (**a**, **b**) presentation of RBD and a cystocele (*). (**c**, **d**) Presentation of VBD. (**e**, **f**) Presentation of urethral funneling. *B* bladder

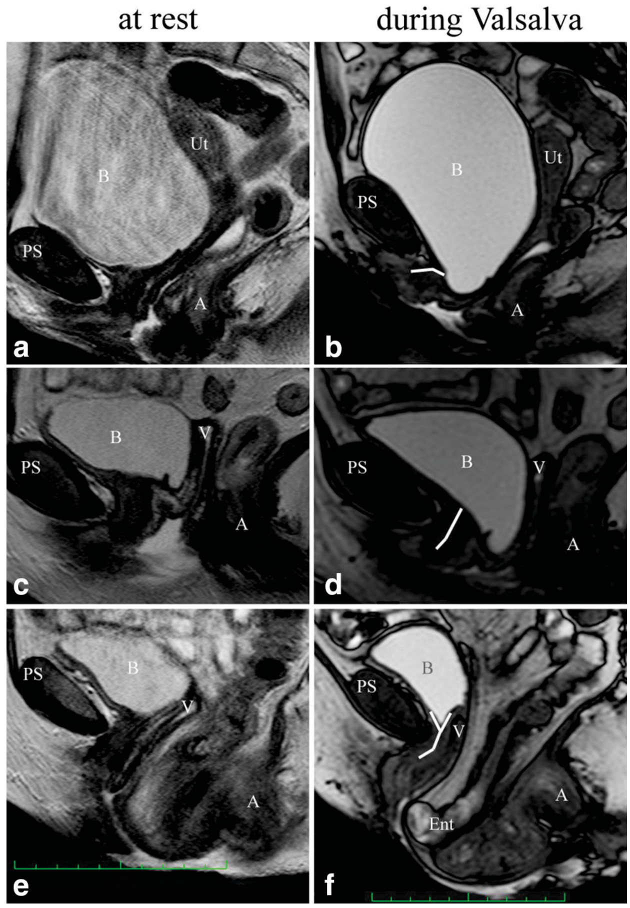

Fig. 3 Images gained from dMRI in three different women. **a**, **b** Presentation of RBD and a cystocele. **c**, **d** Presentation of VBD. **e**, **f** Presentation of urethral funneling. In this patient, urethral measurement and detection of bladder neck behavior were impossible using introital ultrasound due to the large enterocele. *PS* pubic symphysis, *B* bladder, *Ut* uterus, *V* vaginal vault, *Ent* enterocele, *A* anus

plane at rest (TR 3460 ms, TE 85 ms, matrix 512, slice thickness 5 mm, FOV 380 mm) and T2-weighted images in the sagittal plane at maximum strain (TR 4.3 ms, TE 2.15 ms, matrix 256, slice thickness 5 mm, FOV 330) were evaluated at a later time by an experienced radiologist with 6 years of specialization in pelvic floor imaging who was blinded to the clinical and ultrasound results. In accordance with the ultrasound evaluation, dMRI was used to measure the total urethral length along its long axis with the same endpoints defined by ultrasound and document the presence of bladder neck descent or urethral funneling (Figs. 1, 3).

Statistical analysis

Differences in the measurements between the imaging modalities (introital 2D ultrasound and dMRI) at the different examination time points (presurgery and postsurgery) and different functional status of the pelvic floor (at rest and during the Valsalva maneuver) were evaluated by assessing the confidence interval for the difference in means between the respective sets of data using bootstrap analysis. In particular, data were sampled at random (with replacement) 500,000 times, and the respective differences were recorded. We deemed the differences between the two sets to be robust and, therefore, statistically relevant if the two-sided 95% confidence interval did not include zero. This approach has the advantage over classical statistical testing in that it allows an inference of the underlying population rather than restricting the inference to within-sample effects. Congruency in the detection of bladder neck changes was treated as a classification problem and was likewise evaluated by bootstrap resampling. In particular, we treated the ultrasound measurement as the standard and assessed the accuracy of MRI relative to ultrasound; i.e., we calculated the percentage of cases in which the two modalities yielded the same result.

Results

Study population

Forty women had undergone urogynecological surgery (Supplement Fig. 1) both imaging modalities at the pre- and 3-months postsurgical examinations at rest and during the Valsalva maneuver were available and were included in the study. In total, 320 image series (160 per modality) were evaluated.

The median age of the study population was 66 years (range 45–83 years), and the median body mass index was 25.5 kg/m^2 (range 19.2–34.6 kg/m^2).

Urethral length measurement

The urethra could be clearly measured on every pre- and postsurgical dMRI dataset. The measurement could not be performed on the preoperative ultrasound images of nine women during the Valsalva maneuver, mainly due to a large cystocele. The measurement of the urethral length was not performable in the postsurgical ultrasound images of one woman. The absolute values from the study cohort are given in Table 1.

The estimation of the mean difference distribution for the results of the dMRI evaluation compared to those of the introital ultrasound based on 500,000 bootstrap resamples indicated that the urethral length was shorter as measured by dMRI than as measured by ultrasound presurgery at rest, with a median of −0.24 cm (95% CI −0.43 to 0.06 cm), postsurgery at rest, with a median of −0.31 cm (95% CI −0.50 to 0.14 cm), and postsurgery during the Valsalva maneuver, with a median of −0.16 cm (95% CI −0.31 to 0.04 cm) (Fig. 4a, b, d). However, at the presurgical examination during the Valsalva maneuver, the estimation of the mean difference distribution indicated that the urethral length as measured by MRI was longer, with a median of 0.02 cm (95% CI −0.17 to 0.21 cm) (Fig. 4c).

Table 1 Absolute values of urethral length measurement in our study cohort

	dMRI				
	Number	Mean	SD	95% CI	Range
Urethral length measurement (cm)					
Presurgical (rest)	$n=40$	2.15	0.38	2.03;2.27	1.29–2.98
Presurgical (Valsalva)	$n=40$	2.18	0.39	2.06;2.31	1.32–3.07
Postsurgical (rest)	$n=40$	2.04	0.38	1.92;2.16	1.21–2.75
Postsurgical (Valsalva)	$n=40$	1.99	0.42	1.86; 2.12	1.04–2.74
Introital ultrasound					
Presurgical (rest)	$n=39$	2.39	0.44	2.25;2.53	1.40–3.30
Presurgical (Valsalva)	$n=30$	2.12	0.49	1.93;2.28	1.15–2.80
Postsurgical (rest)	$n=40$	2.35	0.48	2.20;2.50	1.20–3.70
Postsurgical (Valsalva)	$n=39$	2.15	0.41	2.03; 2.29	1.37–3.17

dMRI dynamic magnetic resonance imaging, *SD* standard deviation, *CI* confidence interval

Detection of bladder neck changes

Rotated bladder neck descent and urethral funneling were diagnosed most in the preoperative settings in both modalities, while only a small number of patients were diagnosed with vertical bladder neck descent (Table 2). The direct comparison per patient in our cohort showed concordance ranging from 67 to 74%, while the estimation of the concordance indicated slightly poorer outcomes with 50–72% (Fig. 5).

Urethral funneling was diagnosed on dMRI in more than three-quarters of the patients postsurgery and on ultrasound in less than one-third of the patients (Table 2). The detection rate of bladder neck descent decreased from the pre- to postsurgical setting, except for vertical bladder neck descent (Table 2). The direct within-patient comparison in our cohort showed concordance ranging from 53 to 70%, while the estimation of the concordance indicated poorer outcomes with 40–68% (Fig. 5).

Discussion

Studies comparing results that were obtained by introital 2D ultrasound and pelvic dMRI in the same cohort, evaluating whether dMRI can give comparable quantitative information, are seldom found in the literature to date [10]. The aim of this study was, therefore, to directly compare the two imaging modalities of dMRI and introital ultrasound with each other with regard to one measurement (urethral length) and three qualitative parameters (urethral funneling yes/no and vertical and rotated bladder neck descent yes/no), which were proposed to be crucial for gaining a presurgical impression of the anterior compartment [10].

By comparing the performance of the measurement of the urethral length and the diagnosis of bladder neck changes on introital ultrasound and dMRI in forty women before and after pelvic floor surgery, the following results were observed: (i) measurement of the urethral length might be hampered in the introital ultrasound images during the Valsalva maneuver in women with extended pelvic floor disorders, while it is feasible on dMRI in a manner independent of the individual pelvic floor condition; (ii) dMRI measurement of the urethral length is comparable to that of introital ultrasound; and (iii) the diagnostic agreement between dMRI

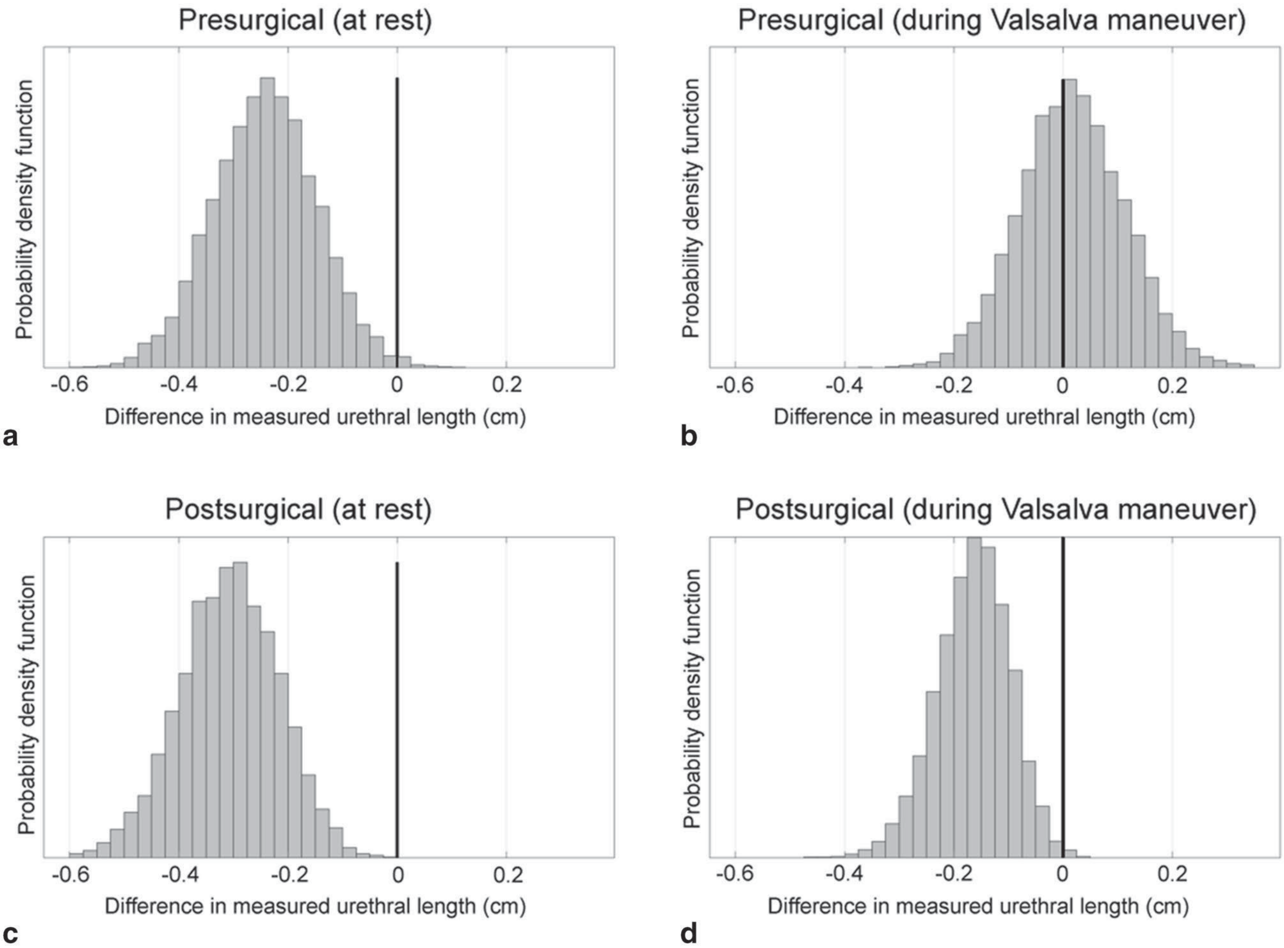

Fig. 4 Estimation of the mean difference distribution for the measurement values of the urethral length (value measured on MRI minus value measured on ultrasound) based on 500,000 bootstrap resamples for both time points (presurgery and postsurgery) at rest and during the Valsalva maneuver. Negative values indicate that the urethral length was measured as shorter on MRI than on US. *MRI* magnetic resonance imaging, *US* ultrasound

Table 2 dMRI and introital ultrasound results and the within-patient concordance in the study cohort

	dMRI	IU	Concordance (%)
Presurgical			$n=39$
RBD	22	20	29 (74.0) [16 yes, 13 no]
VBD	6	7	28 (72.0) [1 yes, 27 no]
UF	24	20	26 (67.0) [15 yes, 11 no]
Postsurgical			$n=40$
RBD	13	8	27 (67.5) [4 yes, 23 no]
VBD	10	7	28 (70.0) [3 yes, 25 no]
UF	31	12	21 (52.5) [12 yes, 9 no]

dMRI dynamic magnetic resonance imaging, *IU* introital ultrasound, *RBD* rotated bladder neck descent, *VBD* vertical bladder neck descent, *UF* urethral funneling, *yes* both modalities detected the pathology, *no* the pathology was not detected on either modality

and introital ultrasound for bladder neck changes is only mild to moderate.

Due to several advantages, e.g., its widespread availability, cost-effectiveness and ability to produce real-time viewing, introital ultrasound remains the mainstay for most clinical situations regarding pelvic floor disorders [21]. Nevertheless, introital ultrasound is dependent on the examiner, and the image datasets might be difficult to evaluate, especially at a later time point, e.g., during an interdisciplinary in-house conference for treatment planning when severe or multicompartment prolapse conditions are present. The dMRI method, however, has its pivotal strength in objectively visualizing all pelvic compartments free of overlap, and it gives a reproducible impression of the pelvic organ behavior during the Valsalva maneuver using a cine mode [3, 8, 9, 22]. Comparing the values of the urethral length described by Pomian et al. using ultrasound (mean 3.01 cm, range 1.9–4.5 cm) and Umek et al. using axial MR images

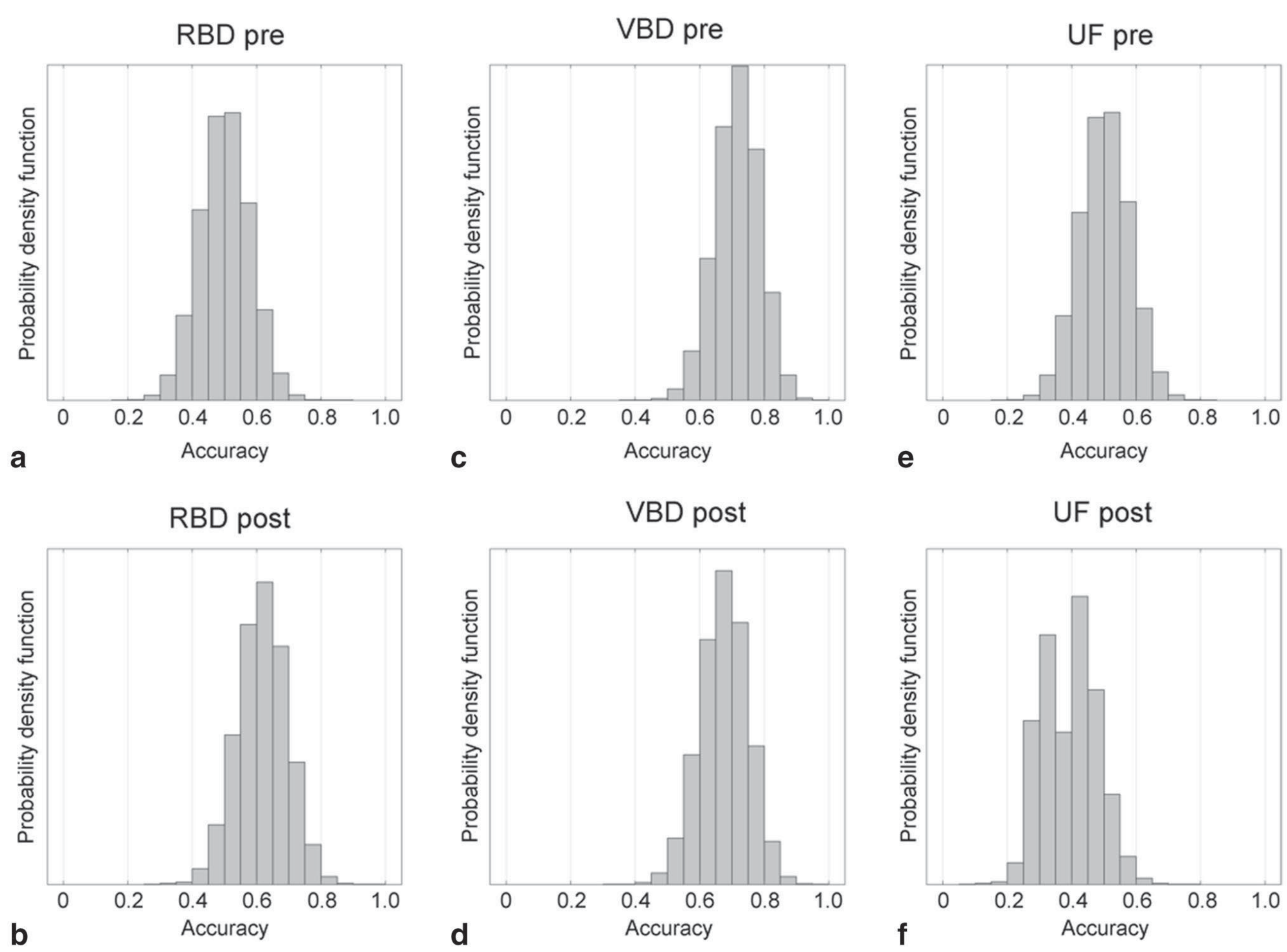

Fig. 5 Estimation of the mean difference distribution for the overall accuracy of both imaging modalities regarding the presence or absence of bladder neck changes based on 500,000 bootstrap resamples. *RBD* rotated bladder neck descent, *VBD* vertical bladder neck descent, *UF* urethral funneling, *pre* presurgical, *post* postsurgical

(mean 2.40 cm, range 2.0–3.5 cm), the urethral length was measured shorter for each modality in our study cohort [10, 23]. Comparing the values of the functional urethral length described by Nager et al. [24] during urodynamics (3.20 cm, range 0.1–5.0 cm), the mean values of our cohort were lower, however, the absolute values were in the given range. This supports the statement of Pomian et al. [10] that there is a fairly wide dispersion of urethral lengths, regardless from the used method. Based on our results, however, the expected intermodality difference of 0.2–2.4 mm between introital ultrasound and dMRI in the same cohort, when estimating a large cohort using bootstrap analysis, can be ignored. A larger study cohort is needed to prove these results.

The detection of bladder neck changes, however, showed more heterogeneous results. The diagnostic agreement between dMRI and introital ultrasound was best for vertical bladder neck descent, followed by the diagnosis of rotated bladder neck descent and last of all for urethral funneling. A reason for these discordant results might be a variance in the bladder filling at the different examination time points. The bladder volume is known to have an influence on the mobility of the urethrovesical junction, and funneling is more easily observed with a full bladder [17]. Another explanatory aspect might be the fact that the ultrasound investigator was not blinded to the diagnosis defined during clinical examination as was the radiologist, which might have biased the assessment of bladder neck changes, especially funneling. Additionally, variation in patient positioning (supine position during dMRI compared to the more upright sitting position during introital ultrasound) or an unintentional pressure with the ultrasound probe might have an impact on the visualization of bladder neck changes in the direct comparison of each patient and image modality. Another explanatory aspect for these divergent results might be a varying personal behavior of an individual woman who is potentially embarrassed while a physician is examining her with an ultrasound probe simultaneously during the Valsalva maneuver, whereas no such interaction takes place during the dMRI examination. Since introital ultrasound served as the gold standard, we were unable to evaluate whether the dMRI-based diagnosis was true in an individual patient when the ultrasound did not show bladder neck changes. This might be an interesting question to be answered in further studies.

It is obvious that there are far more possibilities to observe and evaluate when using introital 2D ultrasound and dMRI; however, this study focused on the comparability of the two different image modalities regarding urethral behavior.

Despite the fact that we are of the opinion that dMRI can be very valuable in the preoperative assessment of patients suffering from PFD, we are aware of the time-consuming and expensive nature of dMRI in a normal clinical setting, which thus limit its use. We acknowledge that our database contained a relatively small number of patients who underwent introital 2D ultrasound during a urogynecological examination and we, therefore, statistically enlarged the cohort by performing a bootstrap analysis.

Conclusion

From our results, we conclude that metric information on the total urethral length from dMRI is comparable to that from introital ultrasound and is, therefore, suitable for treatment planning. The dMRI method is more advantageous in cases with an extended organ prolapse during the Valsalva maneuver. To date, however, dMRI does not give the same diagnosis on bladder neck changes as introital ultrasound does.

