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Sonographic evaluation of spondylolysis: technique description and feasibility study of diagnostic ultrasound for the detection of L5 pars interarticularis fractures

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Objective: *Technique description and verification of L5 pars interarticularis (L5PI) using diagnostic ultrasound (DUS).*

Methods: *Asymptomatic 10-year-old male subject was scanned with diagnostic ultrasound applying a linear array transducer (8-13 MHz) over L5/S1 facets; long-axis slide cephalad to capture both superior (SAP) and inferior articulating process (IAP) of L5. Contiguous hyperechoic cortex with deep acoustic shadowing between the SAP and IAP was assumed to be L5PI. To confirm in vivo technique representing L5PI, two spine models (plastic, human spine) were scanned to verify authors' assumption. Metallic paperclip was placed over L5PI then DUS image captured. Lastly, a subject with known spondylolysis was imaged and sonographic appearance of L5PI compared.*

L'évaluation échographique de la spondylolyse: une description de la technique et une étude de faisabilité de l'échographie diagnostique pour la détection des fractures de l'isthme interarticulaire de la L5

Objectifs: *La description de la technique et la vérification de l'isthme interarticulaire de la L5 (IIL5) à l'aide d'ultrasons diagnostiques (USD).*

Méthodes: *Un sujet masculin asymptomatique âgé de 10 ans a été scanné à l'aide d'une échographie diagnostique utilisant un transducteur linéaire (8-13 MHz) sur les facettes de la L5/S1; un glissement en direction céphalique sur grand axe pour capturer le processus d'articulation supérieur (PAS) et inférieur (PAI) de la L5. Le cortex hyperéchogène contigu avec ombrage acoustique profond entre le PAS et le PAI a été supposé être de l'IIL5. Afin de confirmer la technique in vivo représentant l'indice de l'IIL5, deux modèles de colonne vertébrale (plastique, colonne vertébrale humaine) ont été scannés pour vérifier l'hypothèse des auteurs. Un trombone métallique a été placé sur l'IIL5 puis une image d'USD a été prise. Enfin, un sujet présentant une spondylolyse connue a été imagé et l'aspect échographique de l'IIL5 a été comparé.*

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Results: *The structures localized with the metal paperclip on L5PI models were equivalent to the in vivo DUS image. Spondylolysis demonstrates an abrupt step-off defect at L5PI.*

Conclusion: *We report the first technique description and verification of the L5PI using DUS.*

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KEY WORDS: ultrasound, pars interarticularis, sonography, pars defect, spondylo, spondylolytic spondylolisthesis, stress reaction, stress fracture, anatomy, feasibility, exploratory, pilot study, chiropractic

Résultats: *Les structures localisées avec le trombone métallique sur les modèles de l'IIL5 étaient équivalentes à l'image d'USD in vivo. La spondylolyse montre un défaut abrupt de décrochage à l'IIL5.*

Conclusion: *Nous rapportons la première description technique et la vérification de l'IIL5 à l'aide d'USD.*

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MOTS CLÉS : échographie, isthme interarticulaire, échographie, défaut de l'isthme, spondylo, spondylolisthésis spondylolytique, réaction de stress, fracture de stress, anatomie, faisabilité, exploratoire, étude pilote, chiropratique

Introduction

There is an ever-increasing utilization of musculoskeletal diagnostic ultrasound imaging (DUS) in healthcare; trends within the chiropractic profession are no different.[1,2] Increased application has led to the adoption and integration of the technology into some of the chiropractic institutions with 65% of these institutions reporting DUS training should be provided to students and 75% of institutions reporting that chiropractic programs should be providing accredited postgraduate DUS courses.[3] Except for perinatal imaging and interventional anatomical localization for facet injections, the majority of musculoskeletal DUS has been focused on extremity application for both clinical practice and research application. Although the primary focus of chiropractic is spinal care, there has been limited application to spinal evaluation with DUS in the chiropractic field. The most common reason for individuals seeking chiropractic care is low-back pain.[4] In adolescent athletic patients with low back pain, 47% have been found to have spondylolysis.[5] Although the general population only has an estimated 6.4% prevalence of spondylolysis according to Aoki *et al,*[6] due to the higher prevalence of spondylolysis in the adolescent athletic population, the authors of this article had interest in the ability of DUS to identify the pars interarticularis and defects via DUS, because its relatively low-cost and lack of ionizing radiation exposure.

