Integrated MR Analytical Approach and Reporting of Pelvic Floor Dysfunction

Current Implications and New Horizons

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KEYWORDS

• MR imaging of obstructed defecation • Dyskinetic puborectalis • Anal sphincter achalasia
• Solitary rectal ulcer syndrome • Functional 3-part pelvic floor supporting systems
• Combined analysis of dynamic and static MR imaging • Perineology
• 3-D modeling MR imaging of endopelvic fascia

KEY POINTS

- A diagnostic MR examination of pelvic floor should include MR defecography, dynamic cine MR imaging during straining, and static MR images.
- MR defecography is dedicated for detection and grading of pelvic organ prolapse and structural and functional abnormality of the evacuation process.
- Dynamic cine MR imaging at maximum straining identifies pelvic floor laxity and quantifies the degree of muscle weakness.
- Static MR images are assessed for detection and classification of structural abnormalities.
- The integrated MR analytical approach converts static and dynamic MR imaging from 2 separate types of images into an integrated system identifying specific defect in each patient.

INTRODUCTION

Many clinicians asserted that the optimal approach to treatment of PFD must be individualized for each patient on the basis of both the symptom complex and the specific anatomical and structural abnormalities. Recently, a new MR imaging analytical approach was devised that integrates data provided by both dynamic (cine) and static MR images, to define the predominant defects of the pelvic support system making it possible to pinpoint the underlying defects in each patient to the clinicians and consequently guides them to tailor treatment to the needs of each patient. This approach provides the necessary scientific evidence on which best clinical practice can be based. The first section of this article, explains why this approach was developed and how to apply it. In addition, to make it easy for radiologists to use this approach and to increase surgeons' comprehension of the overall findings, a "Data-Reporting System" was created in which all imaging findings are presented in a structured schematic MR imaging reporting template from a purely functional point of view to enhance the radiologists' interaction with clinicians and bridges the gap between radiology and surgery.

The second section emphasis on what the referring physician needs to know and their requirements to decide on the treatment plan. This section details the vital role of the radiologist in crafting and establishing new aiding tools for the clinician to use in planning reconstructive surgery. "Functional 3-Part Pelvic Supporting Systems Approach"; "Integrated MR Analytical Approach"; "Data-Reporting System"; "Three-axis perineal

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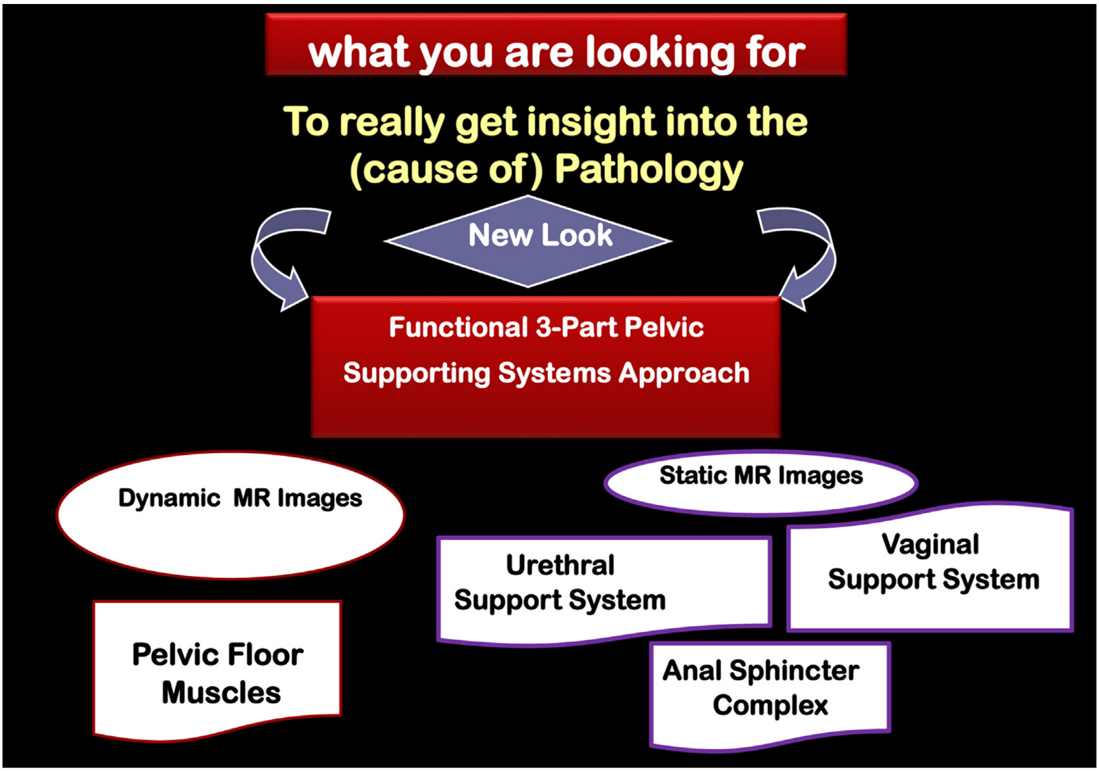

Fig. 1. The chart illustrates the link between the newly adapted 3-part pelvic support system approach and the MR imaging sequences.

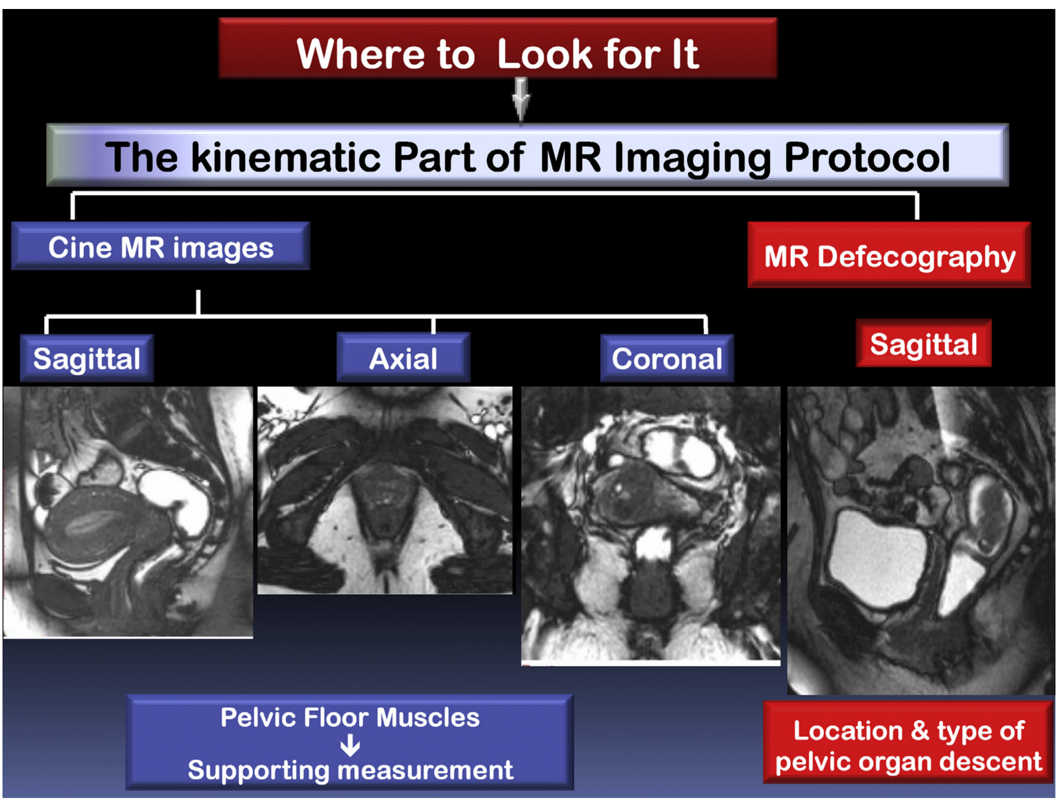

Fig. 2. Chart summarizing the essential kinematic (dynamic cine and MR defecography) imaging protocols for a diagnostic MRI study of patients with PFD.

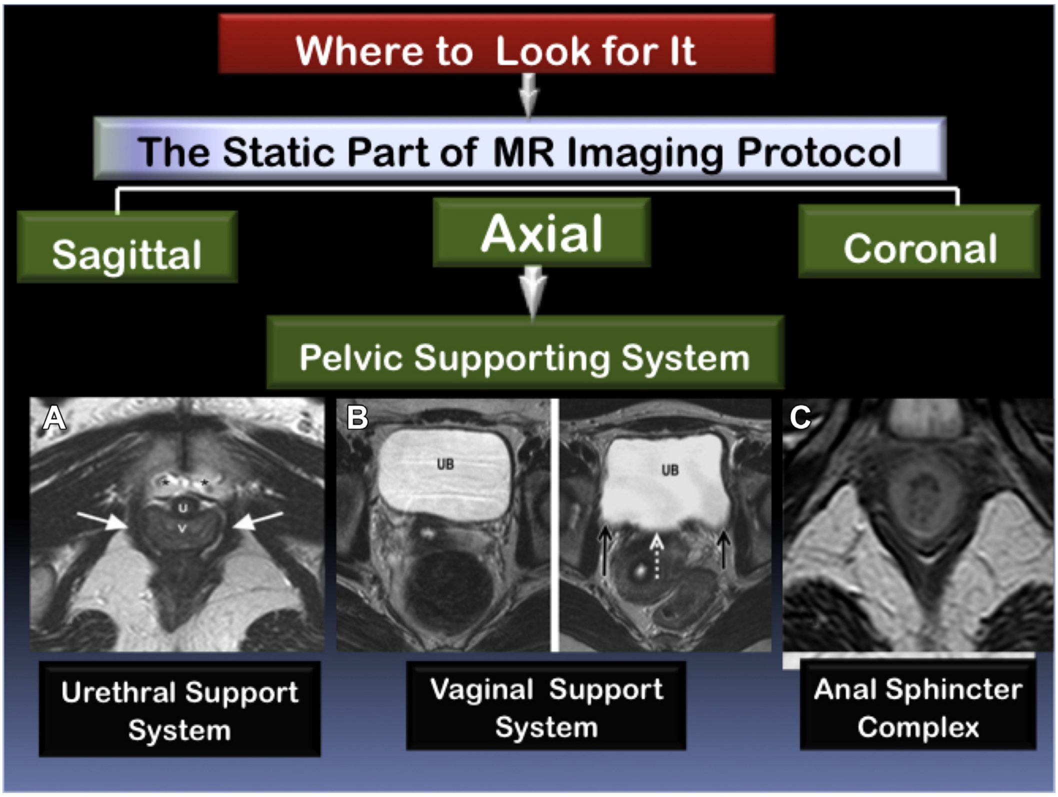

Fig. 3. For assessment of the 3-part pelvic supporting system, the radiologist should look for the underlying pathology in the static axial MR images. (*A*) Axial T2 weighed (T2WI) MR image of the urethral support system. Arrows point to the puborectalis muscle and asterisks indicates the space of Retzius. (*B*) Axial T2WI MR image of the vaginal support system. Black arrows point to the lateral endopelvic fascial defects and dashed white arrow points to the central endopelvic fascial defect. (*C*) Axial balanced fast field echo (BFFE) MR image shows the normal anal sphincter complex. U, urethra; UB; urinary bladder; V, vagina.

