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ORIGINAL ARTICLE

Defecation 1: testing a hypothesis for pelvic striated muscle action to open the anorectum

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Abstract
Background We conducted an observational study to assess the hypothesis that the pelvic muscles actively open the anorectal lumen during defecation.
Methods Three groups of female patients were evaluated with video imaging studies of defecation using a grid or bony reference points. Eight patients with idiopathic fecal incontinence had video X-ray myograms; eight with obstructive defecation had magnetic resonance imaging (MRI) defecating proctograms; and four normal patients had video X-ray or MRI defecating proctogram studies.
Results In all three groups, the anorectum was stretched bidirectionally by three directional muscle force vectors acting on the walls of the rectum, effectively doubling the diameter of the rectum during defecation. The anterior rectal wall was pulled forwards, and the posterior wall backwards and downwards opening the anorectal angle, associated with angulation of the anterior tip of the levator plate (LP). These observations are consistent with a staged relaxation of some parts of the pelvic floor during defecation, and contraction of others. First, the puborectalis muscle relaxes. Puborectalis muscle relaxation frees the posterior rectal wall so that it can be stretched and opened by contraction of the LP and conjoint longitudinal muscle of the anus. Second, contraction of the pubococcygeus muscle pulls forward the anterior rectal wall, further increasing the diameter of the rectum. Third, when the bolus has entered the rectum, the external anal sphincter relaxes, and the rectum contracts to expel the fecal bolus.
Conclusions Our results are consistent with the hypothesis that pelvic striated muscle actively opens the rectal lumen, thereby reducing internal anorectal resistance to expulsion of feces. Controlled studies of electromyographic activity would be useful to further test this hypothesis.

Keywords Mechanism of defecation · Constipation · Fecal incontinence · Pelvic floor disorders · Anorectal · Resistance

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Introduction

The most generally accepted mechanism for normal defecation requires feces to enter the anal canal, stimulate stretch receptors and produce the urge to defecate [1]. This sensory stimulus is followed by relaxation of the internal and external anal sphincters (IAS, EAS), decreasing the pressure within the anal canal. The rectum contracts and, with the assistance of raised intra-abdominal pressure, for example, from a partial Valsalva maneuver, feces are expelled. Petros and Swash [2] proposed an external striated muscle mechanism which stretched open both walls of the anorectum. In this latter schema, the puborectalis muscle (PRM) relaxed, relieving the closure pressure on the posterior rectal wall, thereby allowing the anorectal angle (ARA) to be actively opened by backward and downward vectors created by contraction of the levator plate (LP) and the longitudinal muscle of the anus (LMA). We have tested this hypothesis in a group of patients with idiopathic fecal incontinence (FI) [3].

Active opening of the anorectal tube by pelvic striated muscle contraction external to the rectum is attractive from a flow mechanics perspective. Contraction of striated musculature external to the rectum has the capacity to reduce friction within the rectal tube by stretching its walls, thereby reducing the resistance of the mucosal folds and by opening the lumen, and so reducing the internal expulsion pressure required for evacuation. These dynamic processes are important in women during micturition, reducing micturition pressure to the 5th power for non-laminar flow at urethral opening [4]. The notion that a similar external opening mechanism driven by striated muscles is necessary for defecation has a strong historical basis. For example, Swash and colleagues [5, 6] showed that both fecal and urinary incontinence are associated with weakness of the pelvic floor sphincter musculature, and the pelvic floor diaphragm itself. As the directional muscle forces constituting the core of the hypothesis of an external striated muscle opening mechanism [2] had only been observed in patients with idiopathic FI [3], our aim was to further investigate the concept in three groups of subjects: normal, constipated and with idiopathic FI.

Materials and methods

The video images of three groups of female patients studied with video defecography were assessed.

Inclusion criteria included investigation by clinically indicated diagnostic imaging for anorectal incontinence, evacuation or other problems. Exclusion criteria included neurological conditions such as multiple sclerosis, Parkinson's disease, Hirschprung's disease, myelopathies, peripheral neuropathies or diabetes mellitus.

Group 1 comprised four patients, (mean age 63 years; range 58–72 years) who had no FI or constipation. The indication for inclusion was undiagnosed abdominal pain. One patient underwent X-ray defecography while 3 underwent magnetic resonance (MR). A grid or bony landmarks were superimposed on each video.