Author contributions CDA: data analysis, manuscript writing, and manuscript editing. SMK: data collection and data management. PH: protocol development and manuscript editing. CS: project development and manuscript editing. HUK: project development. SBE: statistical analysis, data analysis, and manuscript editing. KAB: protocol development, data management, data analysis, and manuscript editing

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Compliance with ethical standards

Conflict of interest KA Brocker reports personal fees in the past by Serag Wiessner, Naila, Germany, outside the submitted work. All other authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants who were included in the study.

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3 T MRI-Based Measurements for the Integrity of the Female Pelvic Floor in 25 Healthy Nulliparous Women

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Aims: Measurements indicating a loss of integrity of the levator ani muscle, which is an integral part of the pelvic floor, have been subject of recent studies using translabial ultrasound and 3D-MRI-models. We transferred these measurements into 2D-3 T-MR-images for clinical routine, as it is objective and does not need exhaustive post-processing. **Methods:** The trial was accepted by the local ethics committee. 25 healthy volunteers fulfilled the inclusion criteria and gave written informed consent. Using high-resolution T2-weighted images (TE 5030–7810 ms, TR 88–112 ms, matrix 512, FOV 280–300 mm, ST 2–3 mm), measurements of anteroposterior hiatus (APH), laterolateral hiatus (LLH), hiatal area (HA), hiatal circumference (HC), levator area (LA), maximum muscle thickness (MMT) and levator urethra gap (LUG) were transferred from ultrasound, iliococcygeus width (IW), puborectalis attachment width (PAW), and levator symphysis gap (LSG) were transferred from 3D-MRI-models. We compared our results to previous studies in the literature. **Results:** Mean value was 52.22 ± 6.97 mm for APH, 33.15 ± 4 mm for LLH, $13.22 \pm 3.05\ cm^2$ for HA, 14.19 ± 1.61 cm for HC, $7.14 \pm 1.85\ cm^2$ for LA, 6.45 ± 2.07 mm for MMT, 19.47 ± 2.38 mm for LUG, 45 ± 3.97 mm for IW, 33.94 ± 3.34 mm for PAW, 20.54 ± 5.29 mm for LSG. Our results for APH, HA, LUG, and with limitations LA, were comparable to the literature, while HC, LLH, and MMT showed anatomical variances. Results for IW and LSG were comparable, but challenging to measure. We newly proposed a cutoff value for PAW. **Conclusions:** 2D-3 T-MRI combines high-resolution images with objective measurements of parameters regarding pelvic floor integrity, without resorting to exhaustive post-processing methods. Our results may provide a good foundation for further 2D-MR-studies. *Neurourol. Urodynam.* © 2014 Wiley Periodicals, Inc.

Key words: female pelvic floor; healthy volunteers; magnetic resonance imaging; muscle avulsion; pubovisceral muscle

INTRODUCTION

Translabial 3D ultrasound and magnetic resonance imaging (MRI) have each been proven to be useful in detecting defects of the pubovisceral muscle, correlating well to the symptomatic history of patients and providing safely applicable diagnostic tools without radiation.[1–3] Cost-efficient translabial ultrasound is especially well established in the clinical routine for visualizing defects and for permitting measurement of parameters such as the hiatal area, the hiatal circumference, or the levator urethra gap, which are indicators of a pelvic floor muscle avulsion.[3–7] Translabial ultrasound however also has its limitations as it requires experienced observers to be reproducible.[4,8]

MRI makes it possible to obtain high-resolution images of pelvic floor structures in two or three dimensions by using a 1.5 T or even better a 3 T scanner. This produces in particular higher soft tissue contrast and better resolution.[9–11]

In some recent studies, 3D-MR-models were constructed using a special postprocessing software for measuring parameters such as the iliococcygeus width, the puborectalis attachment width, or the levator symphysis gap.[11]

Irrespective of the imaging modality, reference values and anatomic norm variants of the levator ani muscle complex in young and healthy nulliparous women need to be known to correctly recognize muscle avulsion in affected women.[1,3,12]

2D-3 T-MRI of the pelvic floor with its high resolution contrast may combine the detection of muscle avulsion, the reproducibility of the performed measurements, and the implementation in clinical routine without exhaustive postrocessing methods. We therefore compared our results of 25 nulliparous volunteers with references in the literature using translabial 3D ultrasound or 3D-MR-models.

MATERIALS AND METHODS

This is a descriptive cross-sectional study. The trial protocol was approved by the local ethics committee, and the study was designed in accordance of the Declaration of Helsinki. Inclusion criteria for this trial were age $\geq$18 years, healthy and nulliparous condition, body mass index $< 30\,\frac{kg}{m2}$, and a written informed consent to participate in this study.

Exclusion criteria were pelvic floor dysfunctions (e.g., urinary or fecal incontinence, pelvic organ prolapse) or previous pelvic

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floor surgery, pregnancy, age <18 years, smokers, metal implants, or claustrophobia. Pelvic organ prolapse and urine or fecal incontinence was determined, that is, excluded with anamnesis and by applying standard gynecological clinical examination and cough test with full bladder, according to the ICS classification.[13] Twenty-five healthy volunteers were included in the study.

The examination was performed using a 3 T scanner (TIM Trio, Siemens, Erlangen, Germany). An external phased-array body coil was employed that was centered at the lower pelvis in a supine position. There was no special preparation of the women, and no contrast medium was administered intravenously.

Static native T2-weighted turbo spin echo sequences were acquired in the axial plane (TR 6820 ms, TE 112 ms, ST 3 mm, matrix 512, FOV 300 mm), midsagittal plane (TR 5030 ms, TE 88 ms, ST 3 mm, matrix 512, FOV 280 mm), and coronal plane (TR 7810, TE 88 ms, ST 2 mm, matrix 512, FOV 280 mm). Section orientation of the axial plane was parallel to the horizontal line—specifically the levator hiatus—defined as a straight line from the inferior margin of the pubic symphysis to the posterior part of the puborectalis sling.[14,15]

Measurement of the parameters was performed off-line at a PACS workstation (Centricity PACS, GE Healthcare, Milwaukee, Wisconsin). Two examiners (first author with 8 years and second author with 1 year of experience in pelvic floor MRI) performed the measurements in consensus reading.

All of our statistical analyses are descriptive in nature. We calculated the empirical distribution of measurements, such as mean values and standard deviations.

Observed means were compared to the reference values from the literature by using a two-sided one sample *t*-test. Comparison to the reference values could not be performed by a two sample test, as the corresponding standard deviations were not all given in the literature. Reported *P*-values are not adjusted for multiplicity and should therefore be interpreted descriptively.

Measurement Parameters

We performed measurements of 10 parameters, all indicators for muscle avulsion or pelvic floor weakness. The anteroposterior hiatus is measured by ultrasound on the sagittal plane from the inferior aspect of the pubic symphysis to the inner aspect of the pubovisceral muscle at the anorectal angle, representing the minimal hiatal dimension.[4,7] At this level, the laterolateral hiatus is measured on an axial plane as the distance between the most medial parts of the pubovisceral muscle on each side.[4,7]

The hiatal area and the hiatal circumference were measured on the same axial MR image at the level of the minimum hiatal dimension (Fig. 1a). To calculate the levator area, the circumference including the pubovisceral muscle was measured and the hiatal area was subtracted (Fig. 1b).

The muscle thickness of the pubovisceral muscle can be bilaterally measured and may be an indicator of muscle avulsion.[3] On ultrasound, the greatest diameter can be generally measured in the axial plane up to 1–1.5 cm above the minimum hiatal dimension, as identified in the sagittal plane.[7] On MRI the maximum muscle thickness is measured in the axial plane adjacent to the rectal wall at the level of the upper part of the urethra (Fig. 1c).[16]

The widening of the levator urethra gap is an indication of muscle avulsion.[5] On ultrasound, the distance between the middle of the urethra and the most inferior inner part of the pubovisceral muscle insertion at the os pubis is measured at the level of the minimum hiatal dimension at each side on the axial plane.[5] It was possible for us to measure this parameter similarly on axial 2D MR images (Fig. 2 and Table I).

As the iliococcygeal muscle is important to prevent posterior compartment prolapse, the iliococcygeus width is a predictor for pelvic floor weakness.[17] In a 3D-MRI-model, the iliococcygeus width is measured bilaterally in the coronal plane, including the ischial spine, as shown by Singh et al.[11] To define the parameters in a 2D image on the coronal plane, a ledger line was drawn between the most lateral and the most inferior part of the puborectal sling at each side. Through the intersection of these ledger lines, a second vertical ledger line was drawn parallel to coronal body axis. Finally, the most lateral point of the sling was connected to that vertical ledger line (Fig. 3).

The puborectal muscle forms a sling around the rectum and inserts at the lower inner part of pubic symphysis. An

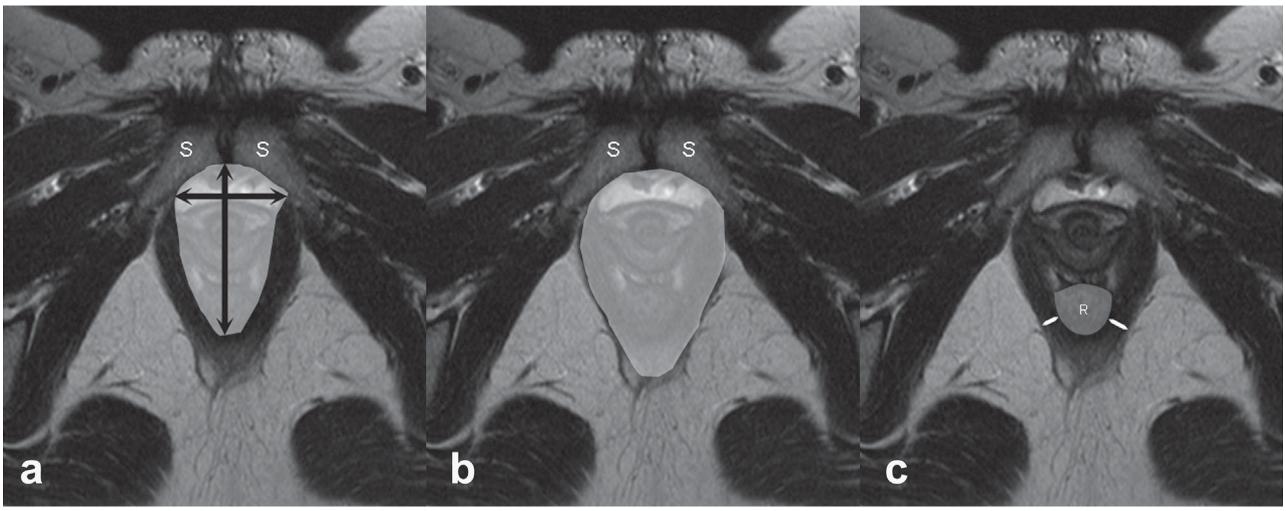

Fig. 1. (**a**) Minimal hiatal area (HA) (whitened area), anteroposterior diameter (HAP), and laterolateral diameter (HLL) (black arrowed lines) were measured in the axial plane at the same slice. S, pubic symphysis; (**b**) The area surrounding the levator and hiatus (whitened area). The levator area (LA) was calculated by subtracting the hiatal area (measurement see Fig. 1a). S, pubic symphysis; (**c**) Maximum muscle thickness (MMT) measured bilaterally at the thickest point of the LAM sorrounding the rectum in the hiatal area (white tapered line). R, rectum.

Fig. 2. Measurement of the levator urethra gap (LUG) was performed bilaterally as the distance between the middle of the urethra and the most inferior inner part of the LAM insertion at the os pubis in the plane of the hiatal area (white arrowed lines). S, pubic symphysis. The puborectalis attachment width (PAW) was measured in the axial plane as the distance between the most inferior visible bilateral insertions of the LAM at the os pubis (white tapered line).

important function is the elevation of the bladder neck and to line and strengthen the orifices of the pelvic floor.[17] The puborectalis attachment width is an indicator of pelvic floor weakness and is measured in a 3D-MR-model on the axial plane as the distance between the most inferior visible bilateral insertions of the pubovisceral muscle at the pubic bone.[18] We were able to transfer this measurement to axial 2D MR images (Fig. 2).

The levator symphysis gap is associated with pelvic organ prolapse and increases if levator ani muscle defects are present or if the stage of prolapse increases.[5,11,18] As descriptions of the measurement technique for the levator symphysis gap in the literature are inconsistent, we measured both sides to determine the distance from the anterior-lateral part of the puborectal muscle to the most lateral part of the pubic symphysis (Fig. 4).[11,18,19]

RESULTS

Twenty-five volunteers with a mean age of 27 years (range 20–33 years) underwent a 3 T MR examination of their pelvic floor between October 2011 and December 2012. All of them fulfilled the inclusion criteria. The total acquisition time was about 15 min. In all volunteers, the levator ani muscle complex, particularly the pubovisceral muscle, was intact, could be identified and evaluated within its v-shaped course from the dorsal aspect of the anorectal angle to its insertion at the pubic symphysis.

Our measurement results for each parameter including the reference value of nulliparous studies in the literature are listed in Table I.

There is no reference value for the puborectalis attachment width proposed for nulliparous women until now, only considered to be normal if symmetric.[18]

In this study, the width between the left and right puborectalis attachment was 33.3 ± 3.34 mm for healthy nulliparous women.

DISCUSSION

Injuries of the levator ani muscle are considered a common cause of pelvic floor dysfunction, increasing with age, obesity, and especially after vaginal childbirth and were evaluated in recent studies using ultrasound or cross-sectional imaging modalities.[5,18–21] Therefore, the detection of these injuries, especially avulsion of the puborectalis muscle, has been of growing interest for urogynecologists. The standard imaging modality to detect injuries of the levator ani muscle is translabial ultrasound.[8] Although, it is widely used and accepted, translabial ultrasound is strongly observer dependend and consecutively less reproducible.[4,8] To solve this problem, 3D-MRI-models were constructed for additional pelvic floor measurements.[11,18,22]

However, 3D-MR-models need a special post-processing software, taking additional time for reconstruction of the images. In clinical routine, 2D-3 T-MRI may combine both, high resolution images for measurement in different planes and the objectivity of the measurement.

Comparing our results of the anteroposterior hiatus with 52.2 ± 6.8 mm to recent ultrasound studies in nulliparous volunteers, they were comparable to Weinstein et al. (52.0 ± 0.5 mm)($P = 0.87$).[23] However, they were enlarged compared to Dietz et al., but within the range of the measured values (45.2 ± 6.7 mm)($P < 0.001$).[7] Reason may be anatomical variance in the study population and the constitution of the pelvic floor muscles, because measurement is performed between one bony marker and one soft tissue landmark.

The results in this study for hiatal area and levator area with 13.22 cm^2 and 7.14 cm^2, respectively, are in the standard deviation given by Dietz et al. with $11.25 \pm 2.7\ cm^2$ and $7.59 \pm 1.72\ cm^2$ ($P < 0.005$, $P = 0.23$) and by Weinstein et al. with $13.4 \pm 1.8\ cm^2$ and $4.8 \pm 2.4\ cm^2$ ($P = 0.77$, $P < 0.001$), respectively.[7,23] The laterolateral hiatus with a mean value of 33.2 ± 4 mm was smaller in our study compared to the results by Dietz et al. with 37.5 ± 5 mm ($P < 0.001$), but also within the range of measured values.[7]

MRI measurement of hiatal circumference was lower in our study group with 14.2 cm compared to Weinstein et al., who assessed a mean hiatal circumference of 18.2 cm in nulliparous women ($P < 0.001$).[23] However, Albrich et al. considered a hiatal circumference of 13.2 cm in a cohort of primipara after cesarean section.[4] Regarding to these contradictory results, this parameter might not be specific for detection of pelvic floor injuries.

The puborectalis muscle thickness in our group of volunteers was comparable to the muscle thickness of 7.0 mm reported by Kruger et al. in nulliparous volunteers for the left side with 7.2 mm ($P = 0.05$) and differed to 5.7 mm for the right side ($P = 0.002$).[24] It is to be mentioned, that Kruger at al. proposed only one value for maximum muscle thickness without side orientation.[24] According to Tunn et al., who assessed primiparous women, we measured a side difference between the left and right puborectalis muscle of about 1.5 mm.[16] Therefore, side differences of muscle thickness might be taken into consideration in the diagnosis of muscle avulsion.

The levator urethra gap was 18.5 mm on the right side and 20.5 mm on the left in our study and was therefore comparable

TABLE I. Measurement Results for Each Parameter in Our Study Population of n = 25 Nulliparous Women Compared to the Reference Values in the Literature (ultrasound parameters (no. 1–7) and 3D-MRI-model parameters (no. 8–10))

No.	Parameter	Mean value (± standard deviation)	Mean value (± standard deviation)	Reference	*P*-value[a]
1	Anteroposterior hiatus (mm)	52.22 ± 6.79	45.2 ± 6.7	Dietz et al.[7] (52 nulligravid volunteers)	<0.0001
			52.0 ± 0.5	Weinstein et al.[23] (23 nulliparous women)	0.8727
2	Laterolateral hiatus (mm)	33.15 ± 4	37.5 ± 5	Dietz et al.[7] (52 nulligravid volunteers)	<0.0001
3	Hiatal area (cm^2)	13.22 ± 3.05	11.25 ± 2.7	Dietz et al.[7] (52 nulligravid volunteers)	0.0047
			13.4 ± 1.8	Weinstein et al.[23] (23 nulliparous women)	0.7705
4	Hiatal circumference (cm)	14.19 ± 1.61	18.2 ± 3.0	Weinstein et al.[23] (23 nulliparous women)	<0.0001
5	Levator area (cm^2)	7.14 ± 1.85	7.59 ± 1.72	Dietz et al.[7] (52 nulligravid volunteers)	0.2357
			4.8 ± 2.4	Weinstein et al.[23] (23 nulliparous women)	<0.0001
6	Maximum muscle thickness (mm)				
	Right	5.67 ± 1.88	7.0 ± 1.1	Kruger et al.[24] (22 nulliparous volunteers)	0.0017
	Left	7.24 ± 1.98			0.5502
7	Levator urethra gap (mm)				
	Right	18.45 ± 2.22	19.7 ± 3.4	Dietz et al.[5] (18 vaginally nulliparous)	0.0096
	Left	20.5 ± 2.12			0.0713
8	Iliococcygeus width (mm)				
	Right	45.82 ± 4.1	45.3 ± 4.6	Singh et al.[11] (9 healthy nulliparous volunteers)	0.5320
	Left	44.18 ± 3.73	48.4 ± 4.3		<0.0001
9	Puborectalis attachment width (mm)	33.94 ± 3.34	Symmetric appearance	Zhuang et al.[18] (69 women with pelvic organ prolapse)	n.a.
10	Levator symphysis gap (mm)				
	Right	19.76 ± 5.15	17.4 ± 2.9	Singh et al.[11] (9 healthy nulliparous volunteers)	0.0317
	Left	21.33 ± 5.42	18 ± 2.0		0.0052

[a]Two-sided one sample *t*-test.

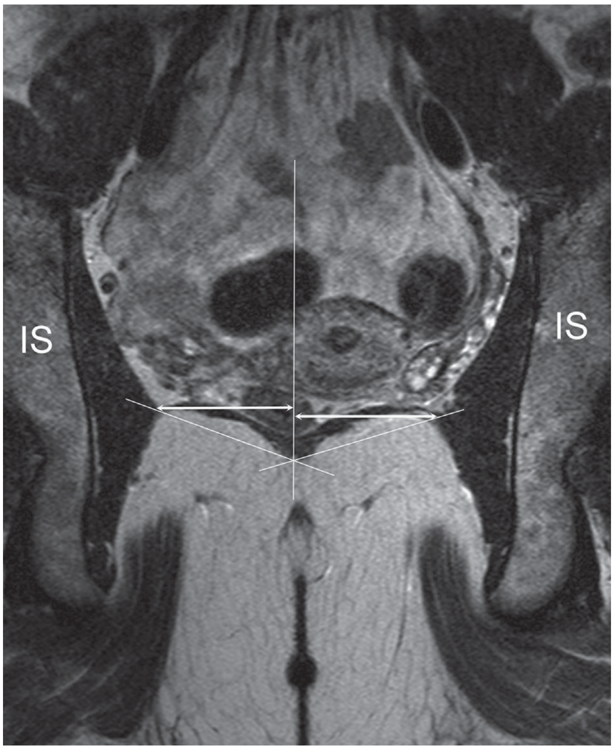

Fig. 3. The iliococcygeus width (IW) was measured bilaterally in the coronal plane on 2D images. A ledger line was drawn between the most lateral and the most inferior part of the puborectal sling at each side. Through the intersection of these ledger lines, a second vertical ledger line was drawn parallel to the longitudinal body axis. Finally, the most lateral point of the sling was connected to that vertical ledger line, defined as IW. IS, ischium.

to Dietz et al., who stated, that a LUG below 25 mm on each side as regular.[5]

Measurements taken from 3D-MRI-models turned out to be less transferrable. Even if our results for the iliococcygeus width with a mean value of 45 mm are comparable to those by Singh et al., who proposed mean values >40 mm for healthy nulliparous volunteers on a 3D-MRI-model, measurement of the iliococcygeus muscle on 2D images was challenging in our study population, as the iliococcygeus muscle cannot be fully depicted in one slice on 2D images due to its shape.[11] Presenting bony markers for exact measurement seems to be the benefit of a 3D-MRI-model.