Box 1
Checklist for the recommended MR imaging reporting scheme

A. Measurements

1. Basic measurements for all compartments
   - Determine PCL.
   - Determine organ-specific reference points.
   - Measure the descent of reference points below the PCL.
2. Measurements for posterior compartment

   Measure the bulging of the anterior rectal wall during maximum straining phase and evacuation phase.

   Measure the ARA at rest, squeezing phase, straining phase and evacuation phase.

B. Reporting

1. Basic reporting for all compartments
   - Report values above the PCL as negative and below as positive.
   - Report pelvic organ mobility.
2. Reporting for anterior compartment
   - Report loss of urine at straining phase.
   - Report urethral mobility at straining phase.
3. Reporting for middle compartment
   - Report uterine descent.

- Report the content of a present enterocele.

4. Reporting for posterior compartment
   - Report presence of a rectal intussusception.
   - Evaluate time-effective rectal evacuation.
   - Point out the change of ARA.

C. Grading

1. Anterior compartment
   - Use the rule-of-3 grading for cystocele.
   - Report cystocele as pathologic starting from °II.
2. Middle compartment
   - Use the rule-of-3 grading for uterine prolapse and enteroceles.
   - Report POP as pathologic starting from °II.
3. Posterior compartment
   - Use the rule-of-2 grading for rectoceles.
   - Report a rectocele as pathologic starting from °II.
   - Use the grading for ARJ starting at 3 cm below the PCL.

Data from [El Sayed RF, Alt CD, Maccioni F, Meissnitzer M, Masselli G, Manganaro L, Vinci V, Weishaupt D. Magnetic resonance imaging of pelvic floor dysfunction - joint recommendations of the ESUR and ESGAR Pelvic Floor Working Group. On Behalf of ESUR and ESGAR Pelvic Floor Working Group . European Radiology,2017; 27(5):2067–2085. 10.1007/s00330-016-4471-7].

evaluation (TAPE) Approach"; "Individualized, defect- specific treatment Approach"; "3-D modeling of the predominant pelvic supporting system defect" are the rising stars of the upcoming new horizon in the diagnosis of the complex disorders of the pelvic floor, reducing the risk of surgical failure, dysfunction recurrence, and re-operation.

MR IMAGING REPORT

In order to achieve an MR imaging report that is critical in decision-making for patient management and /or operative choice, it is of paramount importance to the radiologist to understand clearly the aim of each MR sequences acquired and what to report in each set of the MR images obtained. In other words the radiologist should know "what to look for" and "where to look for it". (**Fig. 1**) illustrate this concept in details. (**Figs. 2** and **3**) provide charts summarizing the essential Kinematic and static imaging protocols for a diagnostic MRI study. In addition the charts specify in which set of the acquired MR images each of the Functional 3-part pelvic supporting system can be assessed.

A clear consensus was reached that the assessment of a MR study of the pelvic floor should include:

- Analysis of the MR Defecography for detection and grading of pelvic organ prolapse and functional abnormality of the evacuation process.
- Assessment of the Dynamic cine MR images at maximum straining to identify pelvic floor laxity and quantifies the degree of muscle weakness.
- Analysis of static MR images for detection and classification of structural abnormalities.
- Both dynamic and static MR imaging findings as well as the results of the metric measurements should be reported in a structured MR reporting scheme1 (**Box 1**).

Analysis of MR Defecography

Dynamic MR imaging examination of pelvic floor are reported in a standardized scheme in all patients of pelvic floor dysfunction, whether the patient's main complaint is related to one or multiple compartment or whether the patients is being referred from urogynecology and/or coloproctology.

Measurements during evacuation recognize and grade the extent of POP, in addition to any structural or functional abnormalities of the evacuation process in obstructed defecation (**Fig. 4**).

Basic measurements for all compartments

- The pubococcygeal line (PCL), drawn on sagittal plane from the inferior aspect of the

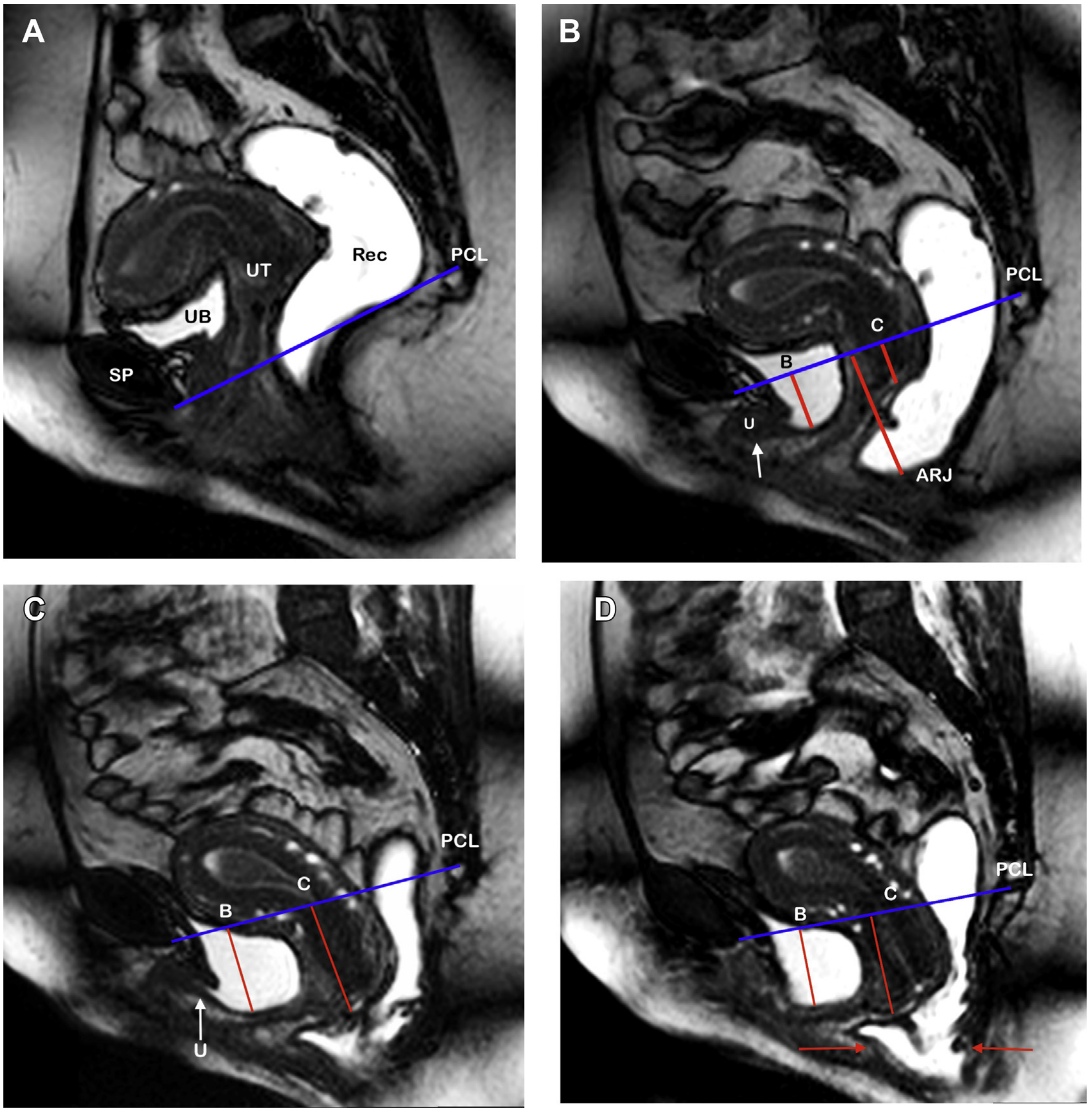

Fig. 4. MR defecography, basic measurements for all compartments. (*A*) Dynamic balanced fast field echo (BFFE) sequence in the midsagittal plane at rest shows how to plot the basic measurements of POP. The PCL, drawn on sagittal plane from the inferior aspect of the pubic symphysis to the last coccygeal joint. (*B*) Dynamic BFFE during maximum straining shows the movement of the organs compared with their location at rest. The distance from each reference point is measured perpendicularly to the PCL. In this case there is abnormal descent of the bladder, uterus and anorectal junction below the PCL. (*C, D*) MR imaging during evacuation (MR defecography) is mandatory, because certain abnormalities and the full extent of POP are visible only during evacuation. In this case, image (*C, D*) during evacuation compared with the maximum staining image (*B*) it is obvious that there is increase of the degree of the pelvic organ descent, development of new pathologies, like the loss of urine and opacification of the urethra (*white arrow* in *C*) in addition to detection of the masked intussusception, which was detected only during excavation (*red arrows* in *D*). ARJ, anorectal junction; B, bladder base; C, cervix; PCL, pubococcygeal line; PS, pubic symphysis; Rec, rectum; U, urethra; UB, urinary bladder; UT, uterus.

pubic symphysis to the last coccygeal joint, is recommended as reference line to measure POP.[1]

- After defining the PCL, the distance from each reference point is measured perpendicularly to the PCL during evacuation.

- In the anterior compartment, the organ-specific reference point is the most inferior aspect of the bladder base.
- In the middle compartment, the reference point is the anterior cervical lip (most distal edge of the cervix) or the vaginal vault after hysterectomy.
- In the posterior compartment, the reference point is the anorectal junction (ARJ).
- Measured values above the reference line have a minus sign and values below a plus sign.[2,3]

- Stress urinary incontinence (SUI) is recorded when loss of urine through the urethra is visualized at maximum straining. The absence of urine loss during MR imaging, however, does not preclude the patient experiencing symptoms.[1]

Grading of pelvic organ prolapse in anterior and middle compartments

Anterior compartments

- It has been reported 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.
- The rule of 3 is the recommended grading system in the anterior and middle compartments starting at 1 cm below the PCL[4,5] (see **Box 1**).
- Urethrocele
  - Urethrocele is the prolapse of the female urethra into the vagina.
  - It often occurs with cystoceles; in this case, the term used is *cystourethrocele*.[6–8]
- Cystocele
  - The bladder base, in particular, may descend up to 1 cm below the PCL during straining in continent women and should not be stated as a cystocele.[9]
  - Grading of cystocele
    - Grade 0: up to +1 cm below PCL
    - Grade 1: +1 to +3 cm below PCL
    - Grade 2: +3 to +6 cm below PCL
    - Grade 3: greater than + 6 cm below PCL

Middle compartments

- True prolapse is complete organ eversion; however, the term is commonly used to generically describe any degree of pelvic organ descent.[10–12]

Classification

- Anterior vaginal wall prolapse[13,14]
  - Cystocele
  - Uterine prolapse
- Posterior vaginal wall prolapse[15]
  - Enterocele
  - Rectocele
- Vaginal vault prolapse
  - Vaginal opacification with sterile lubricating gel to enhance visualization of the vaginal apex is strongly advised, if not mandatory.[16]
- Peritoniocele
  - A peritoneocele is a protrusion of the peritoneum between the rectum and vagina that does not contain any abdominal viscera.
  - If a peritoniocele is present, the report should include the content of the peritoneal sac, because clinical examination alone may have shortcomings in identifying the content.[17–19]