To the authors' best knowledge, evaluation methods with DUS of the pars interarticularis have not been published nor have any publications around the DUS assessment of pathologic alterations of this structure. Non-operative spinal/paraspinal ultrasound is investigational according to the American Institute of Ultrasound in Medicine (AIUM), stating "there is insufficient evidence in the peer-reviewed medical literature establishing the value of nonoperative spinal/paraspinal ultrasound in adults for diagnostic evaluations of conditions involving the intervertebral disks, facet joints and capsules, and central nerves." Therefore, the AIUM states that, at this time, the use of ultrasound in diagnostic evaluations, screening, or monitoring of therapy for these conditions has no proven clinical utility and should be considered investigational.[7] Moreover, the single case study detecting spondylolisthesis using ultrasound focused on the malalignment of facet joints from level-to-level without observation of the pars interarticularis.[8]

Methods

Diagnostic ultrasound (GE LOGIQ e; Milwaukee, WI), using 8-13 MHz linear array transducer was used to obtain images of the pars interarticularis of the fifth lumbar vertebra (L5). For scanning the pars interarticularis at L5, an asymptomatic 10-year-old male was used as a subject for experimental identification of the pars interarticularis due to typical age of onset of spondylolysis and the subject's tissue thickness lending itself to increased image resolution for an initial anatomical comparison to the models.

Each subject and spine model were scanned in the prone position with the L5/S1 motion segment examined. Each subject or parent/guardian signed informed consent and permitted the authors to use images and clinical information. The transducer was placed over the neural arch of the posterior spinal column. In the sagittal plane, the most lateral structure is the hyperechoic transverse process. Through a short-axis glide towards the midline, facet joints were visualized with the characteristic "camel hump" pattern.[9] The lumbosacral junction was located by sliding the transducer caudally, where a downward curved, hyperechoic sacrum appeared. As the sacrum was located, the transducer was then maneuvered slightly cephalad to capture both the superior and inferior articulating process of L5, matching the normal slight angulation of the neural arch as displayed within VH Dissector image (Figure 1). A slight side-to-side short axis glide of the probe was utilized until a contiguous cortex bridge producing a deep acoustic shadow between the superior and inferior articulating process of L5 was achieved (Figure 2). The contiguous hyperechoic region with deep acoustic shadowing corresponded to the cortical region between the superior and inferior articulating processes and therefore, was speculated to be the pars interarticularis of L5.