Group 2 comprised eight patients with bowel evacuation problems (but no incontinence), consisting of rectocele and uterovaginal prolapse (mean age 56 years; range 41–73 years). All patients underwent MR proctography.

Group 3 comprised eight patients with double (urinary and fecal) incontinence as the presenting symptom (mean age 60.5 years; range 24–76 years). All patients in this group underwent video myogram defecography.

Magnetic resonance imaging (MRI) protocol

- When possible, the urinary bladder was half-full and not empty. The rectum was emptied and circa 200–250 ml ultrasound gel inserted.
- The patient was in the supine position with slightly bent legs, and wore a diaper.
- We used a 32-channel body-array coil to obtain T2-weighted turbo spin-echo sequences with 4-mm section thickness in the axial, coronal und sagittal direction to evaluate the anatomic structures of the pelvis. We also performed dynamic MRI study with T2-weighted single-shot gradient-echo sequences also with 4-mm section thickness in the sagittal direction in the center line of the pelvis/pelvic floor. During the examination, the patient was asked to tense the pelvic floor and to defecate and, if necessary, void their bladder. In the group studied, we also created a T2-weighted gradient-echo sequence in the axial direction from the pelvic floor while the patient defecated to assess the hiatus urogenitalis.

Video myogram defecography

In addition to the standard preparations for video X-ray defecography, 10 ml of radiopaque material was used to opacify the bladder outlet and the vagina. In addition, the LP complex was opacified [7]. In this technique, 2 ml xylocaine 2 % was injected into the post-anal skin midway between the anus and coccyx. After 5 min, with the index finger of the examiner inserted into the rectum, the LP muscle was identified by asking the patient to strain; 10 ml of water soluble radio-opaque dye was then injected into the muscle. Each patient was examined at rest, during anal squeezing and straining to defecate leading to bowel evacuation. Changes in the appearances in the evacuation phase relative to the resting phase were assessed (Video 1;

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R = resting; Sq = squeezing; St = straining; D = defecation).

A grid or bony landmarks were superimposed on each video, which was then split into individual frames. Frames were selected from the resting, mid-evacuation and late evacuation phases of defecation. We assessed changes in shape and position of the pelvic muscles and organs and their fibromuscular attachments from these marked-up images. Using these measurements, we tested the hypothesis of active anorectal opening during defecation against the more traditional belief of pelvic muscle relaxation.

Ethics

Written informed consent was given by all the study participants. Ethics Committee approval was required only for the electromyograms (EMG) recorded in those patients studied with video X-ray. No Ethics Committee approval was required for the remaining studies, as these formed part of routine investigative procedures. The principles outlined in the Declaration of Helsinki were followed.

Results

In all three groups, both the anterior and posterior rectal walls appeared to be stretched during defecation. The dynamic changes in anorectal shape were similar in all three groups (Figs. 1, 2, 3): the ARA moved significantly downwards, and began to open; the diameter of the anus increased at least twofold. In addition, the anterior wall of the anus was pulled forwards along with the distal part of the urethra (Fig. 2). These changes in anorectal position during defecation can be resolved as three muscle vectors. The anterior wall of the anus was pulled forwards; the posterior wall of the rectum was pulled backwards, opening the posterior ARA and, approximately, doubling its resting diameter; and the anterior edge of the LP and coccyx was angulated downwards. Though quantitative differences appeared to occur between individual patients, these directional movements were seen, to a greater or lesser extent, in all patients in each of the three groups.

Patterns of defecation

Normal and FI (groups 1 and 3)

The pattern of defecation in the normal group (Fig. 1) and the FI group (Fig. 3) was similar. Backward movement of the upper part of the anorectum and forward movement of its lower part effectively opened and straightened the anorectal tube to at least double its resting diameter. The rectum emptied in one bowel movement, and feces can be seen moving downwards along the posterior wall of the rectum (see video 1).