In recent studies, definition of puborectalis attachment width is varying. Whereas Zhuang et al. defined the puborectalis attachment width to be regular if symmetric, analysing women with pelvic organ prolapse, Hoyte et al. measured the puborectalis attachment width in primipara women for each side separately with 17.67 mm for the left and 17.12 mm for the right side.[18,22] Regarding to these references, we proposed a new reference value for nulliparous women of 33.94 ± 3.34 mm, assessing the entire distance from the left side to the right.

Recent studies have given quite inconsistent descriptions for how to perform the measurement of the levator symphysis gap. On the one hand, Zhuang et al. defined the measurement on a 3D model as the distance from the middle of the inferior symphysis to the nearest aspect of the pubovisceral muscles on each side.[18] On the other hand, Singh et al. and Derpapas et al. measured each side of the levator symphysis gap as the distance from the anterior aspect of the levator ani muscle to the closest point of the pubic symphysis on transversal plane.[11,19] In our study, we measured the width from the anterior-lateral part of the puborectal muscle to the most lateral part of the pubic symphysis still visible on the same transversal slice, similar to

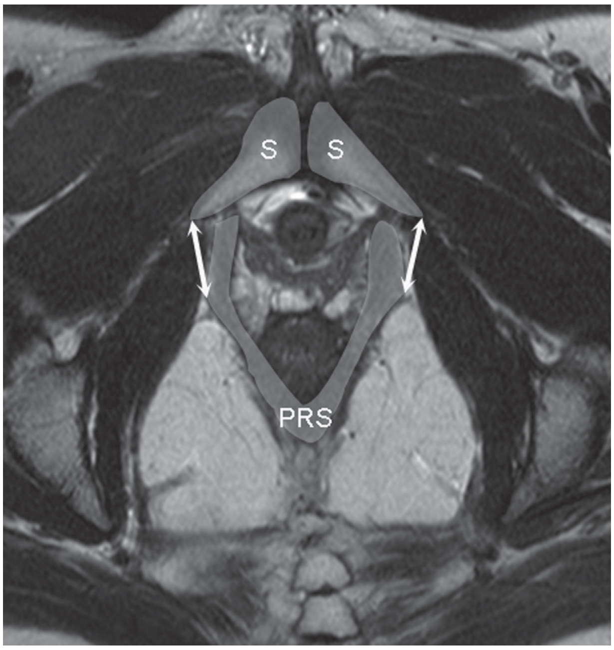

Fig. 4. Levator symphysis gap (LSG): It was measured in the transversal plane as the distance from the anterior-lateral part of the puborectal muscle to the most lateral part of the pubic symphysis still visible on the same transversal slice (white arrowed lines). S, pubic symphysis; PRS, puborectal sling.

Derpapas et al. on axial CT scans, as there was no muscle avulsion.[19]

Our results of the levator symphysis gap with 19.8 mm for the right side and 21.3 mm for the left side were well comparable to the results by Derpapas et al., reporting 21.2 mm for the right side and 22.5 mm for the left side ($P = 0.17$, $P = 0.29$).[19] However, the mean values in our study were higher compared to Singh et al. using a 3D-MRI-model, reporting 17.4 mm for the right side and 18.0 mm for the left side ($P = 0.03$, $P < 0.05$).[11]

Zhuang et al. proposed that the measurement of the levator symphysis gap on 3D MRI is similar to the measurement of the levator urethra gap using ultrasound and stated a value of <28.7 mm as regular.[18] According to the study of Zhuang et al., our results for the levator urethra gap with 18.45 mm on the right side and 20.5 mm on the left side are comparable.[18] Further studies are needed to clarify the question regarding which measured distance is more accurate or if some distances are not feasible and reproducible.

Our study is subject to some drawbacks. First, there were only 25 women in this descriptive study. Statistical analysis was therefore only descriptive. Second, this study was a non-controlled trial, and ultrasound was not additionally performed in the same volunteer. Third, we did not perform a 3D sequence with 1 mm isotropic voxels for 3D remodeling to obtain a direct comparison between the measurement results in each volunteer. Fourth, performing MRI of the pelvic floor is still more expensive compared to ultrasound and its use is restricted concerning claustrophobia, metal implants or pace-makers.

CONCLUSIONS

2D-3 T-MRI of the pelvic floor combines high resolution images with objective measurements of parameters, which are proposed to be indicators for muscle avulsion of the levator ani complex, without resorting to exhaustive post-processing methods. Results of anteroposterior hiatus, hiatal area, levator urethra gap, and with limitations levator area, are comparable to ultrasound results proposed in recent studies, considering, that the reported *P*-values are not adjusted for multiplicity and should therefore be interpreted descriptively. However, hiatal circumference, laterolateral hiatus and maximum muscle thickness exhibit anatomical variance and seem to be not specific for defects of the levator ani complex.

Measurement of the iliococcygeus width is challenging on 2D images due to its shape and the levator symphysis gap needs a clearer description on how to perform the measurement. In addition, we proposed a reference value for the puborectalis attachment width for nulliparous women.

The combination of high-resolution images of the entire pelvic floor and the possibility of observer-independent and objective measurements of the relevant parameters of the levator ani muscle complex to facilitate detection of defects may constitute the most effective benefit of 2D-3 T-MRI up to now.

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ORIGINAL CLINICAL ARTICLE

Early postpartum pelvic floor changes in primiparous women after vaginal delivery using 3T MRI

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AIMS: Detection of early morphological pelvic floor changes after vaginal delivery in primiparous women using 3 Tesla magnetic resonance imaging.
METHODS: A 3 Tesla magnetic resonance imaging was performed using static T2-weighted turbo spin echo (tse) in three planes, T2-weighted tse fat saturated and T1-weighted sequence in transverse plane. All visible changes of pelvic structures (edema, hematoma, tear, or avulsion) were documented. Measurements for the integrity of the pelvic floor were performed and compared to a nulliparous control-group. Differences in pelvic floor parameters were analyzed using an unpaired *t*-test. $P < 0.05$ was considered statistically significant.
RESULTS: Twenty-five primiparous women delivered vaginally at term and underwent postpartum magnetic resonance imaging. Several morphological changes in the pelvis, superficial as well as deep, were detected in all participants. Anteroposterior hiatus, hiatal circumference, hiatal area, laterolateral hiatus, maximum muscle thickness, and levator urethra gap were significantly different to the nulliparous control-group.
CONCLUSIONS: Two-dimensional 3 Tesla magnetic resonance imaging is feasible in a clinical and early postpartum setting establishing a reliable diagnostic tool to evaluate numerous morphological pelvic floor changes and the integrity of the pelvic floor.

KEYWORDS
MRI, pelvic floor, postpartum changes, primipara, vaginal delivery

1 | INTRODUCTION

Vaginal childbirth is a known risk factor for levator muscle trauma, which has substantial implications for pelvic organ support and is strongly associated with female pelvic organ prolapse.[1] Early detection of defects of the levator muscle and subsequent early intervention may delay the clinical effects of labor-related changes in the pelvic floor.[2] Therefore, it seems appropriate to examine the pelvic floor in an early postnatal period as it may be important for preventive measures.[2]

To diagnose levator trauma, ultrasound, and magnetic resonance imaging (MRI) are available imaging methods. Due to its easy accessibility and its cost effectiveness, three-dimensional (3D) ultrasound is frequently applied during pregnancy and the puerperium to visualize the levator ani muscle.[3] However, a known limitation of ultrasound is the limited wave depth into the pelvis, which may leave potential morphological changes undetected after delivery. MRI provides a multiplanar view of the pelvic floor and the entire pelvic structures with an excellent soft tissue contrast.[3] Due to

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developments in MR-imaging such as high resolution 3Tesla(T)-MRI, more detailed visualization of pelvic floor structures, pelvic organs, and their injuries is available.

In a recently published study with 25 nulliparous woman, our group demonstrated that two-dimensional (2D) 3T-MRI combines high-resolution images with objective measurements of parameters regarding the pelvic floor integrity transferred from ultrasound or 3D-MRI-models, without resorting to exhaustive post-processing methods.[4] The results of this study were the basis for this pilot study of 2D 3T-MRI in women after first vaginal delivery.

Firstly, the aim of our explorative study was to analyze pelvic floor MRI measurements and morphological changes and to establish their means and effect sizes. Those parameters included previously published MRI measurements for pelvic floor integrity and all developed morphological changes after vaginal childbirth. Secondly, we compared them to the previously published nulliparous group.[4]

2 | MATERIALS AND METHODS

The study was cross-sectional and of descriptive nature. The trial protocol was approved by the local ethics committee (trial number S-143/2011) and the study was designed in accordance of the Declaration of Helsinki. All patients gave written informed consent.

2.1 | Study population

Inclusion criteria were age ≥18 years, primiparous women who had given vaginal delivery at term in the Department of Gynecology and Obstetrics of Heidelberg University Medical Center between March 2012 and January 2013. Exclusion criteria were gestational age less than 36 + 0 at delivery, age <18 years, previously known pelvic floor dysfunction (eg, urinary or fecal incontinence, pelvic organ prolapse) or previous pelvic floor surgery, metal implants, or claustrophobia. Women were examined during the first week after vaginal delivery. All women who met the inclusion criteria were recruited consecutively and were included in the study, irrespective of a difficult birth history. The control group consisted of healthy nulliparous women who were recruited consecutively and met the same inclusion criteria as the study group, except for delivery data.[4]

2.2 | MR examination

The examination was performed using a 3T scanner (TIM Trio, Siemens, Erlangen, Germany) with an external phased-array body coil which was centered at the lower pelvis with the woman lying in supine position; no special preparation of the women and no administration of contrast medium was needed.[4]

Static native T2-weighted turbo spin echo (tse) sequences were acquired in axial (TR 6820 ms, TE 112 ms, ST 3 mm, matrix 512, FOV 300 mm), midsagittal (TR 5030 ms, TE 88 ms, ST 3 mm, matrix 512, FOV 280 mm), and coronal plane (TR 7810 ms, TE 88 ms, ST 2 mm, matrix 512, FOV 280 mm). T2-weighted tse fat saturated sequence was acquired in axial plane (TR 7490 ms, TE 112 ms, ST 3 mm, matrix 512, FOV 300 mm) as well as T1-weighted sequence (TR 8.6 ms, TE 983 ms, ST 3 mm, matrix 512, FOV 300 mm).[4] Scan duration was 18 min. Section orientation of the axial plane was parallel to the horizontal line (levator hiatus) as previously published.[4]

2.3 | Descriptive analysis

The pelvic floor and the entire pelvis were evaluated at a PACS workstation (Centricity PACS, GE Healthcare, Milwaukee) using transverse T2-weighted (T2w) sequences with and without fat saturation (fs) and T1-weighted (T1w) sequence by documenting any visible changes and its side like muscle, bone or ligament edema, soft tissue hematoma, perineal soft tissue defects, and the width of pubic symphysis. The pubovisceral muscle (PVM) sling was carefully examined for any injury or discontinuity at the insertion at the pubic bone. Muscle avulsion of the PVM was only diagnosed, if the muscle insertion was not seen on any slice or if an abnormality was seen on at least three consecutive slices on axial plane.[5]

2.4 | Measurement parameters

Two readers (CDA with 8 years and FH with 1 year of experience in pelvic floor MRI) performed the measurements of anteroposterior and laterolateral diameter, hiatal area, levator area, maximum muscle thickness, levator urethra gap, and puborectalis attachment width in accordance to the measurements for the integrity of the female pelvic floor in nulliparous women in consensus reading.[4] All parameters have previously been described to be indicators for muscle avulsion or pelvic floor weakness.[3,5–10] The anteroposterior levator hiatus was measured on sagittal plane at the minimal hiatal dimension, which is defined from the inferior aspect of the pubic symphysis to the inner aspect of the puborectal muscle at the anorectal angle; the laterolateral levator hiatus was measured on axial plane at the same level.[3,5,11] The levator urethra gap was measured at each side on axial plane between the center of the urethra and the most inferior inner part of the PVM insertion at the os pubis.[8] In case of muscle avulsion, the obturator fascia was defined as the lateral limit.[12] Maximum muscle thickness was bilaterally measured on the axial plane adjacent to the rectal wall. The puborectalis attachment width was measured on axial plane as the distance between the most inferior visible bilateral insertions of the PVM at the pubic bone.[4,13] In case of muscle avulsion, we also defined the obturator fascia as the lateral limit. The measurements were performed at a PACS workstation using 2D MRI data in consensus reading. Hiatal area, levator area and hiatal circumference were measured with a 3D post-processing program (Aquarius Intuition Viewer Version 4.4.7.64.5131, TeraRecon Inc., San Mateo, CA) due to an enlarged postpartum hiatus with a more sloped position, which was not captured on one axial 2D slice. The parameters were compared to a reference group of healthy nulliparous volunteers, who were previously examined at the same 3T-MRI scanner using the same protocol.[4]

2.5 | Clinical data acquisition

Clinical data were collected from the clinical report and from birth records regarding general pre- and postpartum information and data concerning patients demographics and delivery process (maternal body mass index (BMI) pre-pregnancy and after delivery, age, mode of delivery, duration of second stage of labor, performance of episiotomy and its side, maternal lower genital tract lacerations, birth weight, and head circumference of the neonate).

2.6 | Statistical analysis

Clinical and demographic parameters of the study population, as well as MRI parameters were descriptively analyzed (Tables 1-3). Differences in pelvic floor parameters of the study group and the nulliparous control group were analyzed using an unpaired *t*-test (Table 4). A *P*-level <0.05 was considered statistically significant. Analysis was performed using SPSS Statistics® Version 20 (IBM, Armonk).

3 | RESULTS

3.1 | Patient demographics

Twenty-five primipara fulfilled the inclusion criteria. Median age was 31 years (IQR 26-36 years). Twenty-two women were Caucasian, two were Asian, and one was African. Except for one woman having smoked until her pregnancy, all women were non-smokers. Median BMI before pregnancy was 21 kg/m^2 (IQR 20-23 kg/m^2) and after delivery 26 kg/m^2 (IQR 24-27 kg/m^2). The control group consisted of Caucasian healthy nullipara with median age of 31 years (IQR 26-36 years) and BMI <30 kg/m^2.[4]

3.2 | Birth records

All women delivered between gestational age of 38 + 0 and 41 + 0 with the newborn head in a regular cephalic presentation. The majority of women had a vaginal delivery with intrapartum epidural anesthesia and a regular duration of second stage of labor (SSoL) (less than 3 h) (Table 1).[14] Of those who had epidural anesthesia, the SSoL was prolonged in only one patient. She delivered vaginally without complications or the need for an intervention. The other three women with a prolonged SSoL in our study cohort underwent subsequent instrument assisted delivery due to deterioration of cardiotocography (Table 1). Women who received mediolateral episiotomy had no visible perineal or labial tear. In women who delivered without mediolateral episiotomy, perineal or labial tear was documented in 73% (8/11) and 45% (5/11), respectively (Table 2). Perineal trauma was documented more than twice in women with intrapartum epidural anesthesia compared to those without (Table 2). It was also increased in number in women without instrument assisted delivery (Table 2). Subject related birth records are given in Table 1.

3.3 | Depiction of postpartum changes of pelvic floor structures

MRI was performed after delivery at day 4 in the mean (range 2-7 days).

PVM avulsion was detected in 12%, PVM tear in 20% (Table 2). PVM hematoma was present in 76% (19/25), located (not) at site of attachment in (58%) 42% (Table 2). Beside PVM changes, pubic bone marrow edema was visible in 68%, pubic symphysis edema in 76%, superior pubic ligament edema in 92%, sacrouterine ligament edema in 56%, and internal obturator, transverse perineal, and pirifomis muscle edema in 76%, 100%, and 12%, respectively (Table 3, Fig. 1). Internal obturator and transverse perineal muscle hematoma was visible in 20% and 56%, respectively. The pubic symphysis width was 5-7 mm in 40% and 2.4-4.7 mm in 60% of the women (Table 3). Neither an edema of the sacroiliac junction was visible nor a fracture.

3.4 | Predictors for the integrity of the pelvic floor

Anteroposterior hiatus, hiatal circumference, and hiatal area showed high significant difference in the primipara group compared to the nulliparous control group ($P < 0.001$).[4] Laterolateral hiatus, maximum muscle thickness and levator urethra gap differed statistically significant ($P < 0.05$) (Table 4).[4] Levator area and puborectalis attachment width showed no significant differences (Table 4).[4] In three patients the PVM insertion left sided could not be visualized on any slice. No patient presented with hiatal ballooning.[15] Despite instrument-assisted delivery in five women, hiatal circumference was not enlarged in 80% of those. In 19 women with PVM hematoma measurements for hiatal area, levator urethra gap and laterolateral hiatus were 19.1 cm^2 (±3.8 SD), 20.8 mm (±2.5 SD) (right), and 24.7 mm (±6.5 SD) (left), and 36.5 mm (±3.4 SD), respectively. Compared to women

TABLE 1 Subject related demographics and general information about the delivery process

	Demographics			General information about the delivery process							
Patient No.	Origin	Age	BMI (kg/m^2)	Epidural anaesthesia	Mode of delivery	Duration of 2nd stage of labor	Birth weight (g)	Circumference newborn head (cm)	Mediolateral episiotomy right	Labial tear	Perineal tear (°I-IV)
1	Caucasian	31	23	Yes	Vaginal	Regular	3910	36	Yes	-	-
2	Caucasian	24	20	Yes	Vaginal	Regular	3200	34	-	Bilaterally	°I
3	Caucasian	36	24	Yes	Vaginal	Regular	3300	35	-	Right sided	-
4	Caucasian	33	19	-	Vaginal	Regular	3350	37	Yes	-	-
5	**Caucasian**	**28**	**20**	**Yes**	**Vacuum extractor**	**Rapid**	**2260**	**40**	**Yes**	**-**	**-**
6	Caucasian	30	20	-	Vaginal	Regular	3310	34	Yes	-	-
7	Caucasian	37	20	Yes	Vaginal	Regular	3000	35	-	-	°II
8	**Caucasian**	**35**	**21**	**-**	**Vacuum extractor**	**Protracted**	**3240**	**36**	**Yes**	**-**	**-**
9	Caucasian	37	24	-	Vaginal	Regular	3530	34	-	Bilaterally	°I
10	African	41	22	-	Vaginal	Regular	3050	37	-	Bilaterally	-
11	Caucasian	20	23	-	Vaginal	Regular	3850	37	Yes	-	-
12	Asian	34	17	Yes	Vaginal	Regular	3030	35	-	-	-
13	Caucasian	25	25	Yes	Vaginal	Protracted	3460	34	Yes	-	-
14	**Caucasian**	**26**	**19**	**-**	**Vacuum extractor**	**Protracted**	**3140**	**35**	**Yes**	**-**	**-**
15	Caucasian	37	20	-	Vaginal	regular	2660	33	Yes	-	-
16	Caucasian	32	23	Yes	Vaginal	Regular	2980	34	Yes	-	-
17	Caucasian	26	23	Yes	Vaginal	Regular	3150	34	Yes	-	-
18	**Caucasian**	**31**	**20**	**Yes**	**Vacuum and forceps extraction[a]**	**Regular**	**3150**	**40**	**-**	**-**	**°IV**
19	Caucasian	24	20	Yes	Vaginal	Regular	4170	36	-	-	°I
20	Caucasian	28	21	-	Vaginal	Regular	2900	36	-	Bilaterally	°I
21	Asian	33	21	Yes	Vaginal	Regular	2550	34	Yes	-	-
22	Caucasian	21	25	-	Vaginal	Regular	3630	34	Yes	-	-
23	Caucasian	41	20	Yes	Vaginal	Regular	3680	35	-	-	°I
24	**Caucasian**	**30**	**23**	**-**	**Vacuum extractor**	**Protracted**	**4020**	**36**	**Yes**	**-**	**-**
25	Caucasian	35	22	-	Vaginal	Regular	3950	36	-	-	°II

Bold lines, women with instrument assisted delivery; BMI, body mass index.
[a]In this woman, fundal pressure was performed.