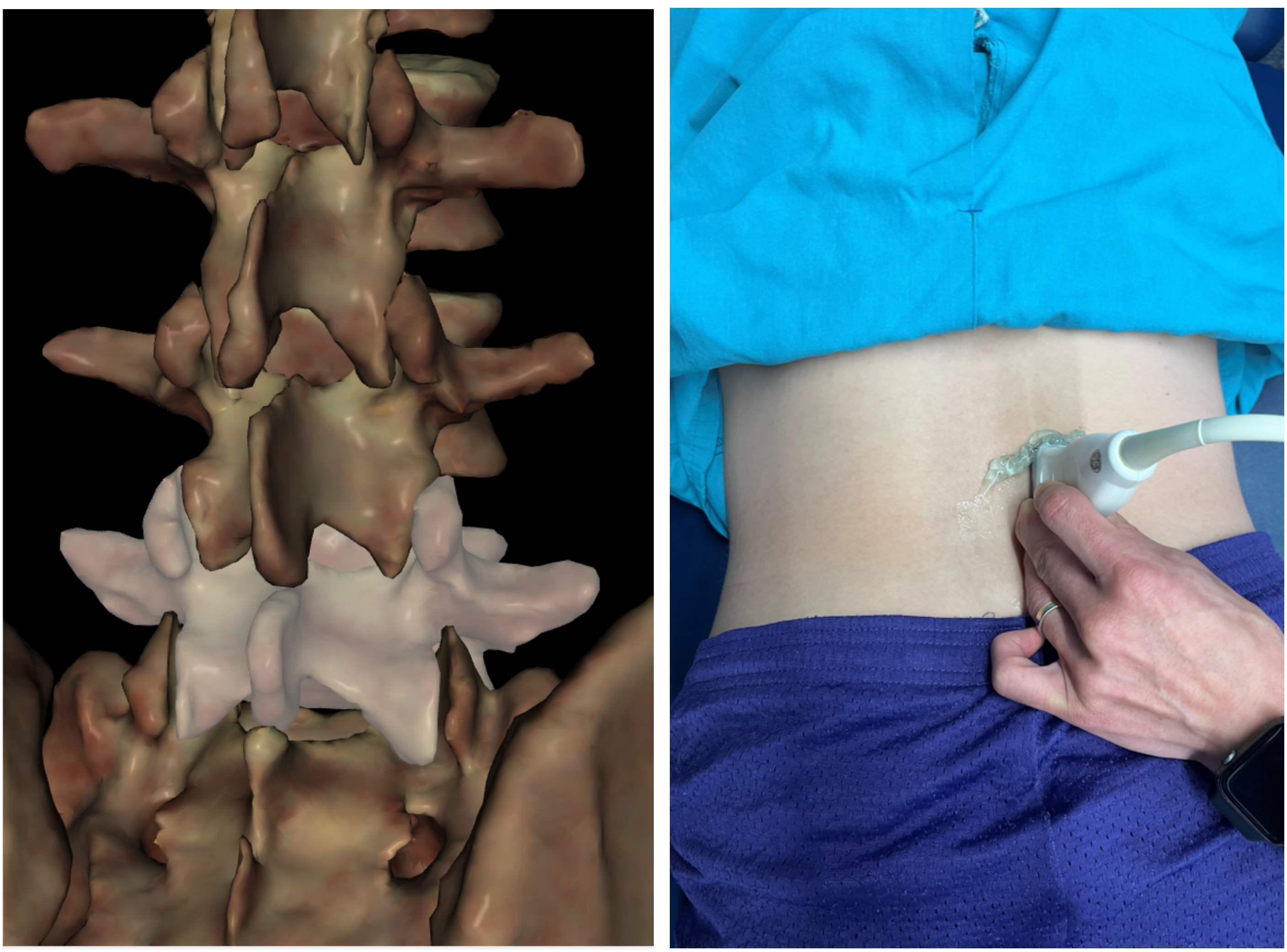

Figure 1.
Placement of the ultrasound probe. (Rectangle= Placement site for the ultrasound probe) Permission to use from Toltech (www.toltech.net)

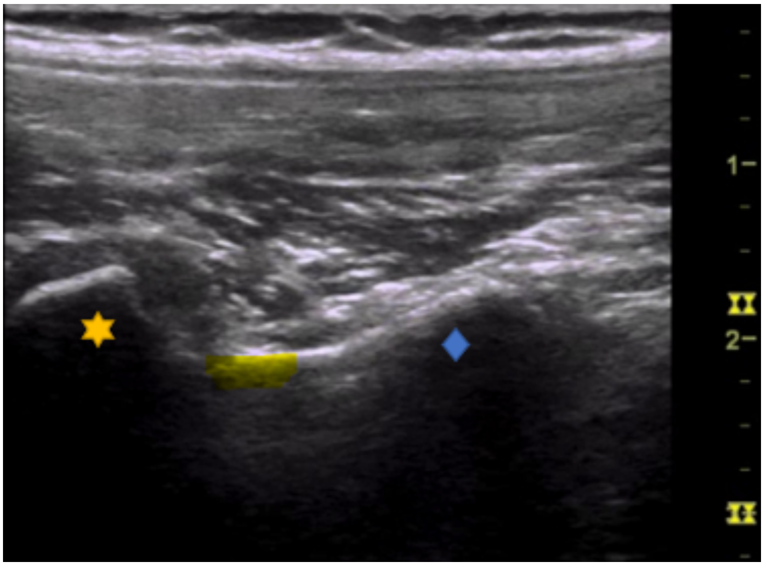

Figure 2.
Ultrasound image of L5 pars interarticularis of a 10-year-old male. (Yellow highlighted area) pars interarticularis; (Star) Superior articulating process at L5; (Diamond) Inferior articulating process at L5.