Grades of pelvic organ prolapse

- Grade 0: above PCL
- Grade 1; mild: descent less than 3 cm below PCL
- Grade 2; moderate: descent 3 cm to 6 cm below PCL
- Grade 3; severe: descent greater than 6 cm below PCL
- Grade 4: cases of complete uterine prolapse[14]

Posterior compartment

Constipation and obstructed defecation

Definitions and general considerations

- Constipation describes a symptom, not clinical a sign, and is particularly subjective, meaning different things to different people.
- There is considerable individual variation in defining constipation:
  - Some patients concentrate on bowel frequency.
  - Others are more concerned about ease of defecation and stool size/consistency.
- Satisfactory definition of constipation must include both infrequent defecation and difficult evacuation.
  - Infrequent defecation
    - Usually defined as less than 3 bowel movements per week
    - Most likely associated with slow transit time
  - Difficult evacuation
    - Straining at stool is considered abnormal if it occurs for greater than 25% of time spent in lavatory
    - Indicates obstructed defecation
  - Chronic constipation
    - Very common
    - Estimated that 1 in 5 healthy, middle-aged adults have symptoms suggesting functional constipation

Obstructed defecation Outlet obstruction is due either to structural or functional underlying pathology.[20–22]

Structural pathology

1. Rectocele
   - A rectocele is diagnosed as an anterior rectal wall bulge and it is measured during maximum straining and evacuation.
   - 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.
   - Due to the different classification of the pathology in the posterior compartment, it has different grading systems from the anterior and middle compartments.[19]
   - The rule of 2 is recommended for grading the anterior rectal wall bulge in rectoceles (see **Box 1**).
     - Grading
       - Grade 0: no outpouching
       - Grade 1: outpouching up to 2 cm
       - Grade 2: outpouching between 2 cm and 4 cm
       - Grade 3: outpouching greater than 4 cm.[23,24]
     - Anterior rectal wall bulge should be reported as pathological if it is grade II and higher, because grade I rectocele can be observed in approximately 78% to 99% of parous women.
2. Descending perineum syndrome (pelvic floor descent)
   - Defined as descent of ARJ greater than 3 cm below the PCL (see **Fig. 4**B)
   - ARJ is defined by posterior impression of puborectalis muscle at most cranial extent of anal canal.
   - Usually generalized process with associated abnormal descent of middle and anterior pelvic floor compartments
   - Often seen in combination with perineal ballooning, rectocele, intussusception, and impaired evacuation
     - Grading
       - Grade I: between 3 cm and 5 cm below the PCL
       - Grade II: with at least 5 cm[5,25]
3. Intussusception and rectal prolapse
   - Rectal prolapse is a circumferential full-thickness intussusception of the rectal wall with protrusion beyond the anal verge.
   - Intussusception (internal rectal prolapse) is full-thickness prolapse of rectum (see **Fig. 4**D) that does not protrude through the anus; it could be either
     a. Intrarectal intussusceptions that are confined to rectal ampulla
     b. Intra-anal intussusception that extends into anal canal
   - Precautions during MR imaging defeco graphy
     - Intussusception occurs only when rectum collapses during evacuation; therefore, the end of evacuation phase is important to identify intussusception (see **Fig. 4**D).
     - Small intussusceptions of the rectal wall are considered normal findings during defecation, observed in approximately 80% of healthy subjects.[5,26]

Functional pathology

1. Dyskinetic puborectalis
   - Also called *spastic pelvic floor syndrome* or *anismus*
   - Defined as involuntary contraction of the puborectalis muscle with failure to relax, which prevents normal rectal evacuation.

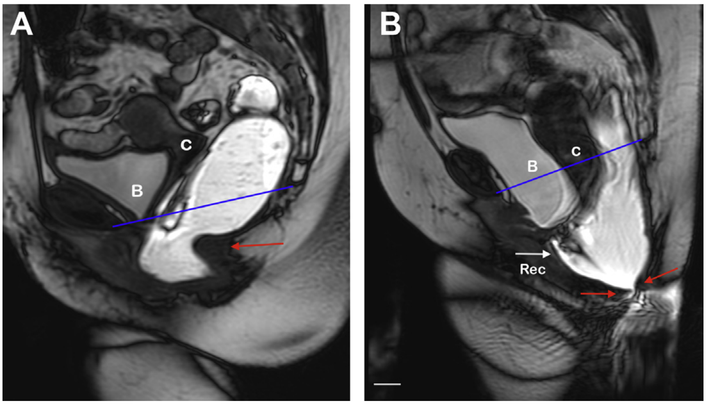

Fig. 5. MR defecography, functional outlet obstruction. (*A*) Paradoxic contraction of puborectalis during defecation (*red arrow*) and relaxed anal sphincter. (*B*) Nonrelaxing or spastic anal sphincter evident by anal canal diameter measuring less than 15 mm (*red arrows*). Note total obliteration of the posterior ARA indicating relaxed puborectalis. There is also grade 3 anterior rectocele. B, bladder; C, cervix; Rec, rectum.

- Not an uncommon cause of obstructed defecation and frequently overlooked at imaging
- Highly likely that many surgical failures occur in patients treated for rectocele because underlying anismus was not recognized
- Diagnostic criteria
  - Normal anorectal angle (ARA)
    - The ARA is the angle enclosed between a line plotted along the posterior rectal wall and the second line is plotted along the central axis of the anal canal on sagittal plane at rest, squeezing and maximum straining.
    - The change of the ARA during evacuation compared with 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.
    - It is recommended to report that the ARA showed the normal changes at different maneuvers rather than the absolute value of the ARA angle, because the literature presents a widespread of normal reference values.
  - MR findings in spastic pelvic floor syndrome
    - Failure of ARA to open
    - Persistent or exaggerated puborectal impression on posterior aspect of ARJ
    - Lack of descent of pelvic floor during defecation
    - Long interval between opening of anal canal and start of defecation
    - Most pertinent finding for diagnosis of anismus is prolonged and incomplete evacuation; using 120 mL of rectal contrast, evacuation times of more than 30 seconds accurately predict this functional disorder (**Fig. 5**A).[5,25,27,28]

2. Spastic anal sphincter contraction
   - Also known as spasmodic contraction of anal sphincter or anal sphincter achalasia
   - Under normal circumstances, expansion of rectum or rectosigmoid causes internal anal sphincter (IAS) reflex relaxation.
   - Patients usually present with painless constipation associated with dry stools.
   - Resting anal pressure is significantly higher than normal on manometry.
   - MR findings
     - Anal canal is not open with dilatation of rectum.
     - Resting dilated rectum or even giant rectum
     - MR defecography is mandatory to show rate of evacuation (see **Fig. 5**B).
     - Static MR should show normal anal sphincter muscle complex to exclude IAS hypertrophy.[20]

Structural and functional pathology

Solitary rectal ulcer syndrome

- Well-recognized diagnosis that describes a combination of rectal prolapse and functional pelvic floor abnormality
- MR findings
  - Usually the imaging findings in these patients are a combination of rectal prolapse and puborectalis dyskinesia.
- Pathogenesis: incompletely understood
  - Prolapsed rectal mucosa is forced downward due to pressures generated during defecation and is compressed by force of paradoxic puborectalis contraction, leading to mucosal ischemia and ulceration secondary to repeated straining.
  - Proctoscopy usually reveals rectal inflammationand ulceration and is accompanied by specific histopathological changes within prolapsing mucosa.[5]

Analysis of Dynamic Cine MR Images at Maximum Straining

- Analysis of the dynamic MR images is dedicated to supportive measurements.
  - These are 5 measurements of supporting structures measured in the 3 orthogonal plane (**Fig. 6**).
  - They are all considered to reflect the status and the weakness of the levator ani.
  - They have proved of value in identification of pelvic floor laxity and quantification of the degree of weakness. They also are useful for follow-up assessment.

Dynamic Sagittal Cine MR images

H-line

- Measured from inferior aspect of pubic symphysis to ARJ
- Length of H-line: 5.8 cm

M-line

- Drawn as perpendicular line from PCL to posterior aspect of H-line
- Length of M-line: 1.3 cm $\pm$ 0.5 SD

Levator plate angle

- Levator plate angle (LPA) is drawn between axis of levator plate and PCL.
- LPA: 11.7° $\pm$ 4.8 SD