Constipated (group 2)

Our subjective impression was that the ARA was not so fully opened out (Fig. 2) as in the normal and FI groups (Figs. 1, 3). Nevertheless, the directional movements during defecation were similar, consisting of descent of the ARA, downward angulation of the coccyx and LP, opening of the ARA. The anterior rectal wall and distal urethra were pulled forwards, with reference to the vertical bony reference line (Fig. 2), and the posterior rectal wall has been pulled backwards.

In all patients, this change in geometry preceded the discharge of contrast medium from the rectum with a lag time of about 1 s.

Straining and anal squeezing (video)

During a voluntary anal squeeze, the pelvic floor lifted upwards, and the ARA becomes more acute (see video 1), thus maintaining continence. In contrast, the change in geometry during straining was almost identical to that seen during defecation. It is important to note the marked mobility of the lower bowel and anorectum, occurring in response to differential application of muscle forces in forward, backward and downward vectors.

Discussion

Our findings demonstrate that the concept of relaxation of all the pelvic floor muscles as a prelude to defecation cannot stand up to analysis. The anorectum derives its geometry from the suspensory ligaments and from pelvic muscle contraction. This is consistent with studies which show that the puborectalis and external anal muscles are in a state of continuous activity, even though this does not reach consciousness [8]. Changes in geometry are also activated by pelvic muscle contraction, evident on comparing the squeezing, straining and defecation segments of video 1. Relaxation of all the pelvic floor muscles would cause the walls of the anorectum to sag and appose, thus considerably increasing frictional resistance to defecation. Indeed, it is central to our hypothesis that the anorectal lumen must enlarge to facilitate defecation. We have demonstrated bidirectional stretching of the rectal walls. Based on previous EMG and video imaging studies of the pelvic floor [9, 10], we deduce that the forward vector can only be the result of contraction of the anterior portion of the pubococcygeus muscle (PCM), as this muscle also pulls forward the distal urethra, exactly as happens during

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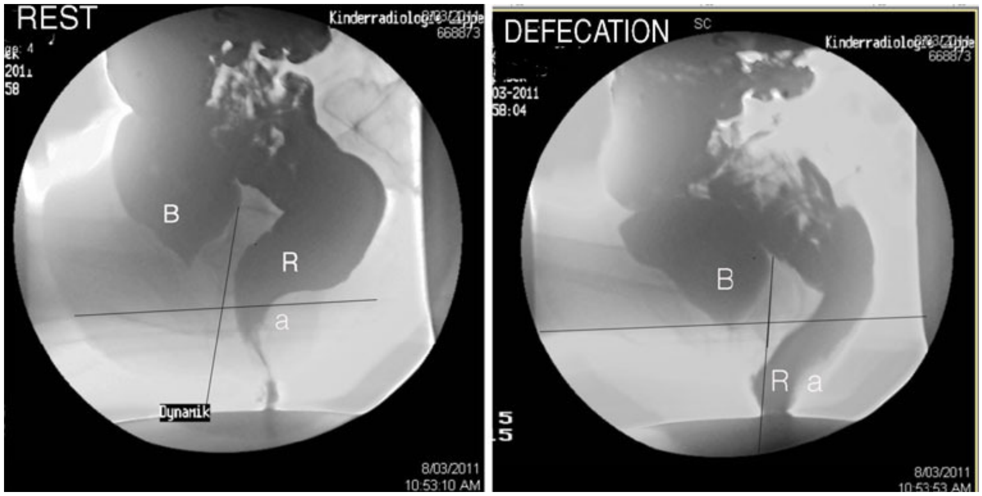

Fig. 1 Proctogram normal subject. *At rest* The rectum "*R*" is resting on the LP with a well-defined ARA "*a*" which is about 110 degrees. *B* bladder. *During defecation* The rectum and ARA have descended below the *horizontal bony* co-ordinate; the ARA "*a*" has opened to approximately 150 degrees; the anterior rectal wall has been pulled forwards; the anorectum has been opened out very significantly, at least to twice its resting diameter. The feces appear to run down the posterior wall of rectum