To confirm the in vivo ultrasound image accurately represented the pars interarticularis, two spine models were scanned to verify the authors' assumption. First, a plastic spinal column model was submersed in a tub filled with water to simulate tissue around a spine. A metal paperclip was placed over the L5 pars interarticularis (Figure 3a); a subsequent ultrasound image was captured (Figure 3b). Additionally, a disarticulated, human dry spine was scanned (Figure 4a) and confirmed the same appearance of the L5PI (Figure 4b) compared to in vivo image.

Figure 3(a).
Plastic spinal column was submersed in a tub filled with water. Paperclip is placed over the L5 pars interarticularis then ultrasound was captured.

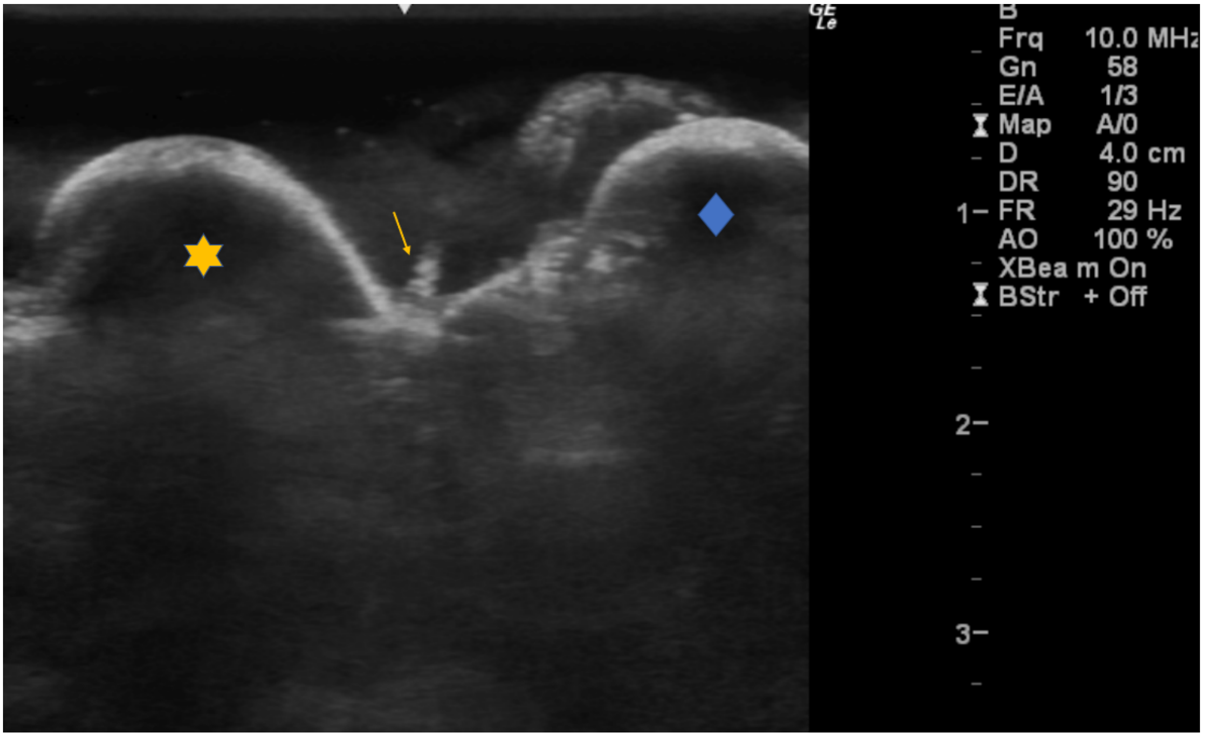

Figure 3(b).
Ultrasound image of the plastic spinal column. (Arrow) artifact from tip of the paperclip pointing to the L5 pars interarticularis; (Star) Superior articulating process at L5; (Diamond) Inferior articulating process at L5.