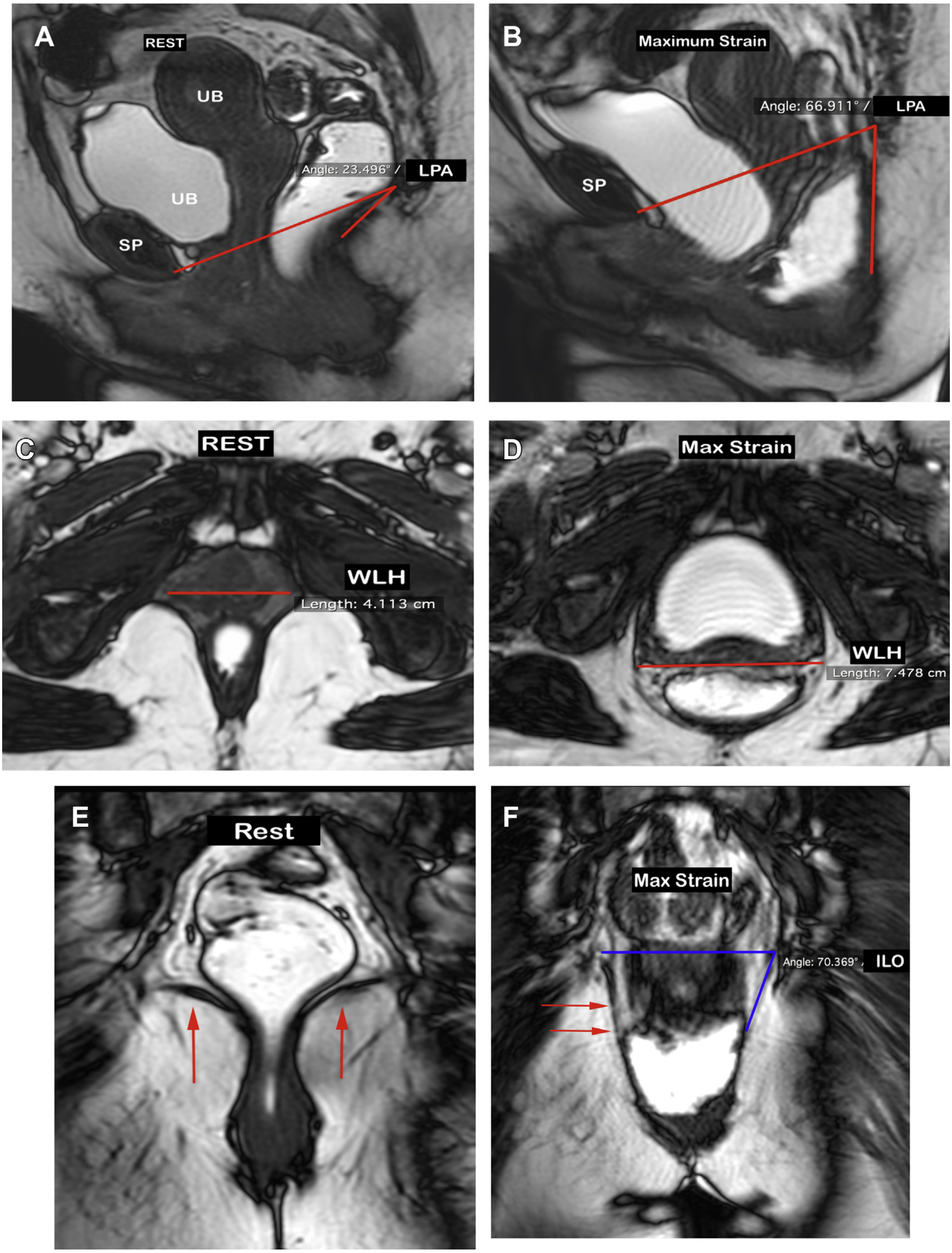

Fig. 6. Dynamic Cine MR images show how to quantify the pelvic floor laxity using the supportive measurements. (*A, B*) Dynamic BFFE MR image of patient with obstructed defection in the mid-sagittal plane at rest (*A*) during maximum straining (*B*) (*A*) shows how to plot the LPA which is enclosed between the levator plate muscle and the PCL. (*B*) Shows marked weakness of the levator plate indicated by LPA measuring 66.9°. (*C, D*) Axial BFFE MR images at rest (*C*), during maximum straining (*D*). (*C*) Shows the level where the WLH is measured at the most inferior point of symphysis pubis. The width of the levator hiatus is enclosed between the puborectalis muscle sling. (*D*) The WLH measures 7.5 cm indicating muscle weakness; the transverse diameter of the muscle reflects the extent of its ballooning and weakness during straining. (*E, F*) Coronal BFFE MR images, at rest (*E*), during maximum straining

Dynamic Axial Cine MR images

- Width of levator hiatus (WLH)
  - Measured on axial image at most inferior point of symphysis pubis during maximum straining
  - Distance enclosed between puborectalis muscle slings
  - WLH rarely exceeds 4.5 cm ± 0.7 SD in women with intact pelvic floor.

Dynamic Coronal Cine MR images

Iliococcygeus angle (ILCA)

- Measured on coronal posterior image at level of anal canal during maximum straining
- Angle defined by line plotted along iliococcygeus muscle sling and transverse plane of pelvis
- Mean of ILCA is reported to be 33.4° ± 8.2 SD in women with intact pelvic floor.

Table 1 gives an overview of the published reference values for quantitative MR measurements of the pelvic floor.

Analysis of the Static MR Images

- It is important to establish the new era of the added value of the static MR image analysis after adapting the new functional 3-part pelvic supporting systems approach, on which the new insight of the defect-specific approach of patient management was established.[9,15]
- Analysis of static images is based on thorough examination of the pelvic organ supporting elements and characterizations of the defects in each of its components: the urethral supporting system, the vaginal supporting system, and the anal sphincter complex.

Urethral Supporting System

Scrutiny of the urethral support system involves imaging of the 1) urethral ligaments, 2) endopelvic fascia (level III fascial support), and 3) the puborectalis muscle[9] (**Fig. 7**).

Urethral ligaments

MR imaging of normal urethral ligaments

- Meticulous cadaveric dissection identified *ventral and dorsal* urethral ligaments on axial T2-weighted turbo spin-echo sequences. The MR imaging findings in volunteers correlated with the MR imaging and gross anatomic findings in cadavers.[9,29]

  The ventral urethral ligaments include
  - The pubourethral (PUL) ligaments, which were found to consist of a group of 3 distinct but related ligaments: proximal PUL (PPUL), intermediate PUL (IPUL), and distal PUL (DPUL). All have a similar anteroposterior orientation running from the ventral urethral surface to the pubic bone. Functionally, the most important is the PPUL, which contributes to suspension of anterior urethral region and appears to counteract opening of posterior vesicourethral angle during stress. The DPUL supports and fixes the distal urethra.
  - The periurethral ligament and paraurethral ligaments that link the proximal urethra to puborectal sling [29,30]

  Dorsal Urethral ligament:
  - A sling-like ligament, the suburethral ligament, was identified along the dorsal aspect of the urethra. It runs posterior to urethra and has a distinct plane of cleavage from the anterior vaginal wall. It extends anterolaterally to pelvic sidewalls forming a suburethral sling. To the best of the author's knowledge, this ligament has not been previously reported.[29]
- The PPUL, periurethral, paraurethral, and suburethral ligaments had visibility scores of 3 (moderately visible) or 4 (easily visible) on MR imaging in 47%, 65%, 47%, and 53% of volunteers, respectively.[29]

(*F*). (*E*) Shows how to the plot the iliococcygeus angle, it is measured between one of the iliococcygeus muscle slings (*red arrows* in *E*) and the transverse plane of the pelvis in posterior coronal images at the level of the anal canal. The ILCA reflects the degree of descent and movement of the muscle. (*F*) Shows the abnormal elongation of the iliococcygeus muscle slings during maximum straining (*double red arrows*). The iliococcygeus muscle should move downward during straining with no excessive caudal descent or elongation. The dynamic cine MR images of this patient in the 3 orthogonal planes during maximum straining show gross evidences of marked pelvic floor muscle weakness. BFFE, Balanced Fast Field Echo; ILO, Iliococcygeous; LPA, Levator Plate Angle; Max, maximum; PCL, pubococcygeal line; SP, symphysis pubis; UB, urinary bladder; WLH, width of levator hiatus.

MR imaging of urethral ligaments abnormalities

- On images obtained in the axial plane, abnormalities are classified as follows:
  - Distortion, when internal architectural changes with waviness of the ligaments are seen
  - Defects, defined by discontinuity of the ligament with visualization of the torn parts [30–32]

Level III endopelvic fascial support

MR imaging of normal level III Fascia

- On static axial T2 weighted MR images, level III fascia supports mid urethra and maintains the following relationships:
  - a) Central positioning of mid urethra
  - b) Small, symmetric-appearing space of Retzius
  - c) Preserved H-shaped vagina
- Functionally, level III fascia provides urethral support and has special importance to urinary continence because the endopelvic fascia at this level is better developed than at more superior levels; therefore, level III provides better support for vesical neck than higher levels. Loss of this normal support at vesical neck may result in SUI.

MR imaging of level III fascial defect

- Level III fascial defect is assessed at the level of urethra and bladder neck.
- The defect is recognizable by the drooping mustache sign, which is caused by the fat in the prevesical space against the bilateral sagging of the detached lower third of the anterior vaginal wall from the arcus tendineus fascia pelvis.[29]

Puborectalis muscle

MRI of the puborectalis muscle

- On the static axial T2 weighted MR images the puborectalis is seen as a sling encasing urethra, vagina, and rectum. It has no attachment to bladder neck but its anterior portion lies in close proximity to mid and lower urethra
- Functionally it is hypothesized that weakness of puborectalis contributes to problems with urinary continence

MRI of puborectal muscle defect

- Muscle defect is recognizable by disruption of the normal symmetrical appearance of the muscle sling or of its attachment to the symphysis pubis

Vaginal Supporting System

Vaginal supporting structures include: 1) Level I and II endopelvic fascia and 2) the iliococcygeus muscle (**Fig. 8**).[33–35]

Table 1
Overview of the published reference values for quantitative MR measurements of the pelvic floor

Parameters	Reference Value ± SD
Anterior compartment according to PCL	
Bladder base position at rest	−2.3 ± 0.46 cm
Bladder base position during straining	0.81 ± 1.11 cm
Middle compartment according to PCL	
Anterior cervical lip position at rest	4.31 ± 0.78 cm
Anterior cervical lip position during straining	−0.79 ± 1.65 cm
Posterior compartment	
Anterior bulge of the rectal wall during straining (rectocele)	2.6 ± 0.6 cm
ARJ at rest	≤3 cm below the PCL
ARJ during squeezing	Elevation of ARJ
ARJ during straining	2.99 ± 1.03 cm
ARA at rest	85°–95°
ARA during squeezing	71° sharpening of 10°–15°
ARA during straining or defecation	103° 15°–25° more obtuse
Measurements for quantification of the pelvic floor laxity	
H-line during straining	5.8 ± 0.5 cm
M-line during straining	1.3 ± 0.5 cm
LPA during straining	11.7 ± 4.8°
ILCA at rest	20.9 ± 3.5°
ILCA during straining	33.4 ± 8.2°
Transverse diameter of levator hiatus at rest	3.3 ± 0.4 cm
Transverse diameter of levator hiatus during straining	4.5 ± 0.7 cm

Data from [El Sayed RF, Alt CD, Maccioni F, Meissnitzer M, Masselli G, Manganaro L, Vinci V, Weishaupt D. Magnetic resonance imaging of pelvic floor dysfunction - joint recommendations of the ESUR and ESGAR Pelvic Floor Working Group. On Behalf of ESUR and ESGAR Pelvic Floor Working Group. European Radiology,2017; 27(5):2067–2085. 10.1007/s00330-016-4471-7].

Level I and II endopelvic fascia

MRI of normal level I and II Fascia

- On static axial T2 weighted MR images, level I landmark is at the level of the funds of the

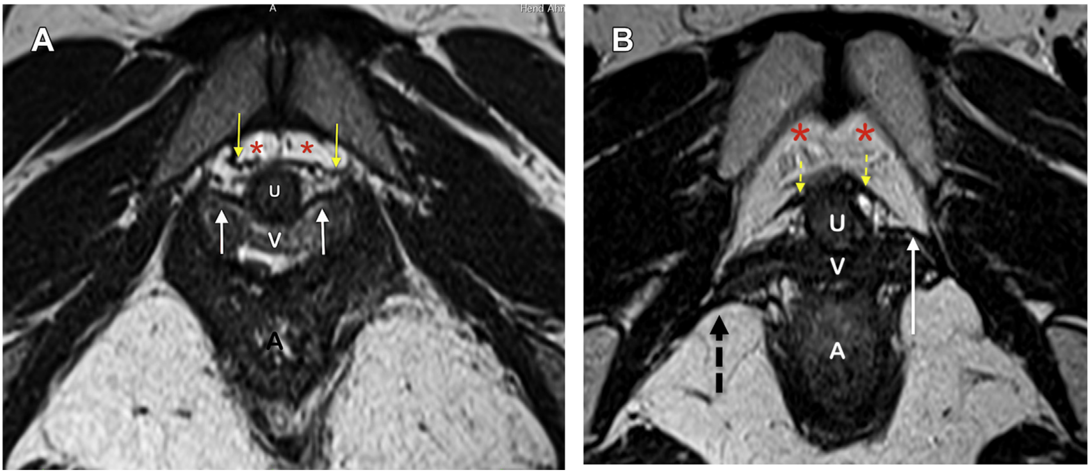

Fig. 7. Static MR image of normal and abnormal urethral supporting system. (*A*) Axial T2-weighted MR image of a woman with a normal urethral support system shows the suburethral ligament (*white arrows*), periurethral ligament (*yellow arrows*), small symmetric Retzius space (*asterisks*) and the normal insertion of the puborectalis muscle on to the posterior pubic symphysis, some anteromedial fibers attach to the vagina and help support the urethrovesical neck. (*B*) Axial T2-weighted MR image in a woman with SUI and history of childbirth perineal tear and forceps delivery, the MR image shows complex multiple urethral supporting system injuries that include bilateral detachment of the suburethral ligament. The ligament on the right side is subluxed backward (*white arrow*) and the periurethral ligament (*yellow arrows*). Also note the abnormal configuration of the Retzius space (drooping mustache) (*asterisks*), with loss of the H-shaped vagina (V), indicating disruption of level III endopelvic fascia. The most severe injury detected is the bilateral detachment of the puborectalis muscle slings from the pubic bone (*black dashed arrow*). It is important to report all of these findings, because it would affect treatment planning. A, anal canal; U, Urethra; V, vagina.

bladder. Level II corresponds to the middle portion of vagina, and is assessed at the bladder base.
- Normally attached lateral vaginal support results in straight posterior wall of urinary bladder.