TABLE 2 Results subdivided in women with or without epidural anesthesia, mediolateral episiotomy, and instrument assisted delivery regarding neonates head circumference, birth weight, hiatal circumference, presence of pelvic floor lacerations, and pubovisceral muscle hematoma

			Epidural anesthesia				**Mediolateral episiotomy**				**Instrument assisted delivery**			
	All		**Yes**		**No**		**Yes**		**No**		**Yes**		**No**	
	***n* = 25**		***n* = 13**		***n* = 12**		***n* = 14**		***n* = 11**		***n* = 5**		***n* = 20**	
	Median	**IQR**	**Median**	**IQR**	**Median**	**IQR**	**Median**	**IQR**	**Median**	**IQR**	**Median**	**IQR**	**Median**	**IQR**
Newborn head circumference (cm)	35	(34-36)	35	(34-38)	36	(34-37)	34.5	(34-36.3)	36	(35-40)	36	(36-40)	35	(34-37)
Hiatal circumference (cm)	17.1	(16.2-17.8)	16.9	(16.2-17.3)	17.8	(16-19.4)	17.3	(16-18.6)	17.1	(16.3-17.8)	15.7	(14.2-18.9)	17.3	(16.8-17.8)
Birth weight (g)	3240	(3015-3655)	3150	(2990-3570)	3330	(3072-3795)	3275	(2900-3685)	3200	(3030-3680)	3150	(2700-3630)	3305	(3007-3667)
Perineal tear	32% (8/25)		38.5% (5/13)		17% (2/12)		-		73% (8/11)		20% (1/5)		30% (6/20)	
Labial tear	20% (5/25)		15% (2/13)		8% (1/12)		-		45% (5/11)		-		25% (5/20)	
MR-visible PVM avulsion	12% (3/25)		8% (1/13)		17% (2/12)		14% (2/14)		9% (1/11)		20% (1/5)		10% (2/20)	
MR-visible PVM tear	20% (5/25)		8% (1/13)		33% (4/12)		21% (3/14)		18% (2/11)		-		25% (5/20)	
PVM hematoma	76% (19/25)		69% (9/13)		83% (10/12)		86% (12/14)		45% (5/11)		60% (3/5)		80% (16/20)	
At site of attachment	42% (8/19)		56% (5/9)		30% (3/10)		58% (7/12)		20% (1/5)		67% (2/3)		44% (7/16)	
Not at site of attachment	58% (11/19)		44% (4/9)		70% (7/10)		42% (5/12)		80% (4/5)		33% (1/3)		56% (9/16)	

IQR, interquartile range; MR, magnetic resonance; PVM, pubovisceral muscle.

TABLE 3 Subject related description of postpartum MR-findings

Patient no.	MR findings: PVM avulsion	PVM tear	PVM edema	PVM hematoma	PVM insertion at pubic bone edema	Pubic bone marrow edema	Pubic symphysis edema	Width of discus interpubicus (mm)	Edema pubic superius ligament	SUL edema	Internal obturator muscle edema	Internal obturator muscle hematoma	Superficial transverse perineal muscle edema	Superficial transverse perineal muscle hematoma	Piriformis muscle edema
1	-	-	-	Yes	Bilaterally	Bilaterally	Yes	4,4	Yes	Bilaterally	Yes	-	Yes	-	-
2	-	-	-	-	Right sided	Bilaterally	-	2,4	Yes	Right sided	-	-	Yes	-	-
3	-	-	Yes	Yes	Bilaterally	Bilaterally	Yes	6,2	Yes	Bilaterally	Yes	-	Yes	Yes	-
4	-	Bilaterally	Yes	Yes	Bilaterally	Right sided	-	4,7	Yes	Bilaterally	Yes	Yes	Yes	Yes	-
5	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**3,2**	**Yes**	**Bilaterally**	**Yes**	**-**	**Yes**	**-**	**Right sided**
6	-	-	-	Yes	Bilaterally	-	Yes	3,2	Yes	Right sided	Yes	Yes	Yes	Yes	-
7	-	-	-	Yes	Bilaterally	Left sided	Yes	3,8	Yes	Bilaterally	Yes	Yes	Yes	Yes	-
8	**-**	**-**	**-**	**Yes**	**Bilaterally**	**Left sided**	**Yes**	**5,0**	**Yes**	**Right sided**	**Yes**	**-**	**Yes**	**Yes**	**-**
9	-	Left sided	Yes	-	Bilaterally	Bilaterally	Yes	3,8	Yes	-	Yes	-	Yes	-	-
10	Left sided	Right sided	-	-	Bilaterally	-	Yes	4,4	Yes	Right sided	Yes	-	Yes	-	-
11	-	-	-	Yes	Bilaterally	-	Yes	2,3	Yes	Right sided	Yes	-	Yes	Yes	-
12	-	-	-	Yes	Bilaterally	Right sided	Yes	3,8	Yes	Right sided	Yes	-	Yes	Yes	Right sided
13	-	-	-	Yes	-	Bilaterally	Yes	5,3	Yes	-	Yes	-	Yes	-	-
14	**Left sided**	**-**	**-**	**Yes**	**Bilaterally**	**Right sided**	**Yes**	**5,3**	**Yes**	**Bilaterally**	**-**	**-**	**Yes**	**-**	**-**
15	-	-	-	Yes	Bilaterally	-	Yes	4,7	Yes	Right sided	Yes	-	Yes	Yes	-
16	-	Left sided	Yes	Yes	-	Left sided	Yes	6,2	Yes	-	-	-	Yes	-	-
17	Left sided	-	-	Yes	-	-	-	3,8	-	-	Yes	-	Yes	Yes	-
18	**-**	**-**	**-**	**-**	**-**	**Left sided**	**Yes**	**5,3**	**Yes**	**-**	**-**	**-**	**Yes**	**-**	**-**
19	-	-	Yes	Yes	Bilaterally	Bilaterally	Yes	5,9	Yes	-	Yes	-	Yes	Yes	-
20	-	-	-	Yes	-	Bilaterally	-	5,9	Yes	-	Yes	-	Yes	Yes	-

(Continues)

TABLE 3 (Continued)

Patient no.	MR findings														
	PVM avulsion	PVM tear	PVM edema	PVM hematoma	PVM insertion at pubic bone edema	Pubic bone marrow edema	Pubic symphysis edema	Width of discus interpubicus (mm)	Edema pubic superius ligament	SUL edema	Internal obturator muscle edema	Internal obturator muscle hematoma	Superficial transverse perineal muscle edema	Superficial transverse perineal muscle hematoma	Piriformis muscle edema
21	-	-	-	-	-	Left sided	Yes	4,4	Yes	-	Yes	-	Yes	-	Bilaterally
22	-	Bilaterally	-	Yes	Bilaterally	Bilaterally	-	5,6	-	-	-	-	Yes	-	-
23	-	-	Yes	Yes	-	Bilaterally	Yes	4,7	Yes	-	-	-	Yes	Yes	-
24	**-**	**-**	**Yes**	**Yes**	**Bilaterally**	**-**	**Yes**	**7,0**	**Yes**	**Bilaterally**	**Yes**	**Yes**	**Yes**	**Yes**	**-**
25	-	-	Yes	Yes	Bilaterally	-	Yes	4,7	Yes	-	Yes	Yes	Yes	Yes	-

Bold lines, women with instrument assisted delivery; PVM, pubovisceral muscle; SUL, sacrouterine ligament.

without hematoma, only hiatal area measurement was enlarged ($16.0\ cm^2 \pm 4.3$ SD, 21.2 mm ± 4.5 SD (right), 24.9 mm ± 6.1 SD (left), 37.2 mm ± 6.4 SD).

4 | DISCUSSION

In this prospective study we evaluated early postpartum morphological changes of the pelvis in 25 primipara after vaginal delivery using two-dimensional (2D) 3T-MRI in comparison to a nulliparous control group. 2D 3T-MRI is feasible in a clinical and early postpartum setting establishing a reliable diagnostic tool to evaluate numerous pelvic floor changes and the integrity of the pelvic floor on the basis of recently published 2D 3T-MRI data in nullipara.[4]

Firstly, performing MRI in the first days postpartum detected several morphological changes of the pelvic structures, superficial, and deep. To the best of our knowledge, these findings especially of the deep pelvic structures were not described in detail before. This may be because postpartum MRI examinations are mostly performed at a later time.[16–18] However, due to the proven relation of levator trauma, vaginal delivery, and increased risk of pelvic organ prolapse early postpartum pelvic floor evaluation is performed with certain frequency using ultrasound.[2,5,19–21] This seems beneficial compared to later evaluation regarding early detection of defects and the possibility for preventive measures.[2,21] Thus we evaluated early postpartum changes on MRI.

Secondly, pelvic floor MRI is often performed using widely available 1.5T-scanner, in certain cases 1.0T-scanner. In our opinion, a 3T-scanner provides more detailed images of soft tissue due to technical developments compared to lower resolution, which is advantageous in detecting slight soft tissue changes but may not be necessarily required for the detection of edema, hematoma or fracture.

A third issue is the integrity of the pelvic floor measurements. All measured parameters differed significantly compared to the nulliparous control group except for levator area and puborectalis attachment width.[4] However, our result for puborectalis attachment width is comparable to Hoyte et al using 3D-MRI-models in primipara.[16]

The mean pubic symphysis width was smaller in our study population compared to Hermann et al using 1.5T MRI for asymptomatic and symptomatic primipara.[22] Those results lead to the presumption that there is a variance of measurements without a direct correlation to delivery changes.

Except for the three detected PVM avulsions left sided, the levator urethra gap did not reach the cut-off value of 25 mm proposed by Dietz et al as an indicator for avulsion.[8] In our opinion, the puborectalis attachment width is not

TABLE 4 Measurement results for the parameters of the pelvic floor of the primipara study group and the nullipara control group

		Primipara $n = 25$	Nullipara $n = 25$ (4)	
	Parameter	**Mean (±SD)**	**Mean (±SD)**	***P*-value***
1	Anteroposterior hiatus (mm)	67.40 (±9.64)	52.22 (±6.97)	<0.001
2	Laterolateral hiatus (mm)	36.65 (±4.13)	33.15 (±4.00)	0.004
3	Hiatal circumference (cm)	18.38 (±4.09)	13.22 (±3.05)	<0.001
4	Hiatal area (cm^2)	17.25 (±1.95)	14.19 (±1.61)	<0.001
5	Levator area (cm^2)	8.48 (±3.03)	7.14 (±1.86)	0.066
6	Maximum muscle thickness right (mm)	4.44 (±1.47)	5.67 (±1.88)	0.013
	Maximum muscle thickness left (mm)	5.90 (±1.22)	7.23 (±1.98)	0.006
7	Levator urethra gap right (mm)	20.90 (±2.99)	18.45 (±2.22)	0.002
	Levator urethra gap left (mm)	24.76 (±6.25)	20.50 (±2.12)	0.003
8	Puborectalis attachment width (mm)	35.19 (±8.16)	33.94 (±3.34)	0.483

*Unpaired *t*-test.

necessarily needed for evaluation of the postpartum pelvic floor if levator urethra gap is measured, particularly as the lateral limit in case of avulsion is not as clearly defined as it is the case with intact muscle attachment.

Compared to other primipara studies performed in the first days postpartum using 3D ultrasound, our results are comparable for anteroposterior hiatus and hiatal area, whereas laterolateral hiatus and maximum muscle thickness showed lower values, while hiatal circumference was enlarged.[5,19]

We found no association between levator ani muscle abnormalities and head circumference, duration of stage of labor or mode of delivery. These results are similar to Durnea et al examining primipara 1 year postpartum but controversial to Falkert et al examining primipara 2 days postpartum.[19,23]

Van Delft pointed out an association of PVM hematoma with episiotomy, instrumented delivery and hiatal measurements.[21] Our data confirm the association to episiotomy and indicatively to instrument assisted delivery, while hiatal measurements were only enlarged for hiatal area.

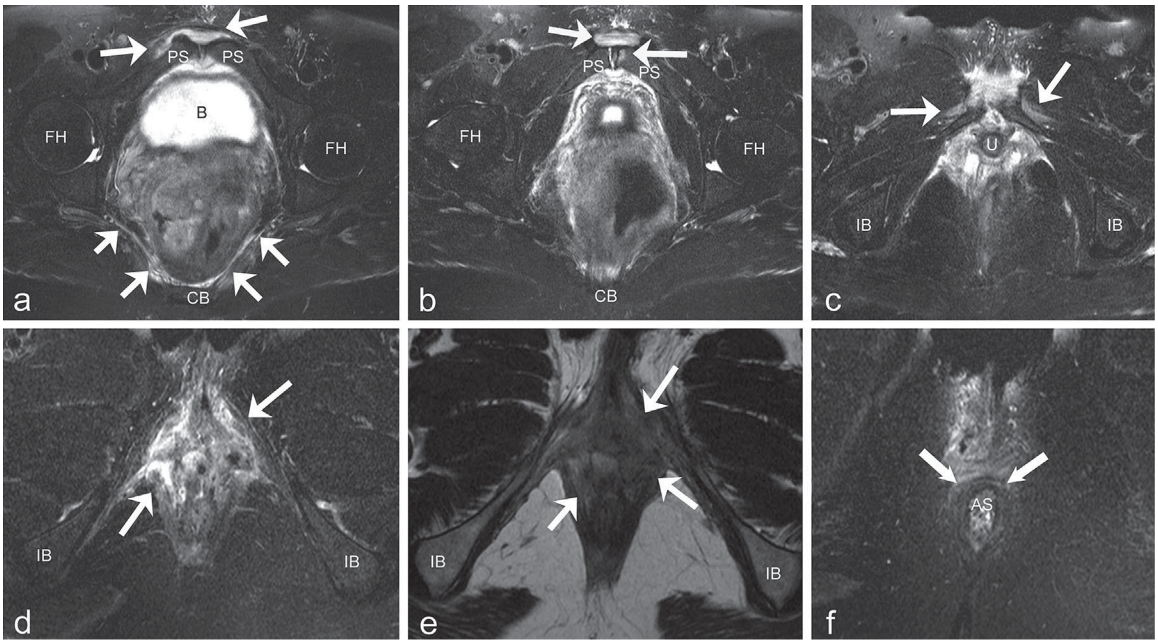

FIGURE 1 Postpartum changes in a woman who delivered vaginally at term without intrapartal epidural anesthesia. The birth weight of the baby was 3420 g, the neonates head circumference was 36 cm and the hiatal circumference was 16 cm. The second stage of labor was prolonged. Delivery was performed using vacuum extractor and mediolateral episiotomy. No labial or perineal tear was present clinically. On MRI on transverse plane from craniad to caudad, sacrouterine ligament, piriformis muscle and pubic symphysis superior ligament edema was visible (a, arrows), as well as pubic bone marrow and pubic symphysis edema (b, arrows), internal obturator muscle and pubovisceral insertion edema (c, arrows) and pubovisceral muscle edema and hematoma (d and e, arrows). The anal sphincter muscle is intact (f, arrows). After three years, she describes ongoing moderate symptoms for stress urinary incontinence and pubic symphysis pain. B, bladder; PS, pubic symphysis; FH, femoral head; IB, ischiatic bone; CB, coccygeal bone; U, urethra; AS, anal sphincter

Fourthly, regarding intrapartum epidural anesthesia, Shek and Dietz describe a protective effect for levator trauma in primipara.[24] In our study cohort, epidural anesthesia also seems to be protective for levator muscle injury, however not necessarily for perineal tears.

Fifthly, measurements for levator urethra gap and puborectalis attachment width laid above the pubococcygeal reference line (PCL) in our study population, whereas measurements for maximum muscle thickness and laterolateral hiatus laid more ventrocaudal of the PCL compared to the control group, which is important for planning the scan distance of the transverse plane in primipara. We therefore recommend to cover the promontory of the sacrum as well as the entire pelvic floor structures and the outer pelvic floor muscles in transverse plane sequence to cover the sacrouterine ligament as well as the postpartum hiatal plane which is located lower and more sloped in early postpartum period.

We acknowledge that this study was planned and designed as a pilot study for 3T-MRI performance of the postpartum pelvic floor in primipara. We therefore examined only a small number of cases and did not focus on functional pelvic floor disorder measurements, additive postpartum ultrasound or mid-term follow up examinations. Although the study was prospectively planned, there was a variation of examination times for MRI during the first week postpartum in our study cohort due to MR scanner availability. To the best of our knowledge, there is no known consequence regarding visible morphological changes depending on the day of examination within the first week. However, MRI performance within the first week after delivery may mask or potentially overestimate visualized changes compared to MR-imaging at a later point of time. We did not differentiate between the types of vaginal delivery (non-instrument-assisted versus forceps versus vacuum extraction) owing to the small numbers that would have resulted in each category. We are aware that the measured means and predictors of levator avulsion need to be validated as uni- and multivariate parameters in a regression analysis. However, the sample size of this explorative study is too small. Thus, the results have to be validated using a larger sample size and regression analysis in the future. Lastly, costs and time consuming efforts of MRI compared to 3D ultrasound have to be taken into consideration and may limit the use of MRI in clinical practice. However, the additional costs have to be weighted against improved detection of significant postpartum changes on MRI compared to 3D ultrasound.

5 | CONCLUSIONS

2D 3T-MRI is feasible in an early postpartum setting and visualizes edema and hematoma in ligaments, muscles and bones beside the PVM, which were not yet described in closer detail. These findings generally remain undetected by ultrasound due to its known technical restrictions in entire pelvis. We found statistically significant changes for biometric measurements compared to our nulliparous group and mostly comparable results to other primipara studies using ultrasound.

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POTENTIAL CONFLICTS OF INTEREST

Nothing to disclose.

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MAGNETIC RESONANCE

Magnetic resonance imaging of pelvic floor dysfunction - joint recommendations of the ESUR and ESGAR Pelvic Floor Working Group

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Abstract
Objective To develop recommendations that can be used as guidance for standardized approach regarding indications, patient preparation, sequences acquisition, interpretation and reporting of magnetic resonance imaging (MRI) for diagnosis and grading of pelvic floor dysfunction (PFD).
Methods The technique included critical literature between 1993 and 2013 and expert consensus about MRI protocols by the pelvic floor-imaging working group of the European Society of Urogenital Radiology (ESUR) and the European Society of Gastrointestinal and Abdominal Radiology (ESGAR) from one Egyptian and seven European institutions. Data collection and analysis were achieved in 5 consecutive steps. Eighty-two items were scored to be eligible for further analysis and scaling. Agreement of at least 80 % was defined as consensus finding.
Results Consensus was reached for 88 % of 82 items. Recommended reporting template should include two main sections for measurements and grading. The pubococcygeal line (PCL) is recommended as the reference line to measure pelvic organ prolapse. The recommended grading scheme is the "Rule of three" for Pelvic Organ Prolapse (POP), while a rectocele and ARJ descent each has its specific grading system.
Conclusion This literature review and expert consensus recommendations can be used as guidance for MR imaging and reporting of PFD.
Key points
• *These recommendations highlight the most important prerequisites to obtain a diagnostic PFD-MRI.*
• *Static, dynamic and evacuation sequences should be generally performed for PFD evaluation.*
• *The recommendations were constructed through consensus among 13 radiologists from 8 institutions.*

Keywords MRI pelvic floor · MR defecography · Recommendations · ESUR · ESGAR

Introduction

Imaging of the female pelvic floor is of rising interest due to an ageing population, harboring an increasing incidence of pelvic floor disorders (PFD) and the rising need for

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comprehensive diagnosis and treatment. The Population Reference Bureau reported the percentage of the population aged 65 and older to be 13 % of the total population in the U.S. in 2010 with an expected increase to 20 % in 2050, whereas in Europe, the percentage was reported around 18 % in 2010 with an expected increase to 28 % in 2050 [1]. Women that are affected by PFD, often complain most about the impairment of their quality of life and ask for sufficient therapy, which is commonly surgical repair [2, 3]. Thus, imaging techniques have been constantly developed in recent years to support therapy planning and management. Magnetic resonance imaging (MRI) of the female pelvic floor, particularly, combines high-resolution images with an excellent soft tissue contrast and provides the possibility to assess noninvasively and more objectively a spectrum of possible disorders affecting the pelvic floor in one examination [4–7]. There is general agreement that MRI of the pelvic floor should encompass static and dynamic MR images, whereas dynamic means imaging under maximum stress to the pelvic floor and MR defecography. Static MR images visualize pelvic floor anatomy and defects of the supporting structures, while dynamic MR images visualize pelvic organ mobility, pelvic floor weakness, pelvic organ prolapse (POP) and associated compartment defects [5, 8–11]. Additionally, MRI may diagnose unexpected underlying masked functional abnormalities, which might be discrepant from the dominant symptom and may influence the choice of the surgical technique in around 42 % of patients with different spectra of PFD [12, 13].

Several studies and detailed reviews are published about MRI of the pelvic floor and different acronyms have been used for this examination including static and dynamic MR of the pelvic floor, MR defecography or MR proctography [4, 12, 14–16]. However, to date, there is neither consensus on a standardized imaging protocol nor on a systematic reporting scheme for MR-imaging of PFD. This may be due to the complexity of the anatomy and the functional interaction of the organs with the supporting structures resulting in a broad spectrum of PFD. Another important factor that contributes to this lack of consensus is the fact that PFD is treated by urologists, urogynecologists or proctologists. Consequently, each clinician may manage the patients' condition from a different perspective. Therefore, MR-imaging acquisition varies according to the referring specialty and their rudiments for proper management and treatment decision. The wide range of different available MR protocols and a lack of standardization additionally increase variation between different centers. There is, therefore a necessity for recommendations from an expert panel that clearly defines the minimum prerequisites to obtain a state-of-the-art MR examination of the pelvic floor. This paper reports the recommendations of a panel of expert radiologists in pelvic floor imaging, which are joined in the pelvic floor-working group, which is under the umbrella of the European Society of Urogenital Radiology (ESUR) and the European Society of Gastrointestinal and Abdominal Radiology (ESGAR).

Materials and methods

The study went through five basic steps that are displayed in Fig. 1.

Step 1 Member recruitment and data sheet creation

Participants for the working group were recruited among ESUR and ESGAR members between 2010 and 2011. The final working group consisted of 13 radiologists from one Egyptian and seven European institutions, all with known expertise in pelvic floor imaging. One member (RFE) created a data sheet to collect technical protocol details of the members' institution. This sheet focused on information about the clinical referrer, patient population, patient preparation, and MR technique (hardware, imaging sequence and imaging parameters).