Figure 4(a).
Human spinal column scanning was done at L5 pars interarticularis with placement of the paperclip over the L5 pars interarticularis.

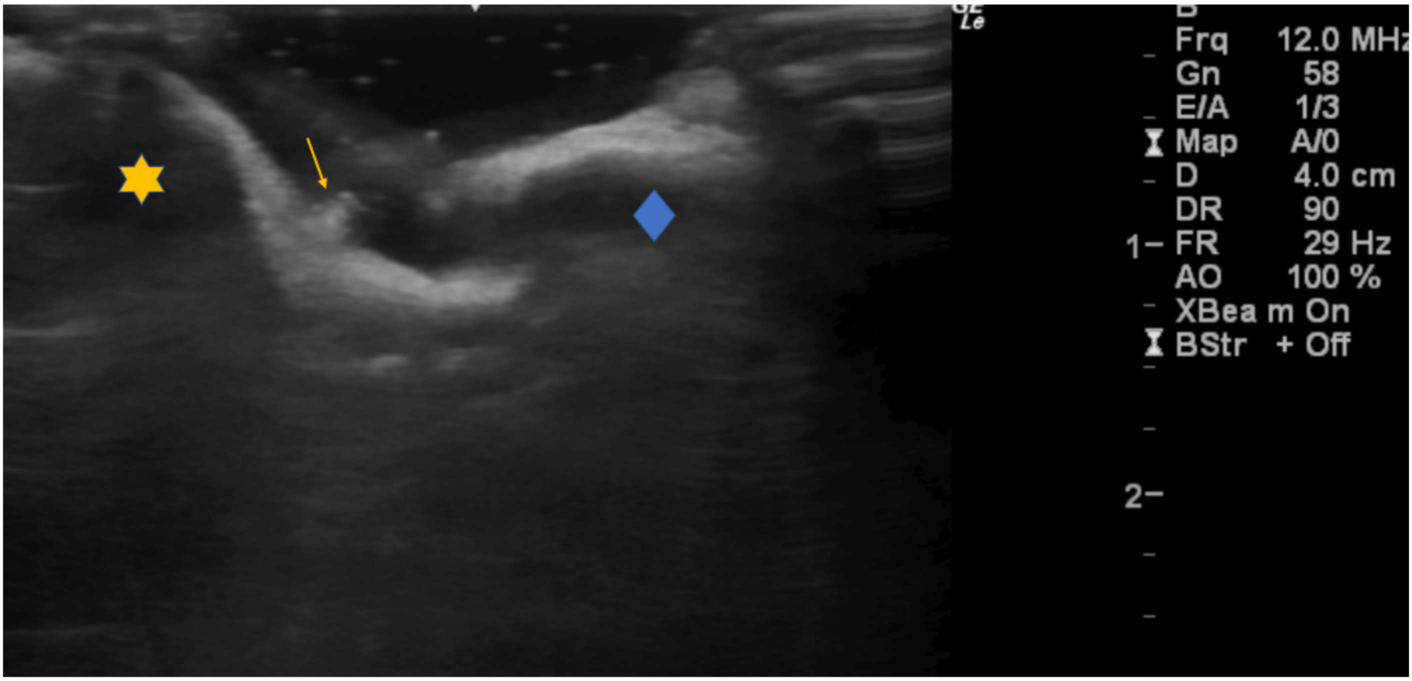

Figure 4(b).
Ultrasound image of the human spinal column. (Arrow) artifact from tip of the paperclip pointing to the L5 pars interarticularis; (Star) Superior articulating process at L5; (Diamond) Inferior articulating process at L5.