MRI of Level I and II fascial defect

- Paravaginal defect:
  - In the axial plane, a paravaginal defect in the fascia is visualized as sagging of the fluid-filled posterior urinary bladder wall, caused by the detachment of the vaginal supporting fascia from the lateral pelvic wall, known as the saddlebags sign.
- Central defect
  - A central defect is indicated by sagging of the central part of the urinary bladder posterior wall.

Iliococcygeus muscle

MRI of the Iliococcygeus muscle

- On static coronal T2 weighted MR images, normally attached iliococcygeus muscle has dome-shaped appearance at rest with upward convexity. With straining, muscle becomes horizontal with basin-shaped configuration.
- Functionally, it is hypothesized that weakness of iliococcygeus muscle contributes to vaginal prolapse.

MRI of Iliococcygeus muscle defect

- In the coronal plane, the iliococcygeus muscle is assessed for loss of the normal symmetrical appearance of its muscle slings or defect and/or disruption of its attachment to the obturator internus muscle.[35]

Anal Sphincter Complex

MR imaging of normal anal sphincter complex

- On axial T2-weighted balanced fast field echo (BFFE) images, the consecutive layers of the anal sphincter from the lumen outward include (Fig. 9A)
  - The innermost high signal intensity layer (the combined mucosa and submucosa)
  - The low signal intensity layer (the submucosal smooth muscle)
  - The IAS (of homogenous intermediate to high signal intensity)
  - The deep external anal sphincter (EAS) (of low signal to intermediate signal intensity)
- IAS
  - Composed of smooth muscle fibers
  - It measures 2-mm to 3-mm thickness with progressive increase in thickness with advancing age
  - Functional correlation

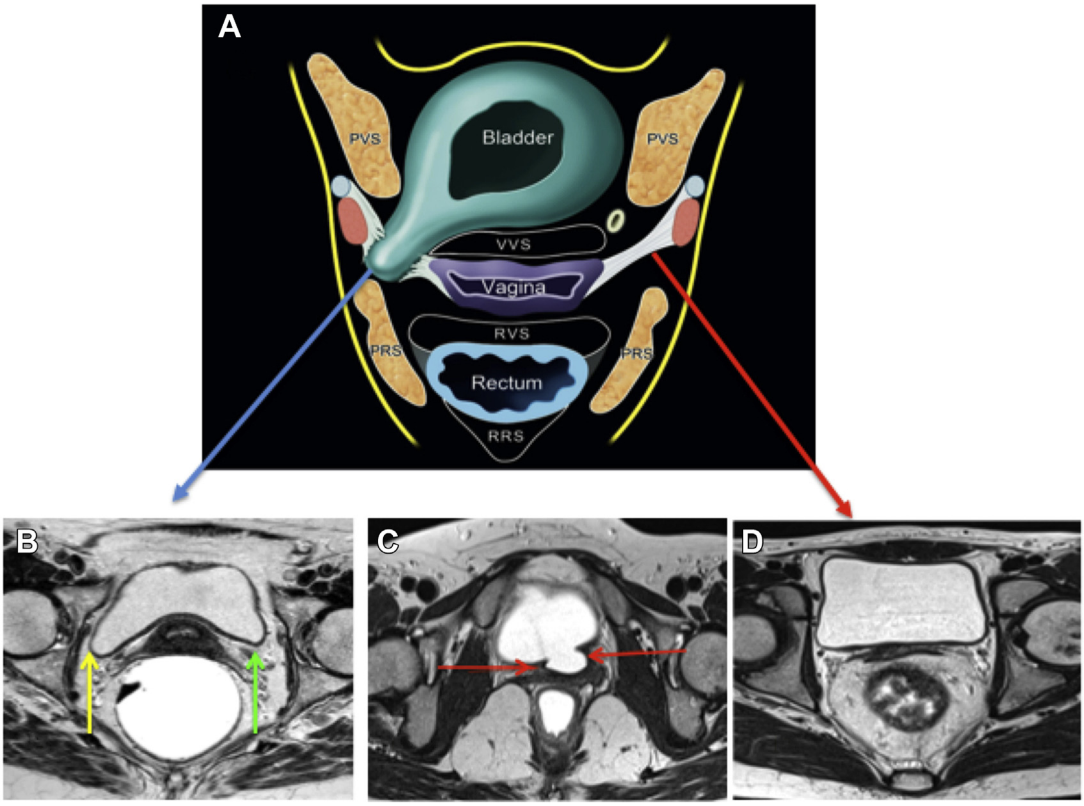

Fig. 8. Static MR image of normal and abnormal vaginal support system. (*A*) In this graphic, there is right-sided endopelvic fascial detachment causing a paravaginal defect. Because of the defective support mechanism, there is sagging of the right posterolateral wall of the urinary bladder (*blue arrow*) to fill the resulting defect. On the left side, however, the vagina is suspended between the 2 ATFP ligaments by lateral fascial extensions. These lateral extensions fuse with the pubocervical fascia superiorly and the rectovaginal fascia inferiorly. Pelvic organs are separated from each other by spaces that allow organs to move independently from each other. RRS, retrorectal space; PRS, pararectal space or ischiorectal fossa; PVS, paravesical space; VVS, vesicovaginal space; RVS, rectovaginal space. (*B*) Axial T2-weighted MR image obtained in a woman with POP shows the consequences of ATFP detachment with sagging of the posterior vaginal wall (saddlebags sign) (*green arrow*). It is asymmetric with the larger defect on the right (*yellow arrow*). The degree of sagging of the bladder wall corresponds to the size of the fascial defect. This may help determine the appropriate surgical approach: surgical repair of fascia, if the defect is small, versus use of mesh, if the defect is large. (*C*) Axial T2-weighted MR image obtained in a woman with POP shows bulging of the central part of the posterior urinary bladder wall. The red arrows point to the site of defect, which results in this type of bulge. In a central defect, the lateral attachment of the fascia to the ATFP is intact with stretching and redundancy of the central pubocervical fascia. Because a central defect is not due to fascial tear but rather fascial stretching, the bladder wall bulging usually is small compared with paravaginal defects. (*D*) Axial T2-weighted MR image shows normal level II endopelvic fasciae, the landmark to define level II is the midvagina at the level of the bladder base. It is important to emphasize that although injury of urethral ligaments can be visualized in some cases, the fascia is not; however, the integrity of the fascia can be inferred by the appearance of surrounding organs. The posterior bladder wall is seen as a straight line, indicating that level II endopelvic fascia is intact as indicated by the red arrow in A. ATFP, arcus tendineus fascia pelvis. ([*A*] *From* El Sayed RF. Overview of middle compartment. In: Shaaban AM, editor. Diagnostic Imaging: Gynecology, 2nd edition. Elsevier, Amirsys; 2015. p. 8/68–8/79; with permission.)

    - Maintains anal sphincter resting tone (contributes up to 85% of maximal anal resting pressure)
- Intersphincteric space
    - Intersphincteric space is a thin, fat-containing space between the IAS and outer striated muscles.
    - It contains longitudinal smooth muscle layer
- EAS

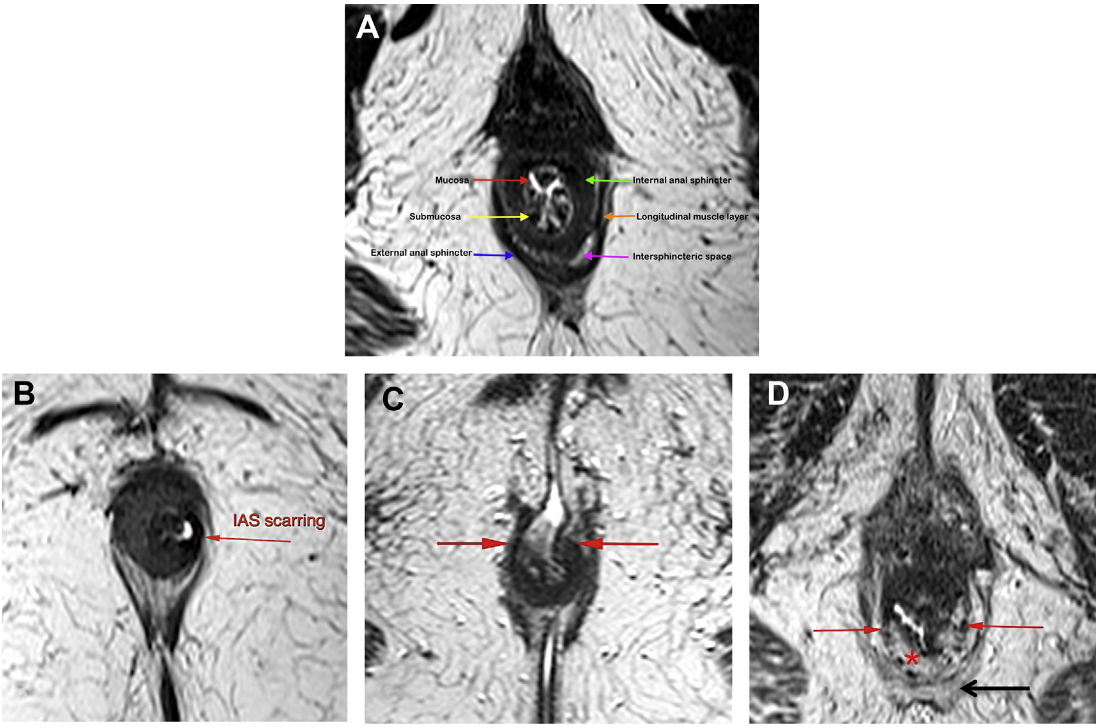

Fig. 9. Static MR image of normal and pattern of injury of the anal sphincter complex (ASC). (*A*) The ASC shows 4 layers of different signal intensity. The mucosa is the thin, folded inner layer of high signal intensity. The submucosa is of low signal intensity and has a folded internal contour and smooth outer contour. The internal anal sphincter (IAS) appears as a homogeneous isointense to hyperintense (relative to the striated muscle) smooth circular band surrounding the anal canal. The longitudinal smooth muscle layer and the fatty component of the intersphincteric space are more prominent at the distal part of the deep EAS (DEAS). (*B–D*) are all axial oblique T2-weighted MR images in 3 different patients presenting with fecal incontinence each patient has different site, side, and type of anal sphincter complex injury (*B*) shows thinning and low signal intensity of the left lateral aspect of the IAS, indicating fibrosis and scarring. (*C*) Shows discontinuity of the DEAS and IAS muscles ring (*red arrows*). A muscle defect should be described according to clock face; this is an anterior defect extending from the 10 o'clock to 2 o'clock positions. (*D*) MR image of a complex case of anal sphincter muscle injury from inner to outer; there is extensive atrophy of the of IAS posteriorly (*red arrows*) compared with its anterior aspect. Loss of muscle is more on the right side, with subsequent shift of the lumen posterior and to the right. Wide intersphincteric space (*asterisk*) with thinning of the longitudinal smooth muscle plus fatty degeneration of the DEAS (*black arrow*).