Step 2 Review of imaging protocols of the participating institutions and data sheet creation for literature review

Data collection, review and discussion of all imaging protocols of the participating institutions took place between 2012 and 2013. During this period modifications on the data sheet were implemented by (RFE) in which full details about both the geometry and the contrast of the static and dynamic MRI during straining as well as those of MRI defecography were added to the original data sheet. The results were presented and discussed in a face-to-face meeting during ECR 2014 during which a consensus was reached to finalize the data sheet for literature research (Appendix 1).

Step 3 Literature search, data collection and analysis

Literature search was conducted in the Medline database for articles published between 1993 and 2013 using the following keywords: "MRI AND Pelvic Floor", "MRI defecography", "MRI pelvic organ prolapse", "MRI anal incontinence", "MRI stress urinary incontinence", "MRI AND defecography", "Pelvic obstruction syndrome and MRI", "Pelvic outlet obstruction and MRI", "MRI and fecal incontinence", "Pelvic floor and MRI", "MRI and urinary incontinence" and "Pelvic organ prolapse and MRI".

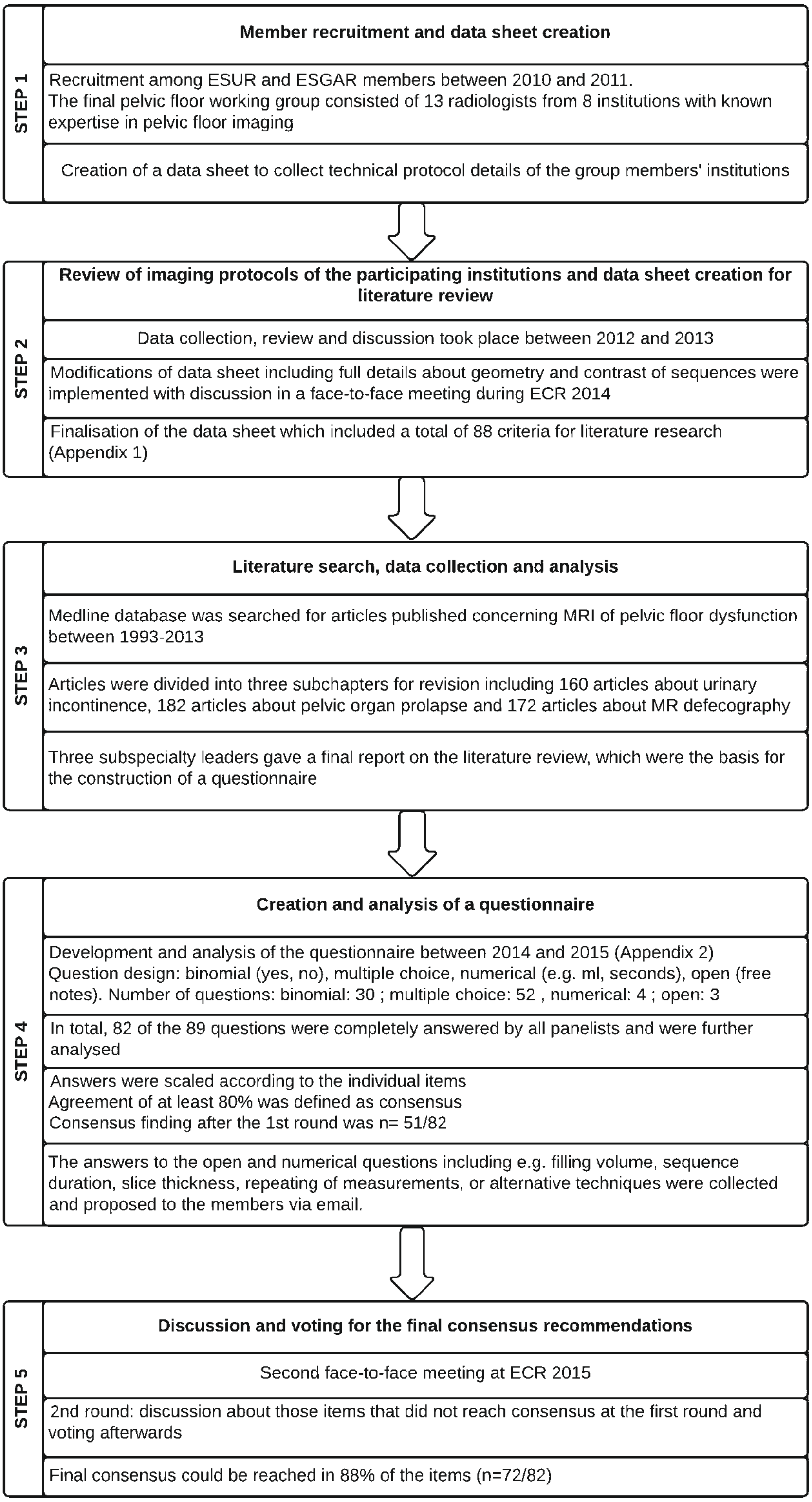

Fig. 1 Flow chart of the five basic steps of the study

Inclusion criteria were original data with full information about the parameters and the protocol of the examination that matched with our final data collection sheet for literature review.

Articles that were not written in English, did not deal with a human study population or lack of information about the performance of the examination were excluded.

The papers concerning MRI of PFD were divided by (RFE) into the following subchapters: urinary incontinence (160 articles), pelvic organ prolapse (182 articles) and MR-defecography (172 articles). Paper revision and data extraction was divided among participating members into three subspecialty groups (urology, gynaecology and proctology) with one leader for each group (GM, CDA, DW). Each subspecialty leader wrote a final report summarizing the data that was agreed upon. The collected evidence by this literature analysis was used to extract the relevant topics, which should be addressed by the working group panelists in order to construct a questionnaire.

Step 4 Creation and analysis of a questionnaire

From October 2014 to March 2015, one author (CDA) developed a questionnaire to define the most important information and requisites needed to perform MRI of PFD with standardized imaging protocol and reporting scheme. It was finalized in consensus with one author of ESGAR (DW). Since all panelists are using MR systems with a conventional closed-magnet design where the patient can only be examined in supine (lying) body position, procedural and technical aspects of pelvic floor imaging was focused to this type of magnet design. The questionnaire included binomial, multiple choice, numerical and open questions, in total 89 items (Appendix 2). This questionnaire was mailed to all panelists. In total, 82 of 89 questions were answered by all experts and were scaled according to the individual item in question for further analysis. The data obtained were analyzed using descriptive statistics. Agreement of at least 80 % was defined as consensus finding.

Step 5 Discussion and voting for the final consensus recommendations

The second face-to-face meeting took place during ECR congress in 2015. For those questions that did not reach consensus at the first round of the questionnaire analysis, wording was modified to obtain better-defined statements subjected for voting by the experts in a face-to-face meeting. During that meeting the panelists discussed those items and were asked to vote. However, there were items that did not reach consensus but were reported by number of panelist to be important and warrants being included in the recommendations. These items were re-analyzed, and those that were found to be supported by case control or cohort studies from the literature, in particular level of evidence 2 according to the sign criteria, whereas expert opinion is level of evidence 4 (www.sign.ac.uk), were also included in the final recommendation.

Results

Consensus was reached for 88 % of 82 items and the recommendations regarding indication, patient preparation, imaging protocol, criteria for MRI assessment and reporting were constructed from these.

Indications for MR imaging of pelvic floor dysfunction

The indications for MR imaging of the pelvic floor that scored the highest number of agreement among the group members and the literature review are rectal outlet obstruction (92 % agreed upon), rectocele (92 % agreed upon), recurrent pelvic organ prolapse (POP) (85 % agreed upon), enterocele (85 % agreed upon) and dyssynergic defecation (anismus)(85 % agreed upon) (Table 1).

Patients' preparation and hardware requirements

Full patients' history of pelvic floor disorder should be taken prior to scanning (consensus 100 %). The patient should be examined at least in a 1.5 T MRI unit with a phased array coil, as this is the most agreed-upon field strength (consensus 100 %). The patient is examined in

Table 1 Most common indications for MR-imaging of pelvic floor dysfunction*

Indications	Score of agreement achieved**
Anterior compartment	
Stress urinary incontinence	7/13
Recurrence after surgical POP repair	7/13
Middle compartment	
Recurrence after surgical POP repair	11/13
Enterocele / Peritoneocele	11/13
POP	7/13
Posterior compartment	
Outlet obstruction	12/13
Rectocele	12/13
Anismus	11/13
Fecal incontinence	10/13
Recurrence after surgical POP repair	9/13
Rectal intussusception	8/13
Non-specific compartment	
Pelvic pain / perineal pain	7/13
Descending perineal syndrome	7/13

POP pelvic organ prolapse

* The indications of MRI in each compartment are listed in a descending order from those that scored the highest number of agreement among both the group members and the literature review

** Number of group members $n = 13$

the supine position with the knees elevated (e.g. on a pillow with firm consistency) as this was found to facilitate straining and evacuation (consensus 100 %). The coil should be centered low on the pelvis to ensure complete visualization of prolapsed organs [4, 15]. The bladder should be moderately filled, therefore voiding 2 hours before the examination is recommended (consensus 100 %).

Prior to the examination the patient should be trained on how to correctly perform the dynamic phases of the examination and the evacuation phase (consensus 100 %). The patient is instructed to squeeze as if trying to prevent the escape of urine or feces and hold this position for the duration of the sequence. For maximum straining, the patient is instructed to bear down as much as she/he could, as though she/he is constipated and is trying to defecate [15]. For the evacuation phase, the patient should be instructed to repeat the evacuation process until the rectum is emptied.

To decrease possible patient's discomfort, a protective pad or a diaper pant should be offered to the patient, which helps to increase patients' compliance during dynamic and evacuation phases (consensus 100 %). No oral or intravenous contrast is necessary [15].

The rectum should be distended in order to visualize the anorectal junction (ARJ), rectoceles and intussusceptions, and to evaluate the efficacy of rectal evacuation (consensus 100 %). Ultrasound gel is the recommended medium to distend the rectum, however, the amount varies between 120 to 250 cc (consensus 100 %). For rectal distension a large amount of gel (180-200 cc) likely improves the capacity of the patient to defecate. A checklist for the recommended patients' preparation is listed in (Table 2).

A rectal cleansing enema prior to the examination is helpful but reached no consensus to be generally performed. Vaginal filling with 20 cc ultrasound gel is helpful for better demarcation, however, it reached no consensus for general performance and its application may be limited due to social or religious backgrounds.

MR-imaging protocol

The recommended MR-imaging protocol is summarized in (Table 3). The protocols consists of static MR sequences and dynamic sequences, whereas dynamic means imaging during straining, squeezing and during evacuation or defecation.

According to the concordance of experts and level of evidence, high resolution T2-weighted images (T2WI) (e.g. Turbo Spin Echo, TSE ; Fast Spin Echo, FSE; Rapid Acquisition with Relaxation Enhancement, RARE)

Table 2 Checklist for the recommended patients' preparation and MR-Imaging protocols

	Done	Concordance of experts *n*=8	Level of Evidence*	Reference
A Patients' preparation				
Equipment: preferable 1.5 T magnet and phased array coil	☐	100%	4	
Take patients' history of pelvic floor disorder	☐	100%	4	
Ask the patient to void 2h before the examination	☐	100%	4	
Train the patient on how to perform squeezing, straining and evacuation	☐	100%	4	
Use a diaper for protection	☐	100%	4	
Do rectal filling with ultrasonic gel	☐	100%	4	
Examine the patient in supine position with elevated knees on a high pillow	☐	100%	4	
B MR-imaging protocol				
1 Recommended static sequences				
T2-weighted TSE, FSE, RARE in sagittal, transverse and coronal plane	☐	100%	2	[15, 17]
2 Recommended dynamic SSFP or BSFP sequences in sagittal plane				
Straining phase	☐	100%	2	[17–19]
Evacuation phase	☐	100%	2	[16, 17, 19]
Squeezing phase	☐	88%	2	[17, 20]

BSFP balanced state free precession, *FSE* fast spin echo, *RARE* rapid acquisition with relaxation enhancement, *SSFP* steady state free precession, *TSE* turbo spin echo

* Level of evidence 2 = based on systematic reviews, case control or cohort studies; Level of evidence 4 = based on expert opinion (www.sign.ac.uk)

Table 3 Recommended MR-imaging protocols

Plane		Sequence	Technique	TE (ms)	TR (ms)	ST (mm)	FOV (mm)	Matrix	Angulation	Number of slices	Level of evidence*
Static MRI sequences 2D MRI											
	Sagittal	T2WI	Turbo/fast spin echo	77-132	500-4210	4	200-300	256-448	Midsagittal	23	2
	Transverse	T2WI	Turbo/fast spin echo	88-132	500-7265	4	200-300	256-512	Perpendicular to the urethra	25	2
	Coronal	T2WI	Turbo/fast spin echo	80-132	500-7265	4	200-260	256-512	parallel to the urethra	26	2
Dynamic MR sequences											
Squeezing											
	Sagittal	T2WI	GE, FFE	1.27-1.88	3.3-397.4	8	250-310	126-280	Midsagittal	1 or 3	2
Straining											
	Sagittal	T2WI	GE, FFE	1.27-1.88	3.3-397.4	8	250-310	126-280	Midsagittal	1 or 3	2
optional[a]	Transverse	T2WI	GE, FFE	1.6-80	5.0-1200	5 or 6	250-310	126-280	Perpendicular to the urethra	5	2
optional[b]	Coronal	T2WI	GE, FFE	1.6	5	5 or 6	300	256	Parallel to the urethra	5	2
MR-Defecography											
	sagittal	T2w	GE, FFE	1.27-1.88	3.3-397.4	8	250-310	168-280	Midsagittal	1 or 3	2
optional[c]	coronal	T2w	GE, FFE	1.27-1.6	5-397	4 or 8	257-350	154-256	Parallel to anorectum	5	2

FFE fast field echo, *FOV* field of view, *GE* gradient echo, *ST* slice thickness, *2D* two-dimensional, *TE* time of echo, *TR* time of repetition, *T2WI* T2-weighted

[a] Technique was reported by 3/8 experts and is supported by reference [15, 21]

[b] Technique was reported by 3/8 experts and is supported by reference [15, 21]

[c] Technique was reported by 3/8 experts and is supported by reference [22]

* Level of evidence 2 = based on systematic reviews, case control or cohort studies; Level of evidence 4 = based on expert opinion (www.sign.ac.uk)

	1.	2.	3.	4.
Recommended sequences*	Imaging at rest in three planes	Imaging during squeezing in sagittal plane	Imaging during maximum straining in sagittal plane	Imaging during evacuation of the rectal gel in sagittal plane
Patients' instruction	Patient is asked to breath normal without requested manoeuvers	Patient is asked to squeeze as if trying to prevent the escape of urine or faeces and hold this position for the duration of the sequence	Patient is asked to bear down as much as she could, as though she is constipated and tries to defecate and hold this position for the duration of the sequence	Patient is asked to evacuate the rectum continously and to relax the pelvic floor before the next evacuation phase
Time duration of the sequence	2-3 minutes each plane	Less than 20 seconds as the patient needs to hold the breath	Less than 20 seconds as the patient needs to hold the breath	The sequence should be repeated until the rectum is emptied (time duration of one evacuation trial is around 50 seconds)
Optional sequences**			Imaging during maximum straining in transverse plane Imaging during maximum straining in coronal plane	Imaging during evacuation in coronal plane

* 100% agreement of expert opinion and level of evidence 2 ; ** Level of evidence 2 without expert consensus (3/8)

Fig. 2 Schedule of the recommended imaging sequences, the instruction given to the patient and the time duration per sequence

in three planes are recommended for static images, whereas steady state (e.g. FISP, GRASS, FFE, PSIF, SSFP, T2-FFE) or balanced state free precession sequence (e.g. trueFISP, FIESTA, B-FFE) in sagittal plane is recommended for dynamic sequences (squeezing and straining) and evacuation sequence (consensus 100 %). The dynamic sequence should not exceed 20 seconds each, as breath holding is required (consensus 100 %). The evacuation sequence

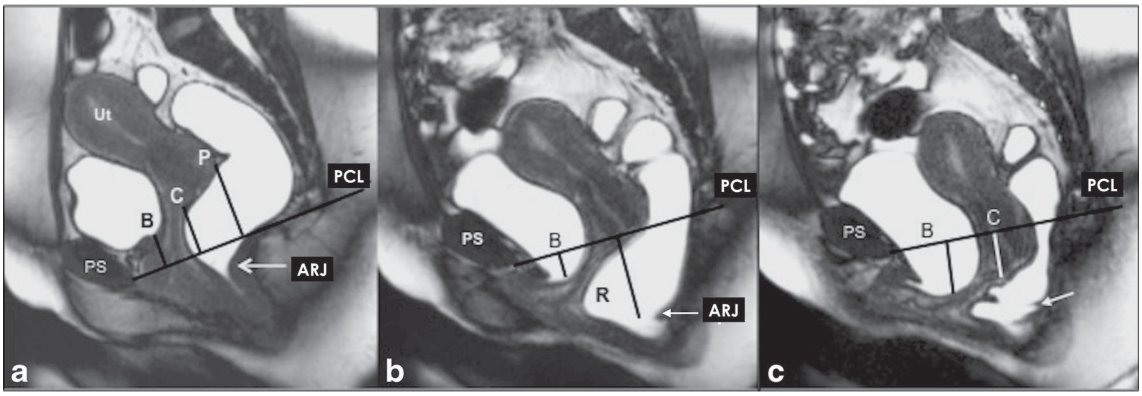

Fig. 3 Basic measurements. **a**. Dynamic Balanced Fast Field Echo (BFFE) sequence in the midsagittal plane at rest shows how to plot the basic measurements of pelvic organ prolapse. The pubococcygeal line (PCL), drawn on sagittal plane from the inferior aspect of the pubic symphysis (PS) to the last coccygeal joint. After defining the PCL, the distance from each reference point is measured perpendicularly to the PCL at rest and at maximum straining. B; bladder base, C; cervix, P; pouch of Douglas, ARJ; Anorectal junction. Measured values above the reference line have a *minus sign*, values below a *plus sign*. **b**. Dynamic BFFE during maximum straining shows the movement of the organs compared to their location at rest. It is recommend to give the difference of the values at rest and during straining for each organ-specific reference point (pelvic organ mobility). R; Rectocele, ARJ; Ano-Rectal Junction. **c**. MRI defecography (BFFE) in the mid sagittal plane during evacuation of the intra-rectal gel. Dynamic MR imaging during evacuation is mandatory, because certain abnormalities and the full extent of POP are only visible during evacuation. In this case compared to the maximum staining phase it is obvious that there is increase of the degree of the pelvic organ descent and development of new pathology including the loss of urine and the detection of masked intussusception, which was detected only during excavation (white *arrow*)

Table 4 Checklist for the recommended MRI reporting scheme

	Done	Concordance of experts *n*=8	Level of Evidence*	Reference
A Measurements				
1 Basic measurements for all compartments				
Determine PCL	☐	100%	2	[15, 24]
Determine organ-specific reference points	☐	100%	2	[25]
Measure the descent of reference points below the PCL	☐	100%	2	[15, 26]
2 Measurements for posterior compartment				
Measure the bulging of the anterior rectal wall at evacuation phase/straining phase	☐	100%	2	[15, 20]
Measure the ARA at rest - squeezing phase - straining phase/evacuation phase	☐	100%	2	[16, 27]
B Reporting				
1 Basic reporting for all compartments				
Report values above the PCL as negative and below as positive	☐	100%	2	[28]
Report pelvic organ mobility	☐	100%	2	[8, 25]
2 Reporting for anterior compartment				
Report loss of urine at straining phase	☐	88%	2	[15]
Report urethral mobility at straining phase	☐	88%	2	[29]
3 Reporting for middle compartment				
Report uterine descent	☐	100%	4	[15]
Report the content of a present enterocele	☐	100%	4	[15]
4 Reporting for posterior compartment				
Report presence of a rectal intussusception	☐	100%	2	[19, 30]
Evaluate time-effective rectal evacuation	☐	88%	2	[31]
Point out the change of ARA	☐	100%	4	
C Grading				
1 Anterior compartment				
Use the "rule-of-three' grading for cystocele	☐	100%	2	[32, 33]
Report cystocele as pathological starting from °II	☐	88%	4	[33]
2 Middle compartment				
Use the "rule-of-three' grading for uterine prolapse and enteroceles	☐	100%	2	[34, 35]
Report POP as pathological starting from °II	☐	88%	4	[35]
3 Posterior compartment				
Use the grading for Anorectal Junction descent (ARJ) starting at 3 cm below the PCL	☐	100%	2	[19, 36]
Report a rectocele as pathological starting from °II	☐	100%	2	[19, 20]
Use the "rule-of-two" grading for rectoceles	☐	88%	2	[16, 19]

PCL pubococcygeal line, *ARA* anorectal angle, *POP* pelvic organ prolapse, *ARJ* anorectal junction

* Level of evidence 2 = based on systematic reviews, case control or cohort studies; Level of evidence 4 = based on expert opinion (www.sign.ac.uk)

should be repeated until the rectum is emptied to exclude rectal intussusception (total time duration around 2-3 minutes)(consensus 100 %). Dynamic MR imaging during evacuation is mandatory, because certain abnormalities and the full extent of POP is only visible during evacuation. Optional MRI sequences can be added and acquired for further assessment of pelvic floor relaxation. These include axial and coronal dynamic sequences during maximum straining. Illustration of all the recommended imaging sequences and patients' maneuvers is summarized in (Fig. 2).