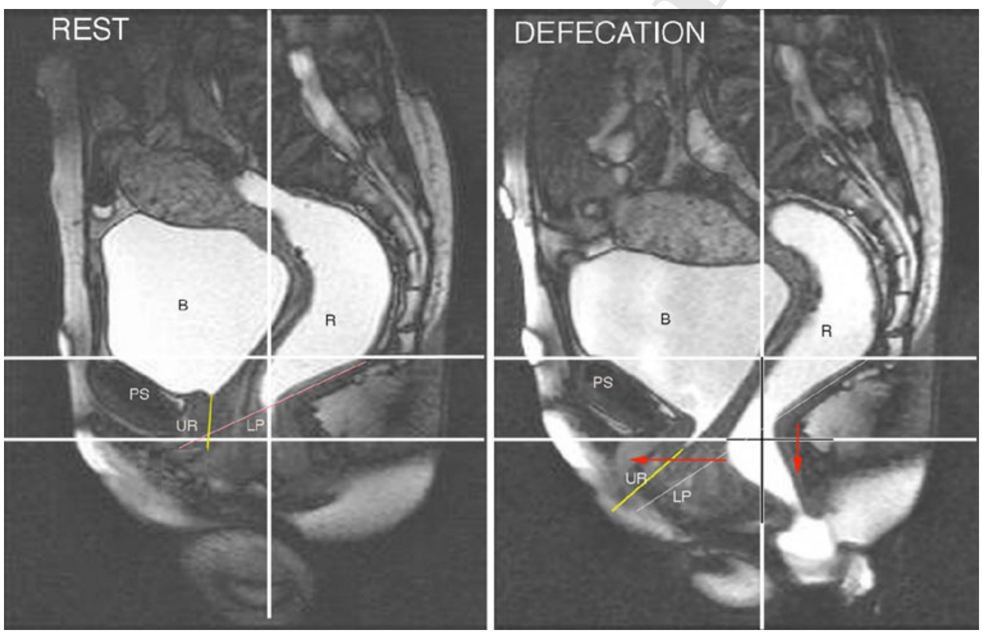

Fig. 2 MRI constipation. *At rest* The vertical bony reference line runs through the anterior part of the space between S2 and S3. The two *horizontal bony* reference points run over the superior and inferior surfaces of the pubic symphysis. The anatomical course of the urethra (*UR*) and *LP* are outlined. *During defecation* Both the urethra and anterior rectal wall have been pulled forwards, altering the angle of the urethra from 92 degrees to the horizontal to 40 degrees. It is not possible for intra-abdominal pressure to do this. A forward movement is only possible with a forward muscle contraction. The angulation of the LP has changed from 28 degrees to the horizontal (at rest) to 38 degrees (in defecation). The ARA, however, has opened out very little, from approximately 100 degrees at rest to 110 degrees on defecation

urethral closure [9, 10] and clearly seen in Fig. 2. The posterior movement of the posterior rectal wall and opening of the ARA can only be explained by contraction of the LP which inserts into the posterior rectal wall. This was demonstrated by backward/downward movement of the space "S" in Fig. 3. The downward angulation of the LP and also of the posterior wall of the rectum causing opening of the ARA can only be explained by contraction of the striated muscle component of the conjoint LMA [11, 12], a striated muscle described by Courtney in 1950 [11], which takes fibers from the PCM, LP, and PRM and inserts into the EAS.

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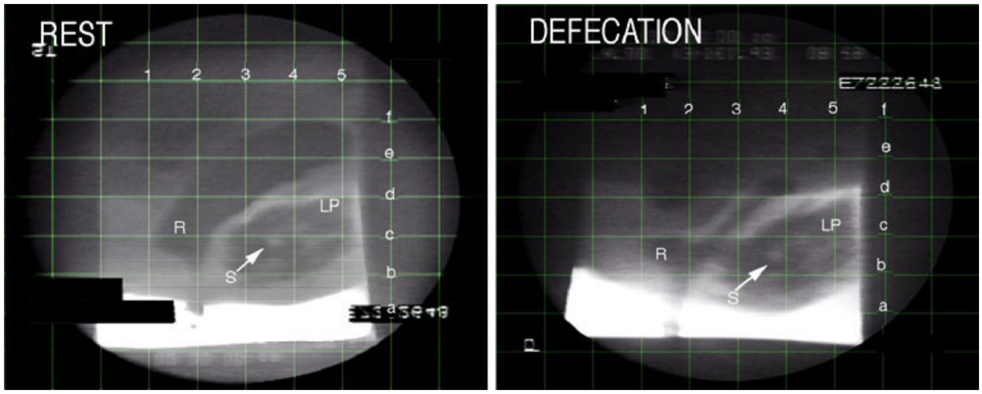