Lastly, a young adult subject (25-year-old male) with known diagnosis of L5 spondylolysis, confirmed on radiographic examination, (Figures 5a and 5b) was scanned with DUS using the previously described technique of locating the pars interarticularis.

Results

A concave smooth hyperechoic bridge with deep acoustic shadowing was identified extending between the superior and inferior articulating processes, consistent with cortical bone of the L5PI on ultrasound. The L5PI localized with the metal paperclip on two spine models were compatible with the baseline, in-vivo DUS image.

DUS of a spondylolysis demonstrated an interrupted cortex, displayed as a hypoechoic gap with an abrupt step-off defect at L5PI that contrasts the normal images of the L5PI obtained on the two models and in vivo subject, but was compatible with the radiographic appearance of a pars defect.

Discussion

This investigation yields promising evidence that the pars interarticularis can be visualized in young individuals by utilizing DUS. The cortex of the pars interarticularis was well defined in all subjects (human, plastic model, and human spine). This provides evidence that a pars interarticularis fracture resulting in spondylolytic spondylolisthesis may be visible using DUS. Further, DUS may provide valuable additional clinical data in cases with inconclusive radiographic evaluation of the lumbar spine. One potential advantage could be evaluating the stability of spondylolysis via real-time, dynamic evaluation that is not available with MRI, CT, or radiography.

Sharpe *et al.*[1] looked at the trends of DUS utilization in the United States of America (USA) over the first decade of this century. The authors reported a 316% increase in the total number of diagnostic DUS examinations paid under Medicare Part B, between 2000 (56,254 studies) and 2009 (233,964 studies).[1] The chiropractic field is also seeing a growth in the number of chiropractic programs using DUS with five out of 24 respondents stating they have DUS at their program, with an additional nine of the 24 respondents having plans to implement the technology during the 2017 study by Rogan *et al.*[3] Because of its unsurpassed spatial