Since the performance of adequate pelvic stress during the dynamic sequences is important in order to assess the full extent of PFD, quality control of the study is essential. The study can only be considered diagnostic if a clear movement of the abdominal wall is seen during squeezing and straining. If no evacuation of rectal content at all or a delayed evacuation time (more than 30 seconds to evacuate 2/3 of the rectal content) is present, anismus should be considered (consensus 88 %) [23].

Image analysis, measurements, grading and MRI report

Image analysis

A clear consensus was reached that the assessment of a MR study of the pelvic floor should include analysis of static images for detection and classification of structural abnormalities. The dynamic images are analyzed with regard to functional abnormalities that are assessed by metric measurements of the three compartments of the pelvic floor (consensus 100 %) (Fig. 3). The measurements help to recognize and grade the extent of POP and pelvic floor relaxation (PFR), as well as they are used to grade anterior rectoceles and enteroceles (consensus 100 %). Both static and dynamic MRI findings as well as the results of the metric measurements should be reported in a structured MR reporting scheme (consensus 100 %) (Table 4).

Due to the different views of the clinical specialists involved in the treatment of PFD, it is suggested to consider adapting the MRI reporting scheme according to the specialty of the referring physician. A proposal for a specialty-based MRI report is given in (Table 5).

Measurements

The pubococcygeal line (PCL), drawn on sagittal plane from the inferior aspect of the pubic symphysis to the last coccygeal joint, is recommended as reference line to measure POP (consensus 100 %). It shows the highest inter- and intraobserver reliability of MRI measurements in women with POP of the anterior and middle compartment compared to all proposed reference lines in the literature with an intercorrelation coefficient (ICC) between 0.70-0.99 (Fig. 3a) [14, 37, 38].

After defining the PCL, the distance from each reference point is measured perpendicularly to the PCL at rest and at maximum strain (consensus 100 %) [26, 29]. In the anterior compartment, the organ-specific reference point is the most inferior aspect of the bladder base (B), in the middle compartment, the organ-specific reference point is the anterior cervical lip (most distal edge of the cervix)(C), or the vaginal vault in case of previous hysterectomy (V), and in the posterior

Table 5 Specialty-based MRI reporting scheme

Urologic patients
Report of pathologies if present
During dynamic sequences
Loss of urine through the urethra at maximum straining
Hypermobility of the urethra
Kinking of the vesicourethral junction
Uretherocele
Cystocele; type (distension or displacement), size (cm), grade
On static images
Damage of the supporting urethral ligaments
Avulsion or defect of the puborectal muscle
Measurements
Pelvic organ mobility
Pelvic floor relaxation
Iliococcygeus angle
Hiatal dimensions
Further evaluation
Additional findings regarding the pelvic organs*
Coexistent middle and posterior compartment disorders
(Uro)gynecologic patients
Report of pathologies, if present:
During dynamic sequences
Cystocele; type (distension or displacement), size (cm), grade
Uterine prolapse: partial or total
Enterocele: type (content of the peritoneal sac), size (cm), grade
On static images
Avulsion or defect of the puborectal muscle
Measurements
Pelvic organ mobility
Pelvic floor relaxation
Iliococcygeus angle
Hiatal dimensions
Further evaluation
Additional findings regarding the pelvic organs*
Coexistent anterior and posterior compartment disorders
Proctologic patients
Report of pathologies, if present:
During dynamic sequences
Rectocele: type (anterior or rarely posterior) size (cm), grade
Rectal mucosal invagination or prolapse: differentiation, extent, grade
Rectal descent: distance to PCL (cm), grade
Enterocele: type (content of the peritoneal sac), size (cm), grade
Lack of changes of ARA
Insufficient opening of the anal canal with inadequate rectal emptying during evacuation
Rectal intussusception
Measurements
Rectocele
Rectal decent
ARA
Pelvic organ mobility
Pelvic floor relaxation
Further evaluation
Additional findings regarding the pelvic organs*
Coexistent anterior and middle compartment disorders

ARA anorectal angle, *PCL* pubococcygeal line, *PFD* pelvic floor disorder.

* e.g. adnexal lesions, uterine diseases, urethral and bladder diverticula, diverticulosis, diverticulitis

compartment, the organ-specific reference point is the anorectal junction (ARJ) (consensus 100 %) (Fig. 3a) [15, 16, 20, 25, 29, 39]. Measured values above the reference line have a minus sign, values below a plus sign (consensus 100 %) [25].

Reporting of the movement of the organs compared to their location at rest is stated to give more valuable information for the referrer than a grading system alone [8, 25]. We therefore recommend giving the difference of the values at rest and during straining for each organ-specific reference point (pelvic organ mobility)(consensus 100 %) (Fig 3a, b).

A rectocele is diagnosed as an anterior rectal wall bulge and it is measured during maximum straining and evacuation (Fig 4). Typically, a line drawn through the anterior wall of the anal canal is extended upward, and a rectal bulge of greater than 2 cm anterior to this line is described as a rectocele (consensus 100 %) [28, 34]. The anorectal angle (ARA) should be drawn along the posterior border of the rectum and a line along the central axis of the anal canal on sagittal plane (Fig. 4b) at rest, squeezing and maximum straining (consensus 100 %) [20, 27].

Pelvic floor relaxation (PFR) often coexists with POP, but it is a different pathologic entity. For quantification of the

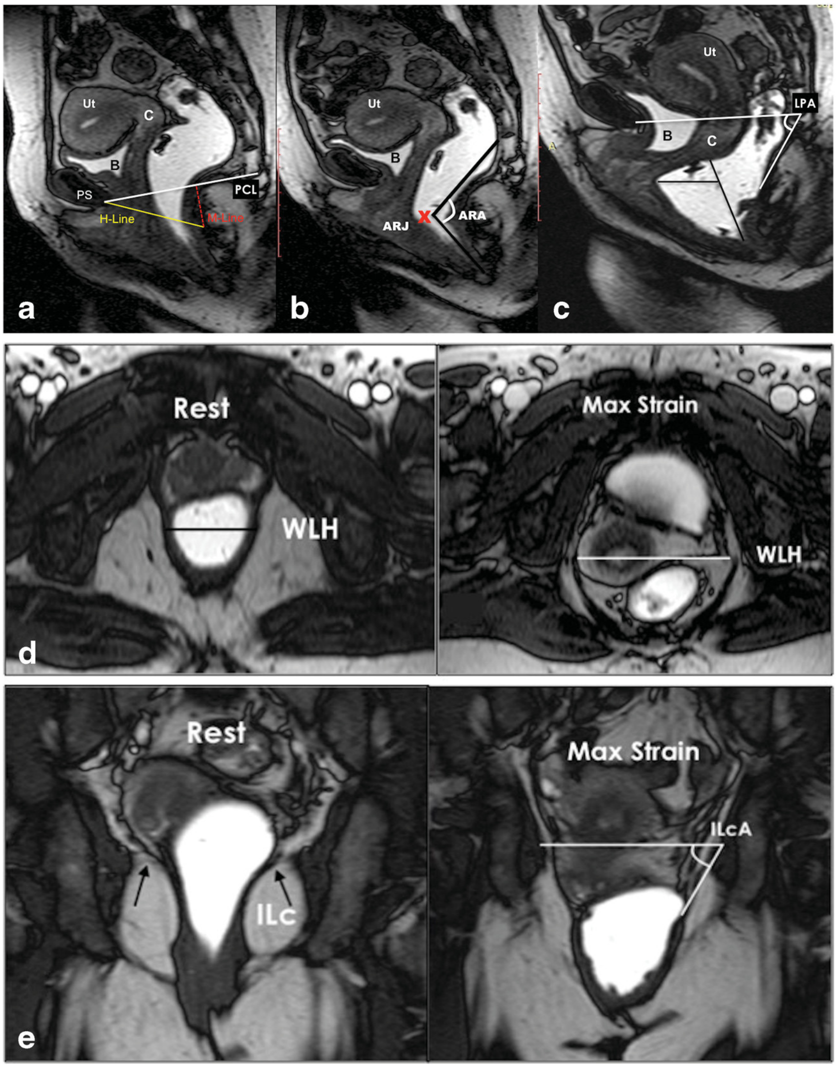

Fig. 4 Pelvic floor relaxation and posterior compartment measurements. **a**,**b**,**c** Dynamic Balanced Fast Field Echo (BFFE) sequence in the mid-sagittal plane at rest (**a**) , mild (**b**), and maximum straining (**c**). (**a**) shows how to quantify the pelvic floor laxity. The H-line extends from the inferior aspect of the pubic symphysis to the anorectal junction, the M-line is dropped as a perpendicular line from the pubococcygeal line (PCL) to the posterior aspect of the H-line. (**b**) Demonstrates the anorectal angle (ARA) drawn along the posterior border of the rectum and a line along the central axis of the anal canal on sagittal plane. ARJ; Ano-Rectal Junction. (**c**) Shows how to measure and diagnose a pathological rectocele: a line drawn through the anterior wall of the anal canal is extended upward, and a rectal bulge of greater than 2 cm anterior to this line is described as a rectocele (R). The levator plate angle (LPA) is enclosed between the levator plate and the PCL. **d**,**e**. Dynamic Balanced Fast Field Echo (BFFE) sequence in axial (**d**) and coronal (**e**) plane at rest and during maximum straining. In the axial plane the width of the levator hiatus is enclosed between the puborectalis muscle slings. On the coronal plane, the iliococcygeus angle is measured between the iliococcygeus muscle and the transverse plane of the pelvis in posterior coronal images at the level of the anal canal

weakness of the levator ani and to reflect pelvic floor laxity, five measurements can be performed [15] , however, it reached no consensus to measure it routinely. The length of the hiatus (H-line), the descent of the levator plate (M-line) and the levator plate angle are evaluated in the sagittal plane (Fig 4a, c), whereas the transverse width of the levator hiatus and the iliococcygeus angle are assessed in the axial and coronal plane during maximum straining(Fig. 4e,d) [15]. Table 6 provides an overview of the entire spectrum of the published reference values for quantitative MR-measurements of the pelvic floor.

Grading

The “Rule of three’ is the recommended grading system in the anterior and middle compartment starting at 1 cm below the PCL (Table 4) [15, 16, 32, 34, 40]. This is based on the fact that the pelvic floor may descend and widen up to 2 cm during abdominal pressure. Consequently, the pelvic organs follow the movement of the pelvic floor inferiorly but without protrusion through their respective hiatuses [4]. The bladder base, particularly, may descend up to 1 cm below the PCL during straining in continent women and should not be stated as a cystocele (consensus 100 %) [24, 34].

The “Rule of two” is recommended for grading the anterior rectal wall bulge in rectoceles (consensus 100 %) (Table 4) [16; 23; 25; 26; 31]. It should be reported as pathological from grade °II, as a grade °I rectocele can be observed in nearly 78-99 % of parous women, while rarely in men [20, 28, 41].

Anorectal junction descent (ARJD) is graded (grade °I) between 3 and 5 cm below the PCL, and (grade °II) with at least 5 cm (consensus 100 %) [36].

Small intussusceptions of the rectal wall are considered to be normal findings during defecation, observed in nearly 80 % of healthy subjects [41].

Reporting other functional abnormalities and structural defects

Functional abnormalities on dynamic MR images

Loss of urine through the urethra during maximum straining records urinary incontinence (UI) and should be reported if present (consensus 88 %)[15]. Urethral hypermobility as a predictor for UI should be reported if present (consensus 88 %) [29]. If a cystocele is present, the differentiation of a distention or a displacement cystocele can be made, which is helpful for therapy planning, however it reached no consensus for general reporting [42].

If an enterocele is present, the report should include the content of the peritoneal sac, as clinical examination alone

Table 6 Overview of the published reference values for quantitative MR-measurements of the pelvic floor

Parameters	Reference value ± standard deviation	Reference
Anterior compartment		
Bladder base position (according to PCL) at rest	−2.3 ± 0.46 cm	[39]
Bladder base position (according to PCL) during straining	0.81 ± 1.11 cm	[39]
Middle compartment		
Anterior cervical lip position (according to PCL) at rest	4.31 ± 0.78 cm	[39]
Anterior cervical lip position (according to PCL) during straining	−0.79 ± 1.65 cm	[39]
Posterior compartment		
Anterior bulge of the rectal wall during straining (rectocele)	2.6 ± 0.6 cm	[39]
Ano rectal junction (ARJ) at rest	≤3 cm below the PCL 0.53 ± 0.99 cm	[34, 39]
ARJ during squeezing	Elevation of ARJ	[36]
ARJ during straining	2.99 ± 1.03 cm	[39]
Anorectal angle (ARA) at rest	85-95° 93° ± 4.8°	[31, 39]
ARA during squeezing	71° sharpening of 10-15°	[16, 27]
ARA during straining or defecation	103° 15-25° more obtuse 108° ± 14.7°	[16, 27, 39]
Measurements for quantification of the pelvic floor laxity		
H-line (hiatus) during straining	5.8 ± 0.5 cm	[15]
M-line (descent of H-line to PCL) during straining	1.3 ± 0.5 cm	[15]
Levator plate angle during straining	11.7 ± 4.8°	[15]
Iliococcygeus angle at rest	20.9 ± 3.5°	[15]
Iliococcygeus angle during straining	33.4 ± 8.2°	[15]
Transverse diameter of levator hiatus at rest	3.3 ± 0.4	[15]
Transverse diameter of levator hiatus during straining	4.5 ± 0.7 cm	[15]

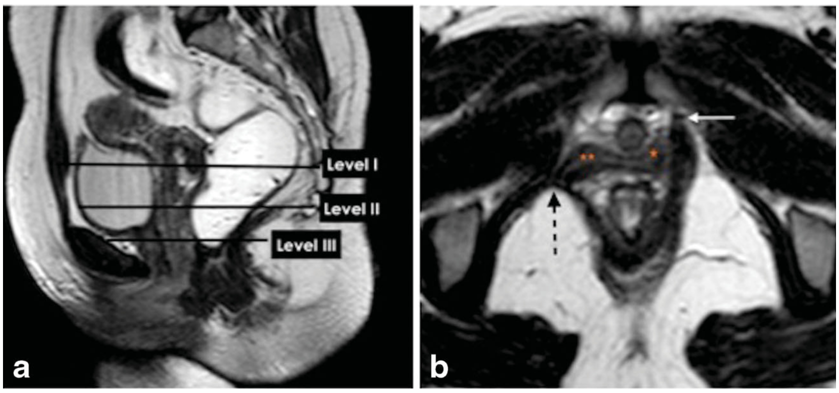

Fig. 5 Functional three -part pelvic supporting system. **a**,**b**. Static T2W Turbo-Spin Echo (TSE) MR images in sagittal and axial plane. (**a**) Sagittal MR image illustrating the levels of the endopelvic fascia (paracolpium) that attaches the upper vagina to the pelvic walls, it is divided into three levels. Level I (suspension); the portion of the vagina adjacent to the cervix (the cephalic 2–3 cm of the vagina) functionally it provides the upper vaginal support. Level II (attachment); located in the mid portion of the vagina, it stretches the vagina transversely between bladder and rectum. The anterior vaginal wall provides urinary bladder support. The posterior vaginal wall and the endopelvic fascia (rectovaginal) form a restraining layer that prevents the rectum from protruding forward. (**b**) Axial T2W image shows detachment of the puborectalis muscle from its origin identified by discontinuity of its attachment to the pubic bone on the right side (*dotted black arrow*) (*white arrow*, normal bony attachment), (** loss of H-shaped vagina on the right side), (*; normal lateral vaginal attachment on the left side)

may have shortcomings in identifying the content (consensus 100 %) [5, 20, 22, 31, 43].

The end of evacuation phase is important to identify intussuception (Fig. 3c) [30].

The change of the ARA during dynamic and evacuation sequence compared to the ARA at rest expresses the functioning of the puborectal muscle. In particular, the ARA should sharpen during squeezing and should become more obtuse during straining and evacuation [16, 27, 39]. We recommend to report the individual function, as the literature presents with a widespread of normal reference values (consensus 100 %).

Structural defects on static MR images

Description of structural defects and anatomical abnormalities, that are assessed in static T2WI are more likely specialty-based PFD-related questions from the referrer (Table 5). The functional three-part pelvic supporting system (Fig. 5) includes the urethral support system, which maintains urinary continence; the vaginal support system, which prevents prolapse; and the anal sphincter complex that maintains anal continence. Urethral support system defects may include urethral ligament defect and / or distortion, level III endopelvic fascial defects, or puborectalis muscle detachment(Fig. 5b), disruption, atrophy or avulsion [15, 18, 21, 33, 44–46]. The spectrum of vaginal support system abnormalities includes level I and II paravaginal fascial defects and/or iliococcygeus diffuse or focal muscle abnormality [35].

Limitations of the study

The study has few limitations. Four panelists who participated in Step 1 and 2 of the study were from the same institution. Therefore, only 1 out of their 4 completed questionnaire was included in the final analysis to avoid biased results. Nevertheless, since all 8 panelists who have completed the questionnaire were from different institutions these recommendations can be considered to represent the entire spectrum of expert opinions in the field of pelvic floor MRI. Second, the recommendations given in this study with regard to technical aspects of MRI of the pelvic floor relate to conventional closed-configuration magnets for MR imaging allowing patient positioning in lying body position only. However, this is the most agreed upon scanner, in addition several studies have shown that patient positioning does not significantly influence diagnostic performance of MR imaging of the pelvic floor [17, 19, 47, 48].

Conclusion

Based on an extensive literature review and analysis and of expert consensus, these proposed recommendations can be used as guidance for standardized MR imaging and reporting of PFD. Nevertheless, our joint ESUR-ESGAR pelvic floor-working group is aware about the complexity of the topic and that further studies are mandatory to achieve additional refinements of guidelines for MR imaging, diagnosing and reporting of PFD.

Appendix 1 Data sheet created to collect the details of the technical protocols of the group members and for literature review

General

Institution Name	Author	Referrer	Indication for MRI of the pelvic floor	Compartment examined
		1 = gynecologist 2 = urologist 3 = proctologist 4 = other		1 = anterior 2 = middle 3 = posterior 4 = anterior and middle 5 = all of them

Patient preparation

Preparation of upper GI-tract	Rectal enema	Rectal filling	Volume of rectal filling (ml)	Use of urethral Folys catheter	Bladder filling	Vaginal filling	Use of IV contrast
0 = no 1 = yes	0 = no preparation 1 = cleansing enema	0 = no filling 1 = ultrasonic gel 2 = potato starch 3 = air		0 = no 1 = yes	0 = empty 1 = moderately filled 2 = full 3 = 1 h void 4 = 2 h void	0 = no filling 1 = sterile gel 2 = normal gel	0 = no 1 = yes

Patient instruction and positioning

Patient Training	patient positioning	patient positioning
0 = on grades of straining 1 = on evacuation 2 = on withholding	1 = supine 2 = sitting 3 = lateral right 4 = lateral left 5 = prone 6 = upright	0 = legs side by side 1 = legs separated 2 = knees elevated 3 = upright

MR scanner

MR-scanner	MR-scanner	Coil Selection
1 = 1.0 T 2 = 1.5 T 3 = 3 T 4 = <1	0 = conventional scanner 1 = open scanner 2 = upright scanner	

Imaging protocol

Static MRI sequences	Dynamic cine MRI sequence during different patients' maneuvers	MR Defecography
	Number of phases A = 3 phases (rest, squeezing, strain) B = 4 (rest, squeezing, moderate- max strain) C = 5 (rest, squeezing, mild- moderate -max strain)	1 = real time fluoroscopy 2 = multiple repetitions

Geometry (for every sequence)

Sequence	Plane	FOV (mm)	Matrix scan	Number of slices	Slice gap	Fold over	REST slabs
1 = T1w 2 = T2w	1 = tra 2 = sag 3 = cor	RFOV(%) Fold over suppression	Matrix recon-struction Scan per-centage	Slice thickness (mm)	Slice orientation	direction	1 = free 2 = parallel

Contrast (for every sequence)

Scan mode	Technique	Echoes	TE (msec)	Flip Angle	Half Scan	Number of signal acquisition	Total scan duration
1 = 2D 2 = 3D	1 = SE 2 = GE		TR (msec)				

Appendix 2 Questionnaire for ESUR/ESGAR pelvic floor recommendations

Name: ______________________

Institution: ______________________

Who refers the patients to your institution?

☐ gynecologist ☐ urologist ☐ proctologist

Indications:

gynecologist	urologist	proctologist
☐ feeling of foreign body	☐ urinary incontinence	☐ Rectal outlet obstruction symptoms
☐ dyspareunia	☐ urinary retention	☐ Rectal (fecal) incontinence
☐ pre- and post surgery	☐ recurrent cystitis	☐ Intussusception
☐ recurrent POP	☐ nycturia	☐ Enterocele, Sigmoidocele
	☐ pre- and post surgery	☐ Rectocele
	☐ recurrent POP	☐ Anismus
		☐ Pre- and post surgical repair of rectal outlet obstruction
other: ☐	☐	☐
☐	☐	☐
☐	☐	☐

Do you use the same preparation for all patients, independent of the referrer?