- ◦ Cylindrical striated muscle layer under voluntary control
- ◦ Predominantly composed of slow-twitch muscle fibers, capable of prolonged contraction
- ◦ The EAS measures 2.7 cm in height (shorter anteriorly in women, approximately 1.5 cm).
- ◦ Nerve supply: inferior rectal branch of pudendal nerve (S2, S3) and perineal branch of S4
- ◦ Functional correlation
  - ▪ Contributes 15% to 20% of resting anal tone
  - ▪ Voluntary control of sphincter complex
  - ▪ Major role in continence control, such as during intra-abdominal pressure or to defer defecation[36]

MR imaging of anal sphincter injury

- Lesions of the anal sphincter are classified according to 1) the muscle injured and 2) the type of lesion (see **Figs. 9**B–D):
  - ◦ According to the muscle injured:
    - ▪ The internal anal sphincter
    - ▪ The external anal sphincter
  - ◦ According to lesion types:
    - ▪ A sphincteric defect is defined as discontinuity of the muscle ring.
    - ▪ Scarring is defined as a low signal intensity deformation of the normal pattern of the muscle layer.[37,38]
    - ▪ Fragmentation and fraying of the muscle fiber this is usually seen in motor car injury, explosion or falling in sitting position.

WHAT THE REFERRING PHYSICIAN NEEDS TO KNOW

Magnitude of Pelvic Floor Dysfunction, Current Treatment, and Reported Recurrence Rate

The most prevalent forms of dysfunction are urinary incontinence, POP, and anal incontinence, all of which affect women 3 times to 7 times more often than men, at an estimated incidence of 23.7% of women in the United States.[39] Approximately 10% to 20% of these patients are symptomatic, and, by the age of 70 years, an estimated 1 in 10 undergoes pelvic floor surgical repair. It also is expected that there will be an increased demand for imaging this population.

Although multiple factors predispose for PFD, the precise pathologic mechanism is poorly understood, and treatment often is started regardless of the specific anatomic lesion involved. This situation was reflected in a study by Olsen and colleagues,[40] who reported that 29% of the procedures performed for incontinence and prolapse were reoperations, suggesting the need for advances in the treatment of these disorders. Clinicians[35,40,41] stated, however, that such advancement in treatment plans could be achieved based only on advanced imaging either in resolution and/or image interpretation and analysis.

Clinician's Requirements for Treatment Advancement

- Several clinicians who specialize in the field of PFD have stated that a "wide variety of surgical procedures have been used, with several based on weak scientific evidence."[42] Other studies[32,35] reported that PFD, such as SUI, results from specific damage to muscles, fascial structures, and nerves of the pelvic floor. Hence, it is required to define the damage occurring in each element of the continence mechanisms, to be able to precisely select treatment plans that are based on the abnormality found in individual patients. They emphasized on the value of switching from the current empirical treatment approach, which is based on a symptom complex that assigns a woman who says she has urine leakage to treatment of SUI to a therapeutic model that investigates and is based on the specific neuromuscular and fascial defect that results in the symptom complex.
- What had long been missing was a tool for accurately defining the anatomic and structural abnormalities in each patient.

NEW HORIZONS AND RADIOLOGIST'S ROLE

Recent advancements in imaging of the anatomic structures with MRI has allowed superior soft tissue resolution and consequently provided a more realistic glimpse of the structural relationships in vivo.[43,44] Based on this imaging advancements several new concepts in imaging, analysis, interpretation, and reporting MRI of pelvic floor had evolved.

Correlation Between Static and Dynamic MR Images

- The terms, *individualized*, *defect-specific treatment approach*, and *combined analysis of static and dynamic MR images*, have been adopted in the author's institutional Cairo University MRI Pelvic Floor Center of Excellency and Research Lab based on original research work, which documented the presence of specific defect in each individual patient, even if 2 patients present with the same symptoms.[15]
- The basis of this approach is simultaneous analysis of findings obtained from static and dynamic MR images of the same patient with correlation with the data obtained to determine whether a particular anatomic defect in the pelvic supporting system detected on static images is associated with a specific dysfunction on dynamic images. The most marked type of defect is reported as the predominant defect **Fig. 10**
- The author recently developed correlative analytical approach that converts static and dynamic MR imaging from 2 separate types of images into an integrated system that can more precisely identify the underlying anatomic defect responsible for symptoms in individual patients with PFD, even allowing differentiation of the underlying anatomic defect when any 2 patients have the same symptoms. This type of information, when reported by a radiologist to a clinician, allows clinicians to contemplate a holistic view of the pelvic floor and gives insight into the diagnosis of these complex disorders.[45]
- To make it easy for radiologists to use this approach and to increase surgeons' comprehension of the overall findings, an MR imaging reporting template is shown in (**Fig. 11**). In this template, all MR findings are presented in a schematic form that synthesizes data for ease of use by clinicians from several different

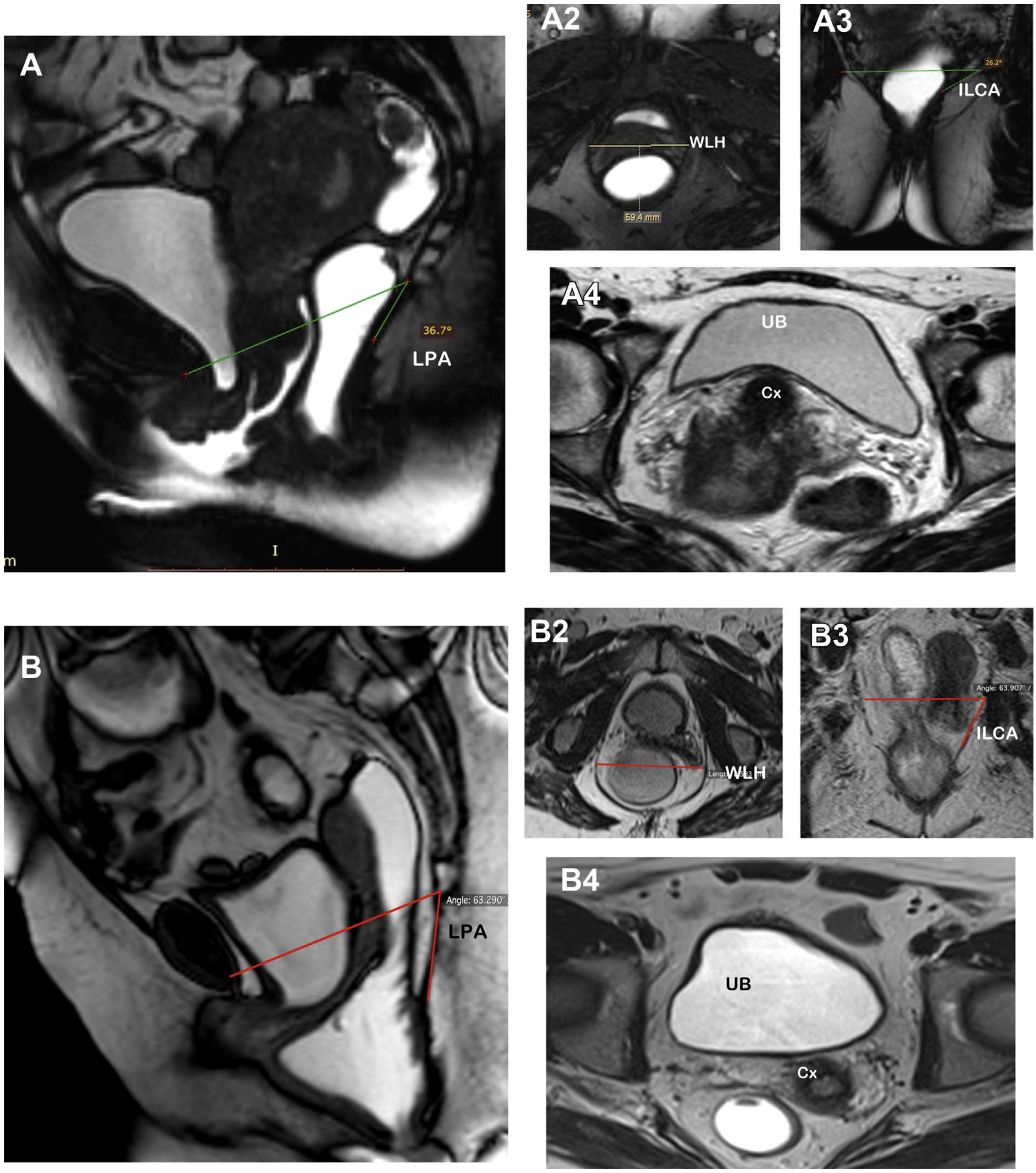

Fig. 10. Correlative analytic approach and how to apply it. (*A*) and (*B*) are dynamic MR images of 2 different patients during evacuation, both patients their MR images show 3 compartments POP but of different grades. (*A*) Shows grade I cystocele, uterine descent and abnormal Ano-rectal junction descent (ARJD). (*B*) shows grade II cystocele, uterine descent, moderate rectocele and abnormal ARJD. The clinicians can diagnose most of these findings if not all of them. How to apply the correlative approach: the radiologist should start with the dynamic cine MR image in the three orthogonal planes to evaluate the degree of pelvic floor muscle weakness. Images A, A2, A3 show mild degree of pelvic floor muscle weakness indicated by the LPA measuring 36.7°, WLH 5.9 cm, and ILCA angle of 26.3° respectively. The radiologist should then assess the static image (A4); which shows bilateral level I endopelvic fascial defect larger on the left side indicated by the deeper sagging of the UB wall on the left side compared to its right side. The final step is correlation between the dynamic and the static MR findings, which reveals that the POP is due to the large fascial defects in (A4) compared with the moderate sagging of the levator plate in (*A*). This patient is candidate for surgical fascial repair. Applying the same steps for reporting the MR images of the second patient (*B*) reveals the LPA of 63.2°, WLH measures 8.59 cm in (B1), and ILCA of 63.9 degree in (B3). The corresponding axial T2-weighted image (B4) at level II endopelvic fascia reveals almost intact fascia reflected by the straight posterior UB wall. In this patient despite that the MR images showed the same POP as the first patient; however, correlation between dynamic and static MR findings shows that the more advanced degree of muscle weakness compared with the fascial status indicates that muscle weakness is the main factor responsible for POP. Physiotherapy in such case is mandatory, not surgical repair of the fascia. Cx, cervix; ILCA, Iliococcygeus angle; LPA, levator plate angle; POP, pelvic organ prolapse; UB, urinary bladder; WLH, width of levator hiatus.