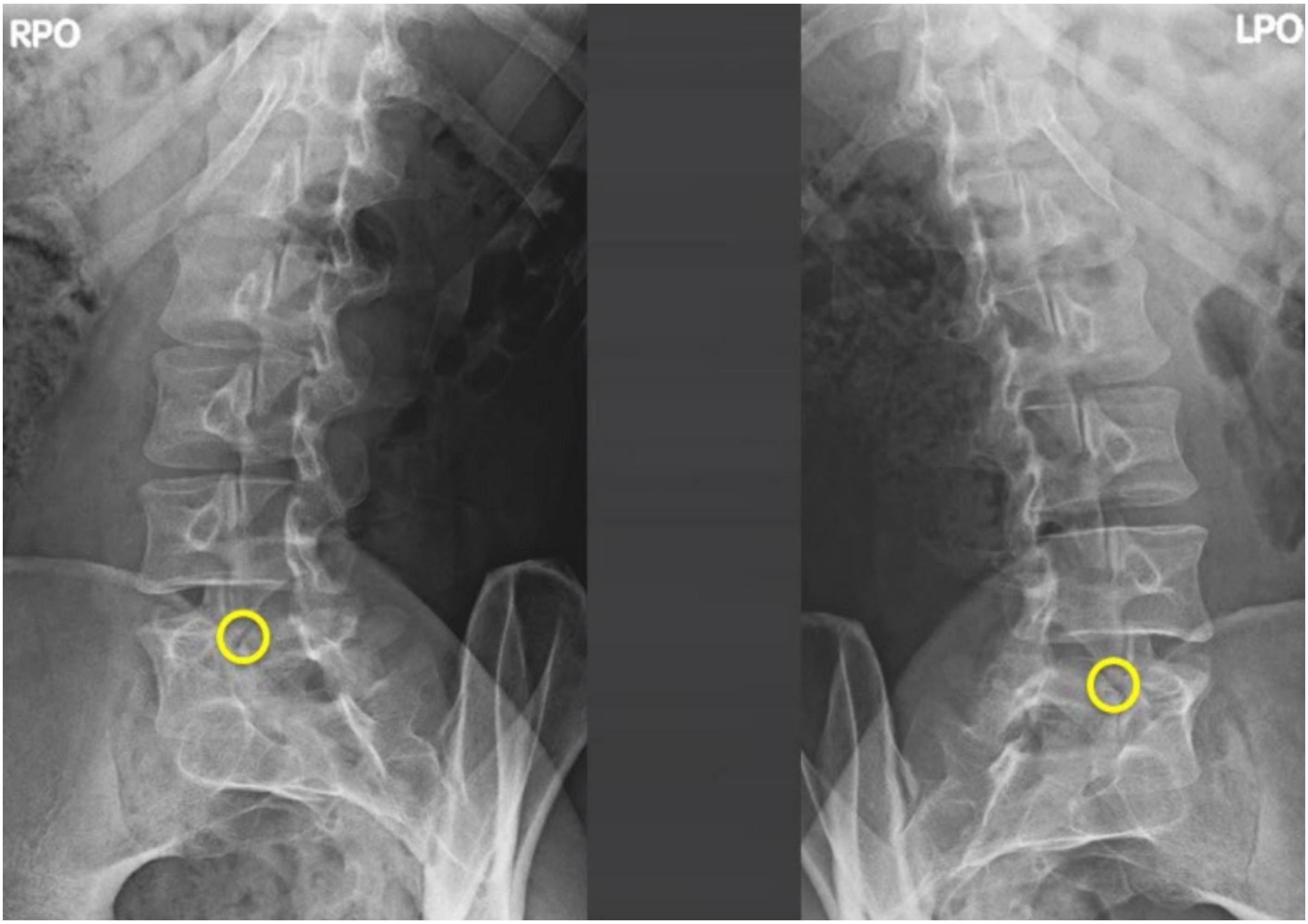

Figure 5(a).
Lumbar oblique radiographs of the same subject scanned in Figure 5b demonstrating bilateral pars defects (yellow circle) at L5.

resolution and dynamic imaging capabilities, applications for DUS have broadened significantly over the years making ultrasound an effective, cost efficient alternative to MRI in many clinical applications, and the imaging test of choice in others.[2] In addition to the benefit of decreased cost, DUS does not have an ionizing radiation dose unlike CT, nuclear imaging, and radiography; each of which are currently used to evaluate spondylolytic spondylolisthesis.

Tibial stress fractures have been reported to be visible using DUS with a defect in the cortex, adjacent edema, and Doppler imaging changes.[10] Given DUS's ability to show hyperemia via power Doppler, it is plausible that it may provide differentiation of acute from chronic pars defects and possibly early identification of stress reactions at the pars interarticularis region prior to progression to a complete pars defect/fracture. Timely diagnosis and management are critical in preventing progression[11] and increase the likelihood of a favorable prognosis including complete healing.5 DUS may be a cost-effective method for monitoring the healing process for spondylolytic spondylolisthesis in the acute setting, as DUS has been shown to provide earlier information about fracture healing and earlier prediction/identification of delayed union and nonunion.[9]