☐ yes ☐ no *If NO, please fill out all sheets (referrer-dependend)*

Do you use the same protocol/sequences for all patients, independent of the referrer?

☐ yes ☐ no *If NO, please fill out all sheets (referrer-dependend)*

Do you recommend an enema prior to the examination?

☐ no ☐ yes ☐ gynecology ☐ urology ☐ proctology

Patients positioning:

gynecology	urology	proctology
☐ supine	☐ supine	☐ supine
☐ lateral decubitus	☐ lateral decubitus	☐ lateral decubitus
☐		

Which coil do you use?

☐ standard body coil

☐ phased array coil

other: ☐

Sequences you use:

gynecology	urology	proctology
☐ only dynamic	☐ only dynamic	☐ only dynamic
☐ static and dynamic	☐ static and dynamic	☐ static and dynamic
other: ☐	☐	☐

How long takes the dynamic sequence, how many repeating measurements do you perform with how many slices?

____

MR Scanner used:

☐ 1.0T
☐ 1.5T
☐ 3.0T
☐ open

Patients from the GYNECOLOGIST

Preparation

☐ empty bladder	☐ vaginal filling	☐ rectal filling
☐ full bladder	☐ no vaginal filling	______ ml agens: ______
☐ not important	☐	☐ no rectal filling

Important sequences

static:

☐ T2 high resolution ☐ sag ☐ tra ☐ cor

Angulation: ______ ST (mm) ______ FOV (cm) ______ first/last slice: ______

☐ T1 high resolution

☐ PD

other: ☐

squeezing: ST (mm)/FOV (cm)

☐ sag ☐ tra ☐ cor

☐ steady-state free precession (FISP,GRASS,FFE,PSIF,SSFP,T2-FFE)

☐ balanced state free precession (trueFISP, FIESTA, b-FFE)

☐

straining: ST (mm)/FOV (cm)

☐ sag ☐ tra ☐ cor

☐ steady-state free precession (FISP,GRASS,FFE,PSIF,SSFP,T2-FFE)

☐ balanced state free precession (trueFISP, FIESTA, b-FFE)

☐

defecation: ST (mm)/FOV (cm)

☐ sag ☐ tra

☐ steady-state free precession (FISP,GRASS,FFE,PSIF,SSFP,T2-FFE)

☐ balanced state free precession (trueFISP, FIESTA, b-FFE)

☐ cor ☐

NOTES:

Patients referrred from the UROLOGIST

Preparation

☐ empty bladder
☐ full bladder
☐ not important

☐ vaginal filling
☐ no vaginal filling
☐

☐ rectal filling
ml ______ agens: ______
☐ no rectal filling

Important sequences

static:
☐ T2 high resolution
☐ T1 high resolution
☐ PD
other: ☐

☐ sag
☐ tra
☐ cor

Angulation: ST (mm) FOV (cm) first/last slice:

squeezing:
☐ sag
☐ tra
☐ cor

☐ steady-state free precession (FISP,GRASS,FFE,PSIF,SSFP,T2-FFE)
☐ balanced state free precession (trueFISP, FIESTA, b-FFE)

ST (mm)/FOV (cm)

straining:
☐ sag
☐ tra
☐ cor

☐ steady-state free precession (FISP,GRASS,FFE,PSIF,SSFP,T2-FFE)
☐ balanced state free precession (trueFISP, FIESTA, b-FFE)

ST (mm)/FOV (cm)

defecation:
☐ sag
☐ tra
☐ cor

☐ steady-state free precession (FISP,GRASS,FFE,PSIF,SSFP,T2-FFE)
☐ balanced state free precession (trueFISP, FIESTA, b-FFE)

ST (mm)/FOV (cm)

NOTES:

Patients referred from the PROCTOLOGIST

Preparation

☐ empty bladder
☐ full bladder
☐ not important

☐ vaginal filling
☐ no vaginal filling
☐

☐ rectal filling
ml ______ agens: ______
☐ no rectal filling

Important sequences

static:
☐ T2 high resolution
☐ T1 high resolution
☐ PD
other: ☐

☐ sag
☐ tra
☐ cor

Angulation: ST (mm) FOV (cm) first/last slice:

squeezing:
☐ sag
☐ tra
☐ cor

☐ steady-state free precession (FISP,GRASS,FFE,PSIF,SSFP,T2-FFE)
☐ balanced state free precession (trueFISP, FIESTA, b-FFE)

ST (mm)/FOV (cm)

straining:
☐ sag
☐ tra
☐ cor

☐ steady-state free precession (FISP,GRASS,FFE,PSIF,SSFP,T2-FFE)
☐ balanced state free precession (trueFISP, FIESTA, b-FFE)

ST (mm)/FOV (cm)

defecation:
☐ sag
☐ tra
☐ cor

☐ steady-state free precession (FISP,GRASS,FFE,PSIF,SSFP,T2-FFE)
☐ balanced state free precession (trueFISP, FIESTA, b-FFE)

ST (mm)/FOV (cm)

NOTES:

Please list the papers, which are the basis for the protocols and the evaluation in your institution:

compartments:

anterior: ☐ bladder ☐ urethra ☐

middle: ☐ vagina ☐ uterus ☐ cervix ☐ bowel/Pouch of Douglas ☐ ☐

posterior: ☐ anus ☐ rectum ☐ bowel/Pouch of Douglas ☐

reference points/landmarks:

anterior:
- ☐ bladder neck
- ☐ bladder base

middle:
- ☐ anterior cervical lip
- ☐ posterior cervical lip
- ☐ most distal part of cervical lumen
- ☐ vaginal vault after hysterectomy
- ☐ posterior peritoneal reflecting fold/lowest part of pouch of Douglas

other: ☐

posterior:
- ☐ posterior peritoneal reflecting fold/lowest part of pouch of Douglas
- ☐ anterior rectal wall
- ☐ anterior anorectal wall

reference line:

		anterior compartment	middle compartment	posterior compartment
☐	pubococcygeal line	☐	☐	☐
☐	mid pubic line	☐	☐	☐
☐	horizontal line	☐	☐	☐
☐	PICS line	☐	☐	☐
☐	SCIPP line	☐	☐	☐
☐	anal line	☐	☐	☐
☐	perineal line	☐	☐	☐

Definition of endpoint of PCL:

- ☐ sacrococcygeal joint (=SCIPP-line)
- ☐ lowest margin of os coccygeus
- ☐ last coccygeal joint

other: ______________________ ☐

Definiton of measured values:

reference point above the reference line ☐ plus sign ☐ minus sign

reference point below the reference line ☐ plus sign ☐ minus sign

measurements for defecography:

- ☐ anorectal angle ARA
- ☐ anorectal junction ARJ
- ☐ anteroposterior hiatal dimension (H-line)
- ☐ descent of H-line to PCL (=M-line)
- ☐ descent of ARJ to PCL (=rectal descent)
- ☐ outpouching of anorectal wall perpendicular to anal line (rectocele)

other ☐

Definition of time-effective evacuation of the rectum

- ☐ 1/2 of the filled rectum
- ☐ 2/3 of the filled rectum
- ☐ complete evacuation

other: ☐

in how many seconds? ______________

Definition of Pathology:

- ☐ any measured descent of the reference point
- ☐ at least grade 1
- ☐ grade 2 or higher

any cofactors? ☐

- ☐ any outpouching of the rectal wall
- ☐ at least grade 2 (>2cm)

any cofactors? ☐ ______________________

NOTES: ____

____

GRADING SYSTEMS:

Do you use different grading systems depending on the reference line?	☐ yes ☐ no
Do you use different grading sytems depending on the referrer?	☐ yes ☐ no
Do you recommend using a grading system at all?	☐ yes ☐ no

PELVIC ORGAN PROLAPSE ***(please sign, if you use one of the listed system and for which referrer)***

☐ Boyadzhyan, Radiographics 2008	Grade 0: above the H-Line Grade 1: 0 - 2 cm below the HL Grade 2: 2 - 4 cm below the HL Grade 3: > 4 cm below the HL		☐ gynecology ☐ urology ☐ proctology
☐ Hecht, AJR 2008	Grade 0: < 1cm below PCL Grade 1: 1 - 2 cm below PCL Grade 2: 2 - 4 cm below PCL Grade 3: > 4 cm below PCL		☐ gynecology ☐ urology ☐ proctology
☐ Yang 1991	Cystocele: B at least + 1 cm below PCL Uterine prolapse: C/V at maximum - 1 cm above PCL Rectocele: R at least + 2,5 cm below PCL		☐ gynecology ☐ urology ☐ proctology
☐ Haylen, N and U 2010	Stage 0: No prolapse is demonstrated. Stage I: Most distal portion of the prolapse is > 1 cm above the level of the hymen. Stage II: Most distal portion of the prolapse is ≤1 cm proximal to or distal to the hymen Stage III: The most distal portion of the prolapse is > 1 cm below the plane of the hymen Stage IV: Complete eversion of the total length of the lower genital tract is demonstrated.		☐ gynecology ☐ urology ☐ proctology
☐ Short POP-Q Version AGUB	Grade 0 No prolapse is demonstrated. Grade 1 Most distal portion of the prolapse is > 1 cm above the level of the hymen. Grade 2 Most distal portion of the prolapse reaches the introitus Grade 3 Most dital portion of the prolapse is > 2cm below the introitus Grade 4 Complete eversion of the total length of the lower genital tract is demonstrated.		☐ gynecology ☐ urology ☐ proctology
☐ Colaiacomo,RadioGraphics 2009 (Kelvin AJR 1999)	☐ *Cystocele* Grade 0: Grade 1: Grade 2: Grade 3:	up to +1cm below PCL +1 to +3 cm below PCL +3 to +6 cm below PCL > + 6 cm below PCL	☐ gynecology ☐ urology ☐ proctology
	☐ *Vaginal Vault* Grade 0: Grade 1: Grade 2: Grade 3:	above PCL 0 to +3 cm below PCL +3 to +6 cm below PCL > + 6 cm below PCL	☐ gynecology ☐ urology ☐ proctology
	☐ *Rectocele* Grade 0: Grade 1: Grade 2: Grade 3:	no outpouching outpouching up to 2 cm outpouching between 2 and 4 cm outpouching > 4 cm	☐ gynecology ☐ urology ☐ proctology
☐ Woodfield, Int Urogyn J 2009	☐ Grade 0: above PCL Grade 1: descent < 3cm below PCL Grade 2: descent 3-6 cm below PCL Grade 3: descent > 6 cm below PCL Grade 4: complete organ prolapse		☐ gynecology ☐ urology ☐ proctology
	☐ Grade 0: no descent Grade 1: descent to 1cm proximal to MPL Grade 2: descent between 1cm proximal and distal MPL Grade 3: descent between 1cm distal MPLand 2cm – TVL Grade 4: descent from 2 cm –TVL to complete prolapse		☐ gynecology ☐ urology ☐ proctology

other: ☐ ______________________________

NOTES: ____

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PELVIC FLOOR RELAXATION ***(please sign, if you use the listed system and for which referrer)***

☐ Boyadzhyan, Radiographics 2008	☐ enlargement hiatus	Grade 0	< 6 cm
		Grade 1	6-8 cm
		Grade 2	8-10 cm
		Grade 3	> 10 cm
	☐ descent H-line to PCL (=M-line)	Grade 0	0-2 cm
		Grade 1	2-4 cm
		Grade 2	4-6 cm
		Grade 3	>6 cm
		☐ gynecology	
		☐ urology	
		☐ proctology	

other: ☐ ______________________________

NOTES: ______________________________

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3T MR-defecography—A feasibility study in sensorimotor complete spinal cord injured patients with neurogenic bowel dysfunction

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ABSTRACT

Introduction: To investigate whether MR-defecography can be employed in sensorimotor complete spinal cord injury (SCI) subjects as a potential diagnostic tool to detect defecational disorders associated with neurogenic bowel dysfunction (NBD) using standard parameters for obstructed defecation.
Material and methods: In a prospective single centre clinical trial, we developed MR-defecography in traumatic sensorimotor complete paraplegic SCI patients with upper motoneuron type injury (neurological level of injury T1 to T10) using a conventional 3T scanner. Defecation was successfully induced by eliciting the defecational reflex after rectal filling with ultrasonic gel, application of two lecicarbon suppositories and digital rectal stimulation. Examination was performed with patients in left lateral decubitus position using T2-weighted turbo spin echo sequence in the sagittal plane at rest (TE 89 ms, TR 3220 ms, FOV 300 mm, matrix 512 × 512, ST 4 mm) and ultrafast-T2-weighted-sequence in the sagittal plane with repeating measurements (TE 1.54 ms, TR 3.51 ms, FOV 400 mm, matrix 256 × 256, ST 6 mm). Changes of anorectal angle (ARA), anorectal descent (ARJ) and pelvic floor weakness were documented and measured data was compared to reference values of asymptomatic non-SCI subjects in the literature to assess feasibility.
Results: MR-defecography provides evaluable imaging sequences of the induced evacuation phase in SCI patients. Measurement results for ARA, ARJ, hiatal width (H-line) and hiatal descent (M-line) deviate significantly from reference values in the literature in asymptomatic subjects without SCI. The overall mean values in our study for SCI patients were: ARA (rest) 127.3°, ARA (evacuation) 137.6°, ARJ (rest) 2.4 cm, ARJ (evacuation) 4.0 cm, H-line (rest) 7.6 cm, H-line (evacuation) 8.1 cm, M-line (rest) 2.6 cm, M-line (evacuation) 4.2 cm.
Conclusions: MR-defecography is feasible in sensorimotor complete SCI patients. Individual MR-defecography findings may help to determine specific therapeutical options for respective patients suffering from severe NBD.

Abbreviations: ARA, anorectal angle; ARJ, anorectal junction; ASIA, American Spinal Injury Association; FOV, field of view; LMN, lower motoneuron; MRI, magnetic resonance imaging; NBD, neurogenic bowel dysfunction; NLI, neurological level of injury; PCL, pubococcygeal line; SCI, spinal cord injury; ST, slice thickness; TE, time of echo; TR, time of repetition; UMN, upper motoneuron.

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1. Introduction

Following spinal cord injury, neurogenic bowel dysfunction (NBD) is defined as a colonic dysfunction due to a lack of central control based on an upper motoneuron (UMN) or lower motoneuron (LMN) lesion with reflexive or areflexive bowel, respectively [1]. It constitutes a major physical and psychological problem in individuals with spinal cord injury (SCI) with a high impact on quality of life and restriction of social activities [1–3].

Patients with sensorimotor complete SCI, classified by the American Spinal Injury Association Impairment Scale (AIS) as AIS grade A (AIS-A), lose sensation of rectal filling, anal sensibility and the ability to evacuate their bowels resulting in impaired defecation [4]. The improvement of bowel function is considered amongst the highest priorities in spinal cord injury patients [5].

All patients with complete SCI suffer from bowel-related symptoms and the frequency of gastrointestinal problems increases in individuals who had been spinal cord injured for more than 5 years [3,6]. To prevent such gastrointestinal complications a specific bowel management program during rehabilitation is required to achieve efficient, effective and consistent stool evacuation to avoid chronic overdistension of the colon [6]. Whereas normal individuals have synergistic activity between rectal smooth muscle and pelvic striated muscles, it is hypothesized that SCI patients have dyssynergic pelvic floor movements which contribute to outlet obstruction [7]. This constitutes one of the key factors interfering with regular bowel function. Sphincter electromyography findings indicate involuntary external as well as internal anal sphincter activity supporting the notion that outlet obstruction may be due to persistant external anal sphincter contractions [8], although results of anorectal manometry did not reveal a clear correlation to clinical bowel dysfunction [7]. Overall, the exact pathophysiological process of outlet obstruction involving the pelvic floor and anorectum of SCI patients has yet to be examined.

The primary objective of this study was to evaluate the feasibility to perform MR-defecography in sensorimotor complete SCI patients, who are not able to squeeze or strain actively. MR-defecography provides visualization of all the compartments of the entire pelvis with excellent soft tissue contrast without application of radiation, allowing reproducible and quantifiable assessment of defecation under standardized conditions [9]. First, we established an adopted procedure for MR-defecography examination in patients with SCI using a conventional 3 Tesla (T) scanner. Second, we evaluated standard parameters for obstructed defecation and compared these results to reference values of able-bodied subjects in the literature.

2. Material and methods

This prospective clinical trial was conducted at the Spinal Cord Injury Center, Heidelberg University Hospital, Germany, specialising in comprehensive care of acute and chronic SCI patients. Subjects were recruited from in house and outpatients during 2010–2012 and those that met the inclusion criteria were included in the study. The study (trial number S-274/2008) was approved by an ethics committee at Heidelberg Medical Faculty, Germany. All patients gave informed written consent after explanation of the procedure.

2.1. Patient population, inclusion and exclusion criteria

We enrolled patients with sensorimotor complete traumatic SCI (**A**merican Spinal Injury Association **I**mpairment **S**cale grade A; AIS-A) and a neurological level of injury (NLI) between Th1 and Th10 to yield a homogenous patient population with only UMN lesions [10]. AIS-A is defined as no preserved sensory or motor function in the sacral segments S4-S5 [10]. As a result all patients suffer from neurogenic bowel dysfunction, a dysfunction of the colon (constipation, faecal incontinence and disordered defecation) due to loss of normal sensory and/or motor control or both [11]. To ensure, that our patients had a stable condition in regards to their bowel management, we enrolled patients only 6 months after SCI. Patients with non-traumatic paraplegia, traumatic brain injury, dementia, cauda equina or conus medullaris lesion, polyneuropathy, inflammatory, traumatic or neoplastic bowel disease, pre-existing pelvic floor weakness or gastrointestinal surgical interventions were excluded. Further, we excluded patients who did not meet the inclusion criteria for MRI, e.g. cardiac pacemaker, metal foreign objects and claustrophobia.

2.2. Defecation procedure, image acquisition and analysis

All MRI studies, which were conducted for research purposes only, were performed at a conventional 3T MR scanner (Magnetom Verio, Siemens, Erlangen, Germany). The exam date was scheduled to meet the bowel evacuation rhythm of the patient.

As SCI patients require different kinds of supporting measures for inducing the defecation process (e.g. suppositories, enemas, digital stimulation), application of Lecicarbon (CO_2) suppositories and digital stimulation were determined for this study. The preparation of the patients before and during MR-examination as well as the performed MR-sequences are listed in Table 1. The sequences were separately and independently analysed offline at a PACS-workstation (GE Medical, USA) by a radiologist with 8 years experience in pelvic floor imaging. The analysis was performed upon two images: (1) a sagittal plane at rest after initial rectal filling and (2) a sagittal plane during notable evacuation. As we analysed sensorimotor complete SCI patients, defined images during squeezing (maximal sphincter contraction) or volitional straining could not be performed. Defecation in spinal cord injured patients is recommended in lateral left-sided decubitus if sitting defecation posture is not possible [12,13]. To facilitate the practicality of additional interventions, e.g. digital rectal examination of the patient, second filling and digital rectal stimulation, lateral decubitus was the preferred position during rest and defecation.

Measurement of parameters was completed on the aforementioned sagittal images as follows (Fig. 1a–c):

The pubococcygeal line (PCL), defined as a straight line from the inferior border of the pubic symphysis to the last coccygeal joint, representing the pelvic floor level, was drawn (Fig. 1a) [14,15]. The horizontal line (H-line) represents the anteroposterior hiatal width of the levator plate and is measured from the inferior border of the pubic symphysis to the posterior aspect of the anorectal wall [16–18]. The M-line (M) representing the hiatal descent was measured perpendicular to the PCL to the posterior endpoint of the H-line (Fig. 1a) [16–18]. The anorectal junction (ARJ), defined as the cutting line between the tangent to the posterior wall of the rectum and a line along the central axis of the anal canal was plotted and a perpendicular line to the PCL was drawn to define rectal descent (Fig. 1b) [9]. The anorectal angle (ARA) was defined as the angle between these two aforementioned cutting lines resulting in the ARJ (Fig. 1b) [9]. Furthermore, the maximum rectal diameter before notable evacuation was measured (Fig. 1c).

After acquisition of the data at rest and during induced defecation, the difference of the measured values (Δ) was calculated for all parameters.

To rate the measured findings, established grading systems for pelvic floor weakness, including hiatal widening (H-line), levator plate descent (M-line) and for rectal descent were used (Table 2) [16,19]. Routinely, all images were analysed for the presence of an

Table 1
Patient preparation and performance of MR-defecography in our study cohort.

Patients' preparation	
1	Ask the patient to avoid rectal evacuation prior to the examination to increase the probability of defecation during MRI
2	Ask the patient to empty the bladder by catheterization right before the examination
3	Position the patient in left decubitus position on a gel mat with knees flexed for stable position and to avoid pressure sores
4	Perform digital rectal examination to assure that the patient has no obstruction
5	Do rectal filling with body temperatured ultrasonic gel using a rectal catheter connected with a bladder syringe
6	Insert two suppositories of Lecicarbon (CO_2) into the rectum to increase the stretching and to initiate defecation reflex
7	Repeat rectal filling and perform digital rectal stimulation if there is no evacuation after 15 min

MR-imaging protocol

	Sequence	Plane	TE (ms)	TR (ms)	FOV (mm)	Matrix	ST (mm)	
1	T2-weighted turbo-spin-echo	Transverse	89	5160	300	512 × 512	4	Static
2	T2-weighted turbo-spin-echo	Sagittal	89	3220	300	512 × 512	4	Static
3	Ultrafast T2-weighted single-slice-true-FISP	Midsagittal	1.54	3.51	400	320 × 256	6	Dynamic*

TE = time of echo; TR = time of repetition; ms = milliseconds; FOV = field of view; ST = slice thickness; mm = millimetre.
* 21 slices, time duration 0:13 s.