Fig. 3 Video X-ray of rectum (*R*) and *LP*. Fecal incontinence. *At Rest* Patient in sitting position. The white oval (*S*) inside the *LP* muscle (*LP*) is a natural space. The superior surface of the *LP* is almost horizontal. The ARA is approximately 120 degrees. *During defecation* The posterior ARA has been pulled open posteriorly by the apparent attachment of LP into the posterior wall of the rectum and has moved downwards to lie between lines *c*, *b*. The ARA is now approximately 160 degrees. The white oval "*S*" has moved downwards from just below *line c* to lie midway between *horizontal lines c*, *b*, and it has moved backwards toward the *vertical line 4*, indicating muscle contraction. The superior surface of *LP* has been angulated downwards. The anterior rectal wall has been physically pulled forwards from *vertical line 2* to lie midway between *ines 3*, *4*

Though the apparent inability in Fig. 2 of the ARA to be fully opened provides a ready explanation for the inability to evacuate the rectum, we emphasize that the measurement of angles in Figs. 1, 2 and 3 is indicative only, and only apply to these particular images. We were not able to capture and measure all the images with sufficient accuracy for comparison. How this active opening mechanism impacts on the process of defecation is analyzed mathematically in "Defecation 2", also published in this issue.

In 1982, an active mechanism involving pelvic striated muscle contraction was proposed by Shafik [13], based on the flap valve relaxation mechanism proposed by Parks [14]. Shafik suggested that defecation requires PRM relaxation, LP contraction and *elevation* of the "suspensory sling", followed by rectal detrusor contraction. Our observations refute Shafik's hypothesis about the mechanism of defecation. We did not confirm any lifting of the rectum. On the contrary, the direction of anorectal opening forces is clearly downwards and backwards (Figs. 2, 4), not upwards as predicted by Shafik.

Although different imaging techniques were used in this study, we are confident that they consistently demonstrate that in patients with constipation and FI, the same movements occurred during defecation.

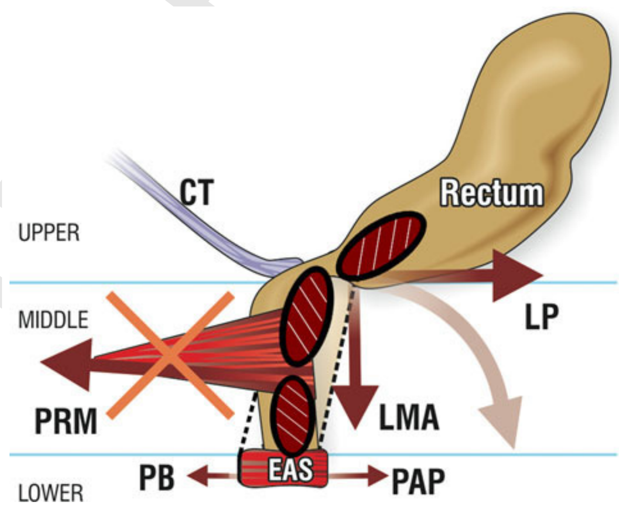

Fig. 4 A hypothesis for the anatomical basis of defecation. The anterior wall of rectum is anchored passively by its connective tissue (*CT*) attachment to the vagina and utero-sacral ligaments. The *PRM* relaxes, indicated by a large "*X*". The *LP* and conjoint *LMA* contract to open out the *ARA* (*broken lines*). The fecal bolus (*ovoids*) is deformed and descends into the anus. The *EAS* relaxes. Contraction of the anterior portion of *PCM* (*forward arrow*) pulls the perineal body (*PB*) forward to open the lower part of the anal canal (*broken lines*). Backward contraction of the post-anal plate (*PAP*) assists this action by splinting the posterior anal wall

Role of intra-abdominal pressure

Purely from a logical deductive perspective, intra-abdominal pressure could not cause selective downward movement and angulation of the posterior wall of the rectum, as it can only affect the anterior rectal wall. We suggest that it is not intra-abdominal pressure consequent on straining which facilitates defecation. Rather, it is the accompanying contraction of the LP which opens the anorectal tube. In 1919, Sturmdorf [15] observed that the LP contracted simultaneously with the abdominal muscles, an observation consistent with the common embryological origin of these muscles [16].