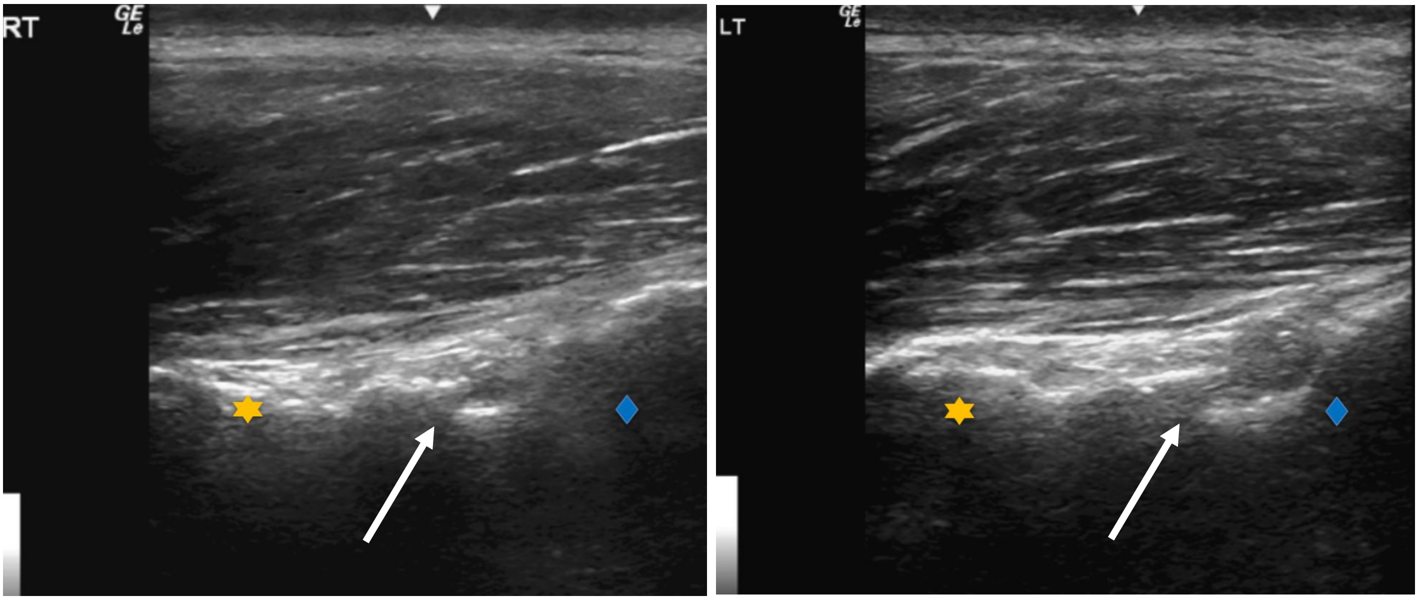

Figure 5(b).
Ultrasound images of the bilateral pars defects at L5; between the superior articulating process (star) and the inferior articulating process (diamond) at L5, a cortical step-off is noted (white arrow) at the pars interarticularis with discontinuity of the hyperechoic cortex.

This study demonstrated sonographic identification of the L5PI, verified using spine models. In a subject with a known spondylolytic spondylolisthesis, a cortical step-off was a noteworthy characteristic appearance in contrast to the smooth, concave L5PI between the articular processes in the unaffected subject and models.

Limitations

There are limitations in this study. This feasibility study only employed a single observer and as with all DUS studies, there can be considerable variability in the inter-observer and intraobserver reliability, especially with respect to the operator's experience in obtaining DUS images. The authors feel an important area of future research would be to evaluate reliability across multiple individuals performing the scan at various skill and experience levels to determine the likely applicability of DUS in the evaluation of the pars interarticularis at a spectrum of skill levels. The authors also acknowledge this study used a single adolescent subject, and therefore the reproducibility is unknown at this time. This subject selection decision was made because typically spondylolysis develops in the adolescent population and the subcutaneous soft tissue thickness of this age group is likely to produce better resolution for anatomic localization. Future studies should attempt to attain a larger sample size with varying age groups and body sizes.

Conclusion

MSK-DUS provides potential for a cost-effective method of evaluating the pars interarticularis in populations at risk for spondylolytic spondylolisthesis. With the relatively low cost compared to CT and MRI as well as the lack of ionizing radiation dose, DUS may be a valuable adjunctive tool in the evaluation and monitoring of the L5PI in subjects and patients with suspected pars pathology. Furthermore, with the well documented findings of stress fracture using ultrasound[12], it is plausible that spondylolytic spondylolisthesis, an acute stress disorder in adolescents, may be detectable via DUS prior to progression to complete fracture.

For future studies, validation on the scanning protocol and reliability study on identifying L5PI analysis is of high importance.

This study provides a foundation for future studies to include but not limited to DUS's ability to identify L5PI fractures, distinguish acute vs. chronic spondylolysis, evaluate stress reactions of pending pars fractures, monitor healing, and measure for motion/instability, given the dynamic capabilities of DUS.

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