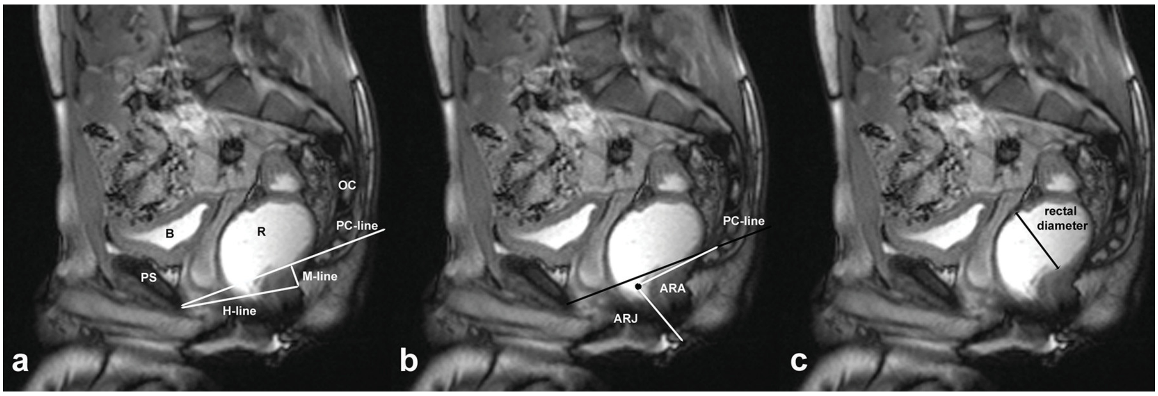

Fig. 1. Measurement parameters performed on the sagittal plane for evaluation of pelvic floor related dysfunction. Image after initial rectal filling with ultrasonic gel in a 19 year old man with sensorimotor complete paraplegia (neurological level of injury is T4), 3 years after injury. (a) The pubococcygeal line (PC-line) is drawn from the inferior border of the pubic symphysis (PS) to the last visible joint of os coccygeus (OC). The hiatal width is measured as the horizontal line (H-line) from the inferior border of the PS to the posterior aspect of the anorectal wall. From this endpoint, the M-Line is drawn perpendicular to the PC-Line to measure the descent of the hiatus to the level of the pelvic floor. B = bladder, R = rectum. (b) The anorectal angle (ARA) is measured between the tangent to the posterior rectal wall and the line through the central axis of the anal canal. The cross point is defined as the anorectal junction (ARJ) (black dot). (c) The rectal diameter was measured after complete rectal filling; alternatively, the sequence before the induced defecation process started was chosen.

Table 2
Grading systems used for evaluation of pelvic floor relaxation and rectal descent.

Grading systems			
Pelvic floor relaxation	Grade	Hiatal enlargement (H-line) (cm)	Hiatal descent (M-line) (cm)
Boyadzhyan et al. [16]	0 (normal)	<6	0–2
	1 (mild)	6–8	2–4
	2 (moderate)	8–10	4–6
	3 (severe)	≥10	≥6
Rectal descent	Grade	Position of ARJ according to the PCL	
Kruyt et al. [19]	0 (normal)	<3 cm below the PCL	
	1 (mild)	3–5 cm below the PCL	
	2 (severe)	>5 cm below the PCL	

ARJ = anorectal junction; PCL = pubococcygeal line.

anterior rectocele, defined as the distance of an anterior rectal wall bulge to a line drawn parallel to the centre of the anal canal, an intussuception or enterocele [20]. Additionally, the anterior compartment was visualized for the possible presence of a vesicocele.

2.3. Statistical analysis

Statistical analysis was performed using SPSS 20 (IBM Corp., Armonk, NY, USA). Descriptive statistics like mean and standard deviation are used to describe the basic features of this cohort of complete paraplegic patients. To compare the samples to a defined population of normal values of historical control data the one sample *t*-test was employed.

3. Results

Twenty consecutive subjects with sensorimotor complete UMN type SCI (NLI from Th1 to Th10) and NBD fulfilled inclusion criteria and underwent MR-defecography with the adopted preparation and study protocol (Tables 1 and 3). MR-defecography was feasible

Table 3
Patient-specific data and cohort-specific MRI results.

Patients demographics and clinical data					
1	Total number of patients		20		
2	Sex	Male	18		
		Female	2		
				Mean	Range
3	Age (years)			47	(19–70)
4	Neurological level of injury (thoracic vertebra)			4	(1–10)
5	Time since injury (years)			20	(3–50)

Cohort specific results of MR performance	Mean	SD
Initial rectal filling volume (ml)	206	±66
Second rectal filling volume (ml)	149	±80

Cohort specific results of MR measurements		Number of patients
1	ARA (evacuation) more acute angled than ARA (rest)	4
	ARA (evacuation) more obtuse than ARA (rest)	16
2	ARJ (rest) normal	15
	ARJ (rest) descent	5
	ARJ (evacuation) descent	12
	ARJ (evacuation) resting within 3 cm below PCL	8
	ARJ (evacuation) elevation to ARJ (rest)	4/8
3	H-line (rest) normal	1
	H-line (rest) enlarged	19
	Grade 1 (n = 15); grade 2 (n = 2); grade 3 (n = 2)	
	H-line (evacuation) shorter than H-line (rest)	5
	H-line (evacuation) enlarged to H-line (rest)	15
	Increase of grade (n = 8); same grade (n = 7)	
4	M-line (rest) normal	7
	M-line (rest) enlarged	13
	Grade 1 (n = 11); grade 2 (n = 2)	
	M-line (evacuation) shorter than M-line (rest)	4
	M-line (evacuation) enlarged to M-line (rest)	16
	Increase of grade (n = 11); same grade (n = 5)	

ml = millilitre; SD = standard deviation; ARA = anorectal angle; ARJ = anorectal junction; H-line = hiatal width; M-line = levator plate descent.

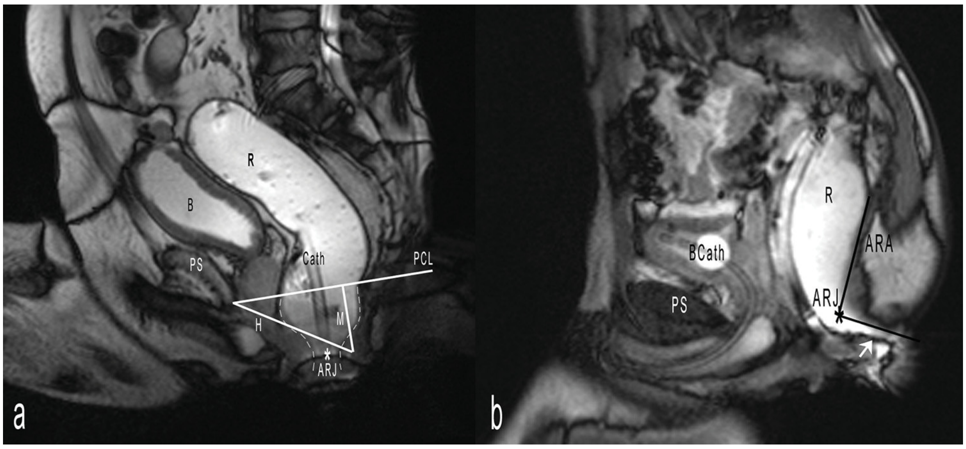

Fig. 2. Illustration of the induced evacuation phase in two SCI patients. (a) 60 year old male, paraplegia American Spinal Injury Association Impairment Scale grade A (AIS-A), neurological level of injury (NLI) is T2, time since injury is 40 years, suffering from severe neurogenic bowel dysfunction (NBD). The rectum was filled with 440 ml of ultrasound gel, the catheter remains in the rectal lumen, evacuation process was initiated after 35 repeated measurements. The rectum shape is sacciform (gray contour) and the anorectal junction (ARJ) (asterisk) is located 4.7 cm below the pubococcygeal line (PCL). Pelvic floor relaxation is present with widening of the hiatus (H) at 7.5 cm and hiatal descent (M) at 4.7 cm. B = bladder, PS = pubic symphysis, R = rectum, Cath = rectal catheter. (b) 24 year old male, paraplegia AIS-A, NLI T4, time since injury is 7 years, suffering from moderate NBD. The rectum was filled with 300 ml of ultrasound gel and evacuation phase started after 9 repeated measurements (arrow). The anorectal angle (ARA) became more obtuse at 124° during the evacuation phase, while ARA at rest was 105° in this patient (not shown). Pelvic floor relaxation grade 1 is present. There is no rectal descent, as the anorectal junction (ARJ) (asterisk) is close to the level of the distal edge of pubic symphysis. BCath = indwelling transurethral bladder catheter, R = rectum, ARA = anorectal angle.

in all patients (Fig. 2). One patient did develop a grade I pressure sore above the left trochanter major, which subsided after subsequent pressure relief within 24 h. The initial rectal filling volume varied depending on the backflow of ultrasound gel, a filling resistance or the beginning of induced defecation (Table 3). A second filling was necessary in 80% of patients (16/20). The mean maximum rectal diameter before evacuation started was 4.9 cm ± 1.5 cm SD.

Table 4
Measurement results of the study group of complete paraplegic patients ($n = 20$) compared to reference values in the literature in asymptomatic subjects without spinal cord injury.

Measurement results for the study group (mean ± SD) compared to references in the literature (mean ± SD)				
Parameters	Study group $n = 20$	Reference*		p-Value**
ARA at rest (°)	127.3 (±16.9)	104.0 (±4.0)	[19]	<0.001
		93.0 (±4.8)	[20]	<0.001
ARA during evacuation (°)	137.6 (±12.6)	126.0 (±3.0)	[19]	<0.001
		108.0 (±14.7)	[20]	<0.001
ΔARA (°)	10.3 (±18.6)	22.0 (±4.0)	[19]	0.011
		15.7 (n.a.)	[20]	0.211
ARJ at rest (cm)	2.4 (±1.4)	2.8 (±0.2)	[19]	0.178
		0.53 (±0.99)	[20]	<0.001
ARJ during evacuation (cm)	4.0 (±1.9)	3.4 (±0.3)	[19]	0.213
		2.99 (±1.03)	[20]	0.037
ΔARJ (cm)	1.6 (±2.0)	2.46 (n.a.)	[20]	0.073
H-line at rest (cm)	7.6 (±1.5)	5.2 (±1.1)	[15]	<0.001
H-line during evacuation (cm)	8.1 (±1.4)	5.8 (±0.5)	[16]	<0.001
ΔH-line (cm)	0.45 (±1.7)	n.a.		
M-line at rest (cm)	2.6 (±1.2)	1.9 (±1.2)	[15]	0.016
M-line during evacuation (cm)	4.2 (±1.6)	1.3 (±0.5)	[16]	<0.001
ΔM-line (cm)	1.6 (±1.7)	n.a.		

ARA = anorectal angle, Δ = difference between at rest and during evacuation phase, ARJ = anorectal junction, H = H-line, M = M-line, SD = standard deviation; the measurements of ARJ and M-line were performed relatively to the pubococcygeal line.
* Asymptomatic subjects.
** Using one sample t-test for continous variables.

Regarding the measurement results of our SCI study cohort in comparison to reference values in the literature of asymptomatic able-bodied subjects the mean ARA and hiatal width (H-line) were significantly increased at rest as well as during evacuation (Table 4) [9,17,21–23]. Additionally, the mean levator plate descent (M-line) during induced defecation was significantly increased, while the other measured parameters showed no significant differences (Table 4) [23].

Regarding the results within our cohort, hiatal width and levator plate descent were already enlarged at rest (mostly grade 1) in 19 and 13 patients. Enlargement of the hiatal width and levator plate descent during induced evacuation was noted with an increase of grade in 8 and 11 patients, indicative of pelvic floor relaxation (Table 3). It was remarkable that 4 patients showed an elevation of the ARJ and a more acute ARA during evacuation. Additionally, 5 patients presented with a shortening of the hiatal width during evacuation, indicative of a contrary movement of the pelvic floor (Table 3). 9 out of 20 patients presented with an anterior rectocele (2.74 cm ± 0.32 SD) and 3 out of 20 patients presented with an intra-rectal intussusception (Fig. 3). None of the patients presented with an enterocele or a vesicocele.

4. Discussion

To the best of our knowledge, this is the first prospective study to show that 3T MR-defecography is feasible in a homogeneous cohort of 20 chronic sensorimotor complete paraplegic SCI patients using standard sequences for MR-defecography procedure. Contrary to volitional bowel evacuation employed in healthy subjects, defecation was successfully induced in SCI subjects by eliciting the defecational reflex after rectal filling with ultrasonic gel and application of two lecicarbon suppositories/digital rectal stimulation.

As previously stated, the vast majority of SCI patients suffer from NBD. In the case of SCI with specifically an UMN injury – the patient population utilized in this study – the most relevant clinical problems arise around chronic constipation [24]. Furthermore, UMN type NBD constipation with faecal retention is considered to be due to an outlet obstruction (anorectal dyssynergia) rather than a prolonged colon transit time [25]. Therefore, the aim of our MR-defecography based study was to investigate whether this method is feasible in complete SCI patients with NBD.

Similar to MR-defecography performed in individuals without SCI we evaluated changes of ARA, ARJ, M-line and H-line, as well as maximum rectal widening to obtain indirect information about muscular activity of the pelvic floor [26,27]. The overall mean values for MR-defecography in complete paraplegic patients in our study were: ARA (rest) 127.3°, ARA (evacuation) 137.6°, ARJ (rest) 2.4 cm, ARJ (evacuation) 4.0 cm, H-line (rest) 7.6 cm, H-line (evacuation) 8.1 cm, M-line (rest) 2.6 cm, M-line (evacuation) 4.2 cm. Pelvic floor relaxation, combining hiatal widening (H-line) and levator plate descent (M-line) was found in all study subjects.

In our study population, four SCI subjects presented with a contrary movement of the ARA during induced defecation due to an involuntary contraction of the puborectalis muscle sling (Fig. 4). Narrowing of the ARA is physiologically observed during squeezing, but in SCI patients with complete loss of sensorimotor function, this change in the ARA is most likely caused by involuntary muscle contraction, namely spasticity. If spasticity of the pelvic floor muscles significantly contributes to outlet obstruction, SCI patients may benefit from a selective botulinum toxin infiltration into the puborectalis muscle [28].

Based on this study, the examination procedure is feasible and safe in complete SCI patients. We observed one case with a mild grade I pressure sore, which subsided within a few hours after the exam. Considering the potentially prolonged examination time (up to 2 h), this risk needs to be considered and appropriate precautions taken to avoid pressure sores. In this study a gel mattress and frequent skin checks between rectal fillings were introduced.

Some limitations of our study are: The overall number of UMN SCI patients examined with MR-defecography was small and the feasibility study was only performed as a single centre study. The reproducibility of MR-defecography in SCI patients at different clinical sites has to be explored. We examined sensorimotor complete SCI subjects who cannot perform voluntary squeezing or active evacuation. As a consequence, the modified MR-defecography procedure in SCI patients included only images at rest and during induced defecation. Currently, no able-bodied patient population available to be matched in terms of age, gender or type of defecational disorder nor any SCI control group exists within the literature

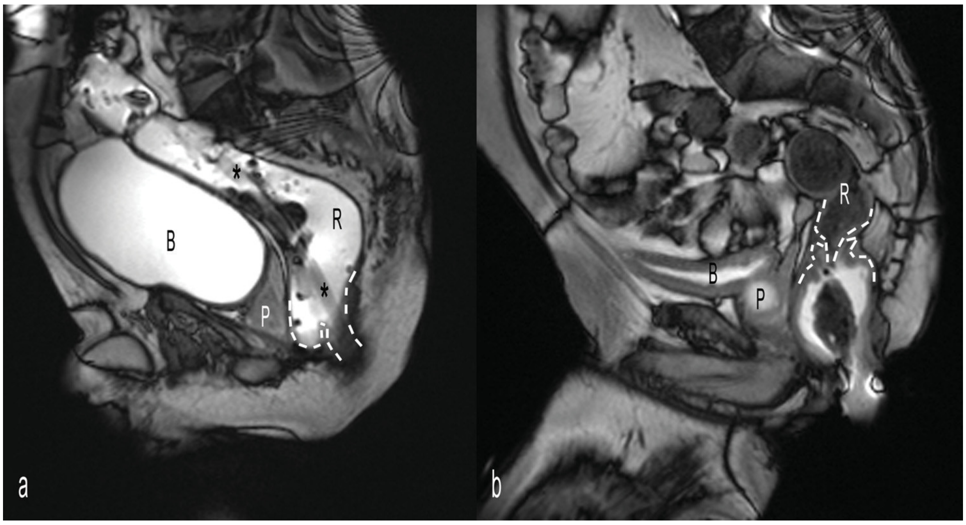

Fig. 3. Visualization of a rectocele and an intussusception during induced defecation in two study subjects. (a) 54 year old man with sensorimotor complete paraplegia, neurological level of injury (NLI) is T3-6, 13 years after injury, suffering from severe neurogenic bowel dysfunction (NBD) presenting with a small anterior rectocele during induced defecation (white dotted line). (b) 45 year old man with sensorimotor complete paraplegia (NLI, T12), 11 years after injury, suffering from minor NBD presenting with an intra-rectal intussusception during induced defecation (white dotted line). B = bladder; P = prostate; R = rectum; * = rectal catheter.

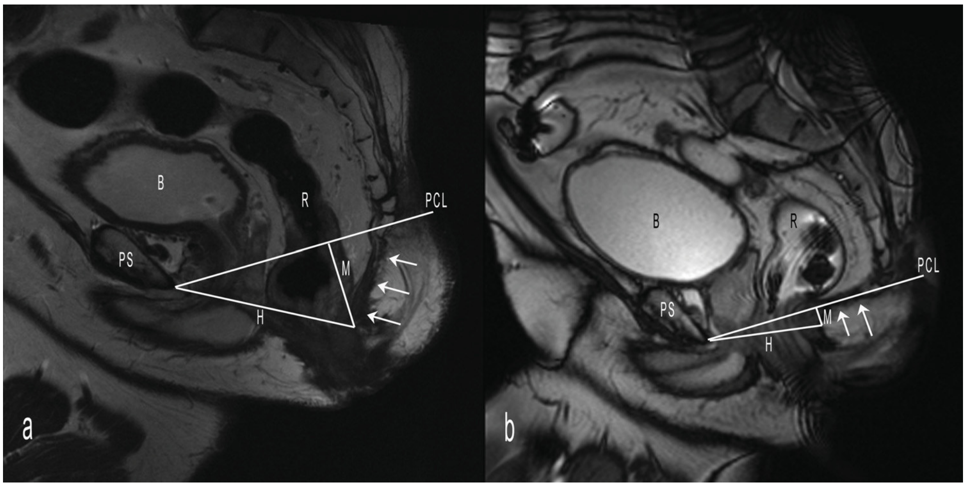

Fig. 4. 59 year old male with sensorimotor complete paraplegia (neurological level of injury, T7), 40 years after injury, suffering from severe neurogenic bowel dysfunction presenting with spasticity of the pelvic floor muscles and absence of evacuation. (a) Image at rest with an enlarged hiatus (H) at 9.9 cm and a hiatal descent (M) at 4.4 cm. The iliococcygeal muscle is stretched (white arrows). (b) Image after rectal filling with 350 ml of ultrasound gel, application of two suppositories of lecicarbon and rectal digital stimulation. The iliococcygeal muscle contracts presented in the horizontal course (white arrows) and the H and M-line shorten to 5.5 cm and 1.0 cm, respectively. B = bladder, R = rectum, PS = pubic symphysis, PCL = pubococcygeal line, H = H-line, M = M-line.

for comparison. However, we show here the feasibility in comparison of different parameters in SCI patients to the results of asymptomatic volunteers in the literature. Although, at this point, we cannot determine the value of MR-defecography in respect to therapeutic consequences for chronic constipation in SCI patients and cannot recommend it currently as a routine clinical tool to examine SCI patients with chronic constipation NBD.

5. Conclusions

The 3T MR-defecography procedure adapted from able-bodied individuals represents a feasible and safe diagnostic tool for dynamic evaluation of defecation in sensorimotor complete paraplegic SCI patients. Taking advantage of the defecation reflex instead of voluntary stool evacuation allows visualization of pelvic floor contractions and potential outlet obstructions. In addition, pelvic floor disorder related pathologies can be detected. Further reproducible radiological results will support decision making in respect to specific therapeutical options in SCI patients suffering from severe NBD.

Conflict of interest statement

None.

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Role of the funding source

The foundation had no influence on the study design, on the collection, analysis or interpretation of the data, on the writing of the report or on the decision to submit the article for publication.

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