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Deductions, correlations and interpretations of our observations

Our observations are consistent with decreased anal pressures recorded during defecation [1]. Active opening out of the anal canal by an extrinsic muscular mechanism will cause the intra-anal pressure to fall, since the area of recording will increase (pressure = force/area). Our video observations were consistent with rectal contraction and raised intra-abdominal pressure to expel during defecation, as stated [1]. The backward movement of the white oval space in the LP (Figs. 3, 4) is consistent with a backward vector due to contraction of the LP. PRM relaxation [2] is a prerequisite for our hypothesis; it releases the pressure of the PRM on the posterior rectal wall [4]. Given that the LP inserts into the posterior wall of the rectum, any contraction of the LP will stretch the posterior rectal wall backwards [4]. Downward angulation of the coccyx and superior surface of the LP coincided with opening of the ARA (Figs. 2, 4). This preceded the commencement of evacuation of fecal contents, suggesting that rectal contraction followed opening of the anorectal canal. Downward angulation of the LP (Figs. 2, 4) can only be caused by contraction of the striated component of the conjoint LMA. It has a vertical orientation and comprises striated muscle fibers from the LP, PCM and PRM.

According to the hypothesis of total pelvic floor relaxation, the fecal bolus would open out a relaxed, but still small, anal canal entirely due to the pressure generated by rectal contraction. Our observations do not support such a hypothesis. Furthermore, the pressure needed to push feces through an unopened anorectal tube is potentially very large, given the frictional forces generated by a narrow tube [4].

Hypothesis for the mechanism of defecation (Fig. 4)

We observed partial relaxation of the pelvic floor, initially of the PRM and, once the bolus has entered the rectal canal, of the IAS and EAS. The forward and backward vectors (Figs. 1, 2, 3) remain active throughout defecation. PRM relaxation (Fig. 4) releases forward pressure on the posterior rectal wall. This allows the vector forces generated by the LP and LMA to open the ARA (broken lines, Fig. 4). The LMA contracts initially against its connective tissue attachment to the uterosacral ligaments (CT in Fig. 4) and inferiorly against a contracted EAS. The fecal bolus itself aids in the maintenance of anorectal distension during its passage. The IAS and EAS relax reflexively when the fecal bolus reaches the lower part of the anus. The lower part of the anus is also pulled open (forward arrow, Fig. 4). This hypothesis, of initial contraction of the LMA and EAS, followed by relaxation of the EAS on entry of the bolus into the anal canal, is consistent with Shafik's EMG and pressure studies in dogs [17]. Shafik excised the rectum and anus and attached the sigmoid colon to the anal remnant to form a "neorectum". Therefore, what was subsequently measured could only be the effect of the extrinsic forces acting on the neorectum. Shafik observed that "distension of the neorectum effected a significant increase in the neorectal pressure and a momentary increase of the EMG activity of the EAS, followed by a decline of rectosigmoid junction pressure and balloon expulsion to the exterior" [17]. Shafik's experimental EMG observations [17] are consistent with our finding that initial contraction of LMA/EAS (Fig. 4) opens the superior part of the anorectal canal (broken lines, Fig. 4). Contraction of the anterior portion of PCM would not be detected by an EMG electrode in the EAS, as the PCM inserts into the lower and posterior part of the pubic bone.

Limitations of our study

The measurement of angles in Figs. 1, 2 and 3 are indicative and only apply to these images. We have not studied the variability of muscle vectors during defecation, preferring to limit our studies to principles. Nonetheless, we anticipate that accurate measurements will be important for understanding symptomatic anorectal dysfunction in clinical practice. We did not record EMG activity from the specific muscles we have suggested as contracting or relaxing, relying on the known anatomy and the muscle vectors seen.

Conclusions

We see our study as providing a new research direction in understanding the common clinical problem of defecatory disorder, to be further tested by more precise quantitative observations using high quality imaging, and also, functional electromyography, although the latter is somewhat invasive.

Conflict of interest The authors declare that no conflict of interest exists.

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