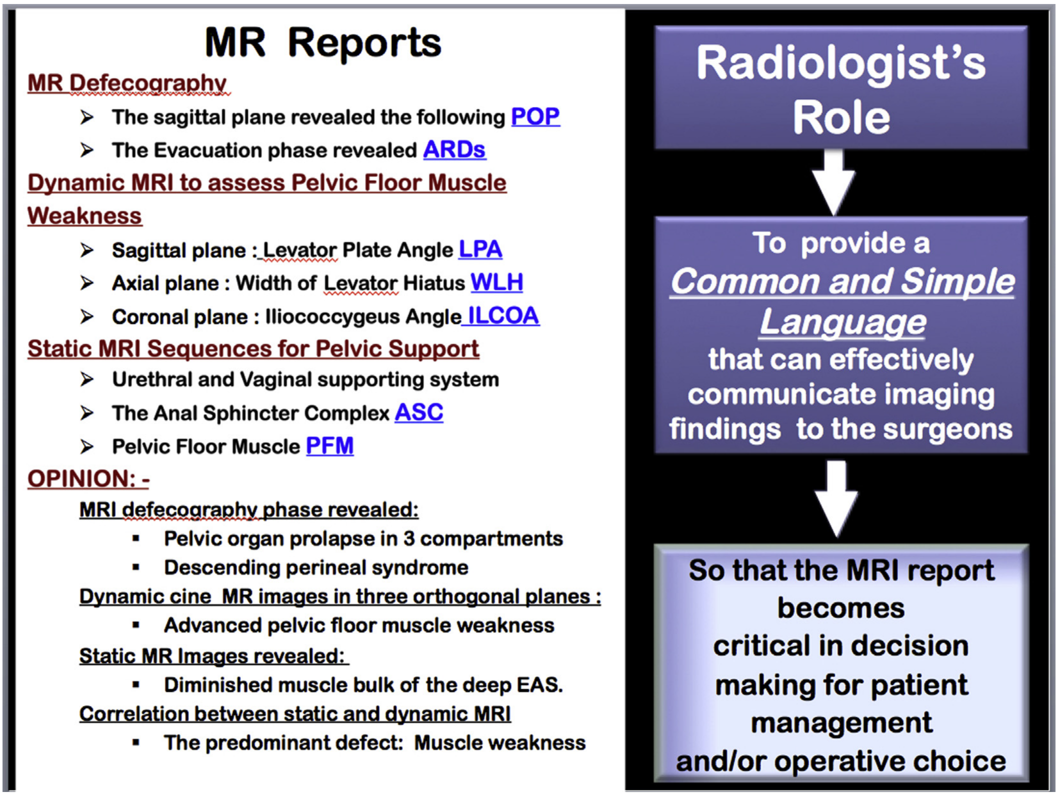

Fig. 11. A guide to radiologists on how to report the MR imaging findings systematically and comprehensively on both the static and dynamic images, using a recently developed integrated MR imaging analytical approach from a purely functional point of view that could enhance radiologists' interaction with clinicians and bridges the gap between radiology and surgery, consequently both of them can share the management decisions in each patient. ARDs, ano rectal junction descent; EAS, external anal sphincter; POP, pelvic organ prolapse.

subspecialties. A diagnostic algorithm (Fig. 12) can be used to help tailor imaging according to the patient's symptoms and the clinical findings.[45]

Three-axis Perineal Evaluation

Beco and Mouchel[46] have defined a 3-axis perineal evaluation (TAPE) approach, which they call *perineology* (Fig. 13).

Concept

The investigators recommended TAPE in the assessment of a patient presenting with PFD, even if the main symptom is apparently related to 1 of the 3 pelvic compartments. This is because, anatomically, each organ system in the pelvic floor—urinary, genital, and intestinal—traverses the pelvis and exits through its own orifice. Thus, these systems are intricately related in function and structural support, which is why, among patients with PFD, 95% have abnormalities in all the 3 pelvic compartments, even if a patient is presenting with symptoms that involve only 1 compartment.[46] Therefore, disorders of each of these components should be evaluated in light of their impact on the function of the surrounding structures and the functional anatomy of the pelvic floor. Hence, the investigators believed that physicians treating women with PFD should adopt a global approach, taking into consideration all the 3 pelvic compartments, and must clearly understand the anatomy of the pelvis and the associated urinary, genital, and anorectal abnormalities. This calls for noninvasive preoperative and postoperative imaging methods that can depict the 3 pelvic compartments simultaneously. MR imaging is ideal for this purpose.[45]

Aim

The aim of perineology is anatomic restoration with respect to biomechanics and physiology, so that each defect must be corrected without inducing trouble on other levels, which is why

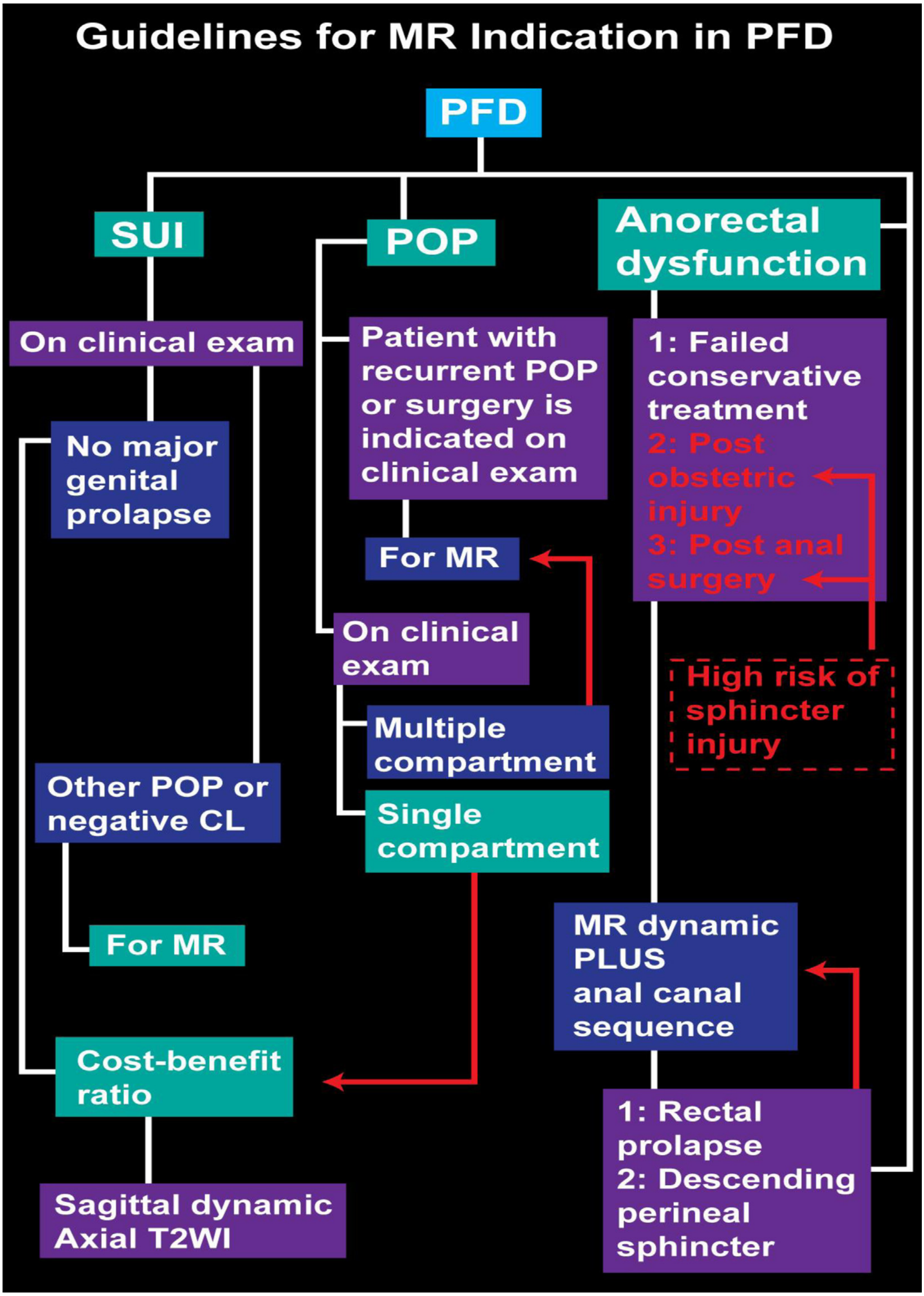

Fig. 12. This diagnostic algorithm can be used as a guideline to help tailor imaging according to a patient's symptoms and the clinical findings. The radiologist should be aware that defects in multiple compartments are present in 90% of patients with PFD. It is essential to consider all 3 pelvic compartments as an integrated unit. (*From* El Sayed RF. Multicompartmental imaging. In: Shaaban AM, editor. Diagnostic Imaging: Gynecology, 2nd edition. Elsevier, Amirsys; 2015. p. 8/88–8/101; with permission.)

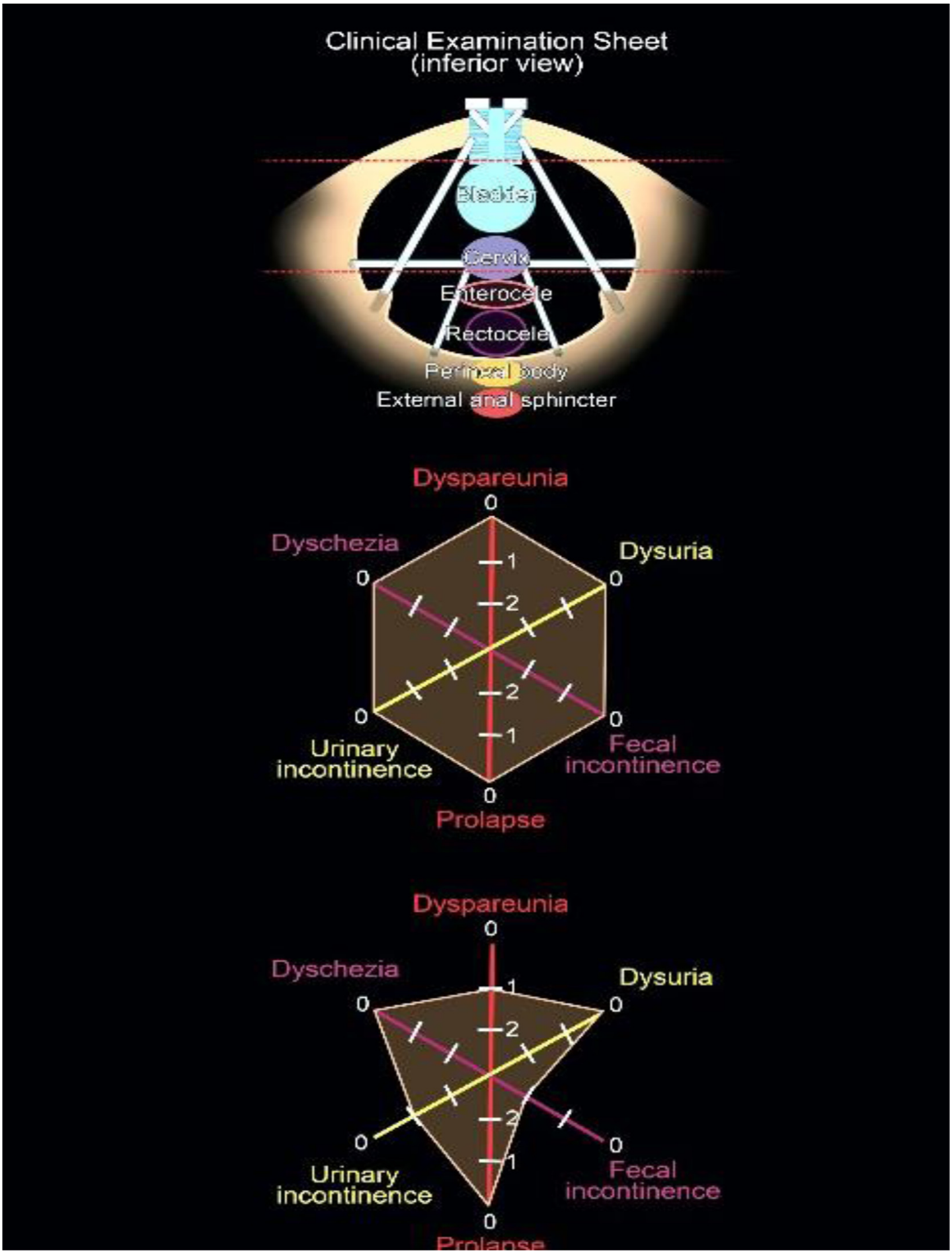

Fig. 13. (*Top*) This clinical examination sheet can be used to record examination findings. Each structure is assessed and noted, with the degree of POP recorded. (*Middle*) The TAPE is a plot to graphically represent the functional state of the perineum. Each of the 3 axes reflects a spectrum of related perineal pathologies. The gynecologic axis is in red, encompassing dyspareunia and prolapse. The urologic axis is in yellow, representing dysuria and urinary incontinence. The coloproctologic axis is in pink, reflecting dyschezia and fecal incontinence. For each axis, there are 3 levels of severity: 0 = not present, 1 = mild, and 2 = severe. (*Bottom*) This TAPE is of a patient with problems on all 3 axes: mild dyspareunia, severe fecal incontinence, and mild urinary incontinence. Knowing the physical examination findings and patient symptoms helps the radiologist tailor the MR examination and address the specific complaint. (*From* El Sayed RF. Multicompartmental imaging. In: Shaaban AM, editor. Diagnostic Imaging: Gynecology, 2nd edition. Elsevier, Amirsys; 2015. p. 8/88–8/101; with permission.)

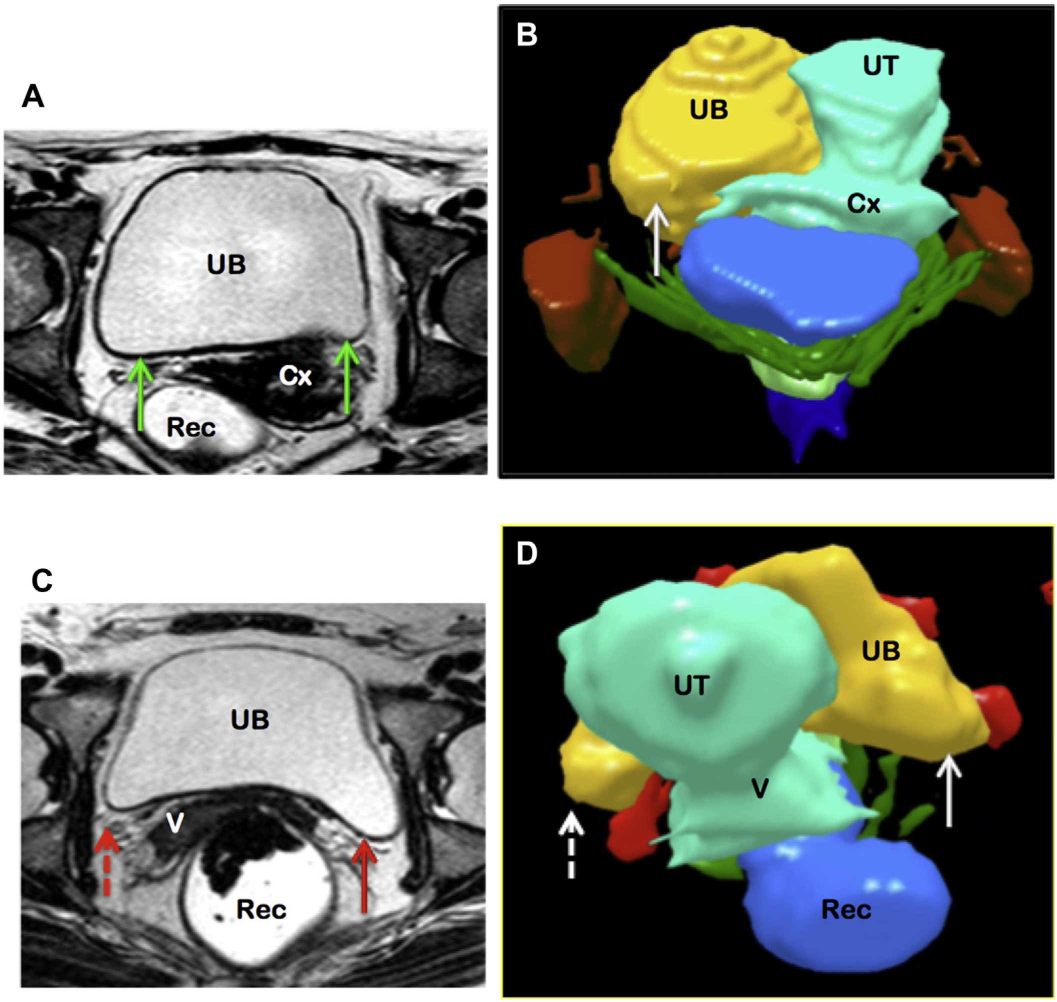

Fig. 14. 3D- Modeling of the predominant pelvic supporting system defect. (*A*) Static axial T2WI of a normal healthy volunteer with no pelvic floor dysfunction shows straight posterior urinary bladder wall indicating normal level I endopelvic fascia (*green arrows*). (*B*) The corresponding 3-D reconstruction post imaging processing using manual segmentation of sequential source images, shows that the intact fascia is reflected on the urinary bladder posterior wall (*white arrow*) in the 3D model same as in the 2D MR image. (*C*) Static Axial T2W MR image of female patient with POP shows sagging of the posterior urinary bladder wall, to fill the gap caused by detachment of the pubocervical fascia from the lateral pelvic wall (*red arrows*). (*D*) Is the corresponding 3-D modeling of the MR image effectively portraying the sagging urinary bladder (*white arrows*). Introducing the 3D- advanced post imaging processing modeling in our institution and research lab and its outcome has impressively enhanced the preoperative interpretation of the fascial defect by the surgeons. For example in this case the size of the defects on the right side (*dashed arrows* in *C* and *D*) are identical if compared to the larger defect on the left side solid (*arrows* in *C* and *D*) provide the surgeons with vivid information about the structural damage that will need to be repaired during the operation. To our knowledge applying this 3D modeling specifically on pelvic supporting endopelvic fascia has not been reported before. Cx, cervix; Rec, rectum; UB, urinary bladder; UT, uterus; V, vagina.

this approach is the result of the fusion between the disciplines of urogynecology and coloproctology. Combining TAPE with the author's recently developed integrated MR analytical approach puts a complete assessment of the patient, both clinically and radiologically, within reach of both radiologists and clinicians.[46]

Three-dimensional Modeling MR Imaging of the Functional 3-part Pelvic Supporting Systems

Concept

MR imaging is the imaging gold standard in PFD. Reducing rate of recurrence depend on accurate preoperative assessment. Despite the importance of MR imaging, surgeons may find difficulties in the interpretation of the MR images, especially in complex cases.

This raises the concept of 3-D postprocessing of MR images to perform a complementary 3-D model, which could be easily read by the surgeons.

Apart from the well-established role of 3-D surface rendering in maxillofacial reconstructive surgeries, in recent years, the conception of 3-D models has been gaining space as a promising aiding diagnostic modality in the preoperative planning in other new specialties ,for example, as perianal lesions, but this is an option yet little explored in the treatment of anal fistulas.[47,48]

Hypotheses

In the author's pelvic floor research laboratory, the author hypothesized that introducing 3-D modeling MR imaging would enhance preoperative interpretation of the predominant pelvic supporting system defect by the surgeons.

The 3D model was achieved by 3D reconstruction advanced post imaging processing technology named “manual segmentation” of huge number of sequential source images. Axial T2 weighted MR imaging sequence was used as the source images for segmentation. After manual segmentation, surface rendering is applied to obtain the final 3D model, which demonstrates each anatomical structure in a different colour.

Objectives

The generated (engineered) model gave a better orientation to complex cases (**Fig. 14**) and was utilized by the surgeons in the author's institute as a road map for pelvic floor reconstructive surgery planning, even more challenging the 3-D model was taken advantage of during surgery.

Summary

Although multiple factors predispose for PFD, the precise pathologic mechanism is poorly understood, and treatment often is started regardless of the specific anatomic lesion involved, possibly due to lack of understanding of normal anatomy and physiology of the pelvic floor, lack of solid data on selection criteria for the various surgical techniques, and sparsity of data on the outcome of different procedures.

All diagnostic modalities, including physical examination and standard MR imaging assessment, are directed toward 2 basic goals: detecting if prolapse of a specific organ is present and determining the degree of prolapse.

The author of this article believes, as do others, that as new modalities of evaluation emerge, anatomic concepts of form and function change.

With changing concepts, it is necessary to reexamine and redefine the underlying anatomy, which requires a functional classification system based on scientific evidence. On the basis of the new 3-part pelvic support system classification,[4] a correlative analytical approach was created that can pinpoint each patient's structural and anatomic defects, providing better data for treatment planning.

In conclusion, the functional 3-part pelvic supporting systems approach; integrated MR analytical approach; TAPE approach; individualized, defect-specific treatment approach; and 3-D modeling of the predominant pelvic supporting system defect are the tools of the upcoming new horizon in the diagnosis of the complex disorders of the pelvic floor. They are all considered in the author's research laboratory as the rising stars for a new era of MR imaging, image analysis, diagnosis, and treatment decisions of PFD based on a concrete more realistic glimpse of the structural relationships in vivo.

Disclosure

The author has nothing to disclose.

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