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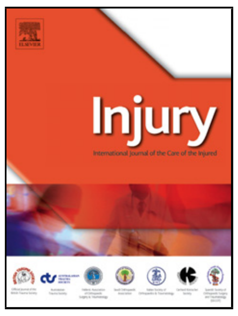

Title: A Novel Method To Correctly Place The Fasciotomy Incision For Decompression Of The Anterior And Peroneal Compartments Of The Leg

Author: Ian Pallister Rhys M. Morris Tom Lloyd Nicholas J. Marsden Thomas Wright Michael Gilbert Jonathan Phillips

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Title Page

A Novel Method To Correctly Place The Fasciotomy Incision For Decompression Of The Peroneal And Lateral Compartments Of The Leg.

Ian Pallister MBBS, MMed Sci, FRCS (Tr & Orth), MD
Professor of Trauma & Orthopaedics
Morriston Hospital
College of Medicine
Swansea
SA6 6NL

Rhys M Morris MRCS
Lecturer in Trauma
Morriston Hospital
College of Medicine
Swansea
SA6 6NL

Dr Tom Lloyd BSc, MRes, MBChB
F1 Doctor
Wales

Nicholas J Marsden MBBCh BSc MRCS
Plastic Surgery SpR,
Welsh Centre for Burns & Plastic Surgery,
Morriston Hospital,
Swansea

Thomas Wright FRCS
Consultant Plastic Surgeon
Frenchay Hospital
Bristol

Michael Gilbert MB ChB FRCA
Consultant Anaesthetist
Morriston Hospital

Jonathan Phillips PhD, MSci, DipIPEM(S), MSc CSci
Senior Research Officer in Medical Imaging
Institute of Life Science
College of Medicine
Swansea University
SA2 8PP

A Novel Method To Correctly Place The Fasciotomy Incision For Decompression Of The Anterior And Peroneal Compartments Of The Leg.

Key Words

Fasciotomy, compartment syndrome. ACS. Inter-muscular septum.

ABSTRACT:

Incorrectly placed fasciotomy incisions can lead to catastrophic complications in compartment syndrome. Two distinctly different techniques are widely practiced to decompress the anterior and peroneal compartments. In one technique the anterior compartment is decompressed directly, and then the peroneal via the inter-muscular septum, avoiding the peroneal perforators. The second technique relies on surface anatomy landmarks to place the skin incision immediately over the inter-muscular septum, and then the respective fascial envelopes are incised separately.

A study in healthy active volunteers was conducted to explore the feasibility of a new technique for the placing the incision very accurately over the inter-muscular septum and so avoiding perforator vessels.

Hypothesis:

The inter-muscular septum can be reliably identified using hand-held ultrasound, and confirmed with MRI.

Methods:

Fourteen healthy active volunteers underwent hand-held ultrasound to identify the antero-lateral inter-muscular septum in the left lower limb, which was then marked using cod liver oil capsules. The positions of the anterior, septal and peroneal perforators were then identified using hand-held Doppler, and marked in the same way. MRI was then used to measure the relationship between the surface land marks, the septum (compared to its US position), and the relationship of the perforators themselves.

Results

Hand held ultrasound was successful in identifying the position of the inter-muscular septum in healthy volunteers, as confirmed on MRI scanning. The position and number of peroneal and anterior perforators proved very variable. Direct decompression of the anterior compartment would

result in the loss of all anterior perforators in all subjects. Decompression with the skin incision over the inter-muscular septum would not jeopardise any peroneal muscular perforators.

Conclusion

This new technique enables decompression both the anterior and peroneal compartments through an accurately placed incision, sparing the greatest number of perforators. Two brief case histories in which the technique was used are presented.

BACKGROUND:

Failure to adequately decompress all four compartments in the lower limb has disastrous consequences, which at best may result in the loss of a limb, and at worst, may prove fatal [1, 2].

Two techniques have been described for the decompression of the anterior and peroneal compartments. In one, the surgeon attempts to place the skin incision directly over the inter-muscular septum between the anterior and peroneal compartments [3]. Each is then decompressed by a separate deep incision releasing the fascia directly over each compartment. In a very swollen or malaligned limb, it is possible to misplace the skin incision, and so have difficulty locating the inter-muscular septum. Undermining the skin edges may prove necessary and if the surgeon hasn't orientated themselves correctly it is possible to fail to decompress the anterior compartment. Furthermore, if placed too lateral, it has been suggested that the incision will compromise the peroneal perforators which may provide a useful soft tissue reconstruction option in the case of certain patterns of open fracture. If damaged, a patient may be consigned to having a free tissue transfer in an injury which was otherwise amenable to a local flap.

The alternative approach places the skin incision much more anteriorly and decompresses the anterior compartment directly by incising the fascia exactly in line with the skin incision, about 1.5-2cm lateral to the tibial crest [4, 5]. This is then followed by medial retraction of the muscle bulk of the anterior compartment to allow decompression of the peroneal compartment by incision of the inter-muscular septum. Direct decompression the anterior compartment is assured and undermining the skin to locate the inter-muscular septum is unnecessary, and the peroneal muscular perforators will not be compromised. However, there are risks including damage to the superficial branch of the common peroneal nerve when incising the inter-muscular septum [6], poor vascularity and blistering of the narrow skin bridge over the tibial fracture itself. Finally, if a below knee amputation is ultimately required, then fashioning of the flaps to close the amputation is very challenging.

Fasciocutaneous flaps are a mainstay in soft tissue reconstruction following open fractures in the lower limb, thanks to better understanding of the consistent nature of perforating vessels and the three dimensional territories supplied by them [7-10]. These territories (angiosomes) are blocks of tissues supplied by perforators which arise from the deep principal vessels of the limb, traverse compartments, pierce the deep fascia and then arborise to supply the subcutaneous tissue and skin. Perforators may be muscular or septal, depending upon whether they penetrate the substance of a muscle belly en route to the deep fascia, or run a course intimately related to an inter-muscular septum. The anatomical relationships were described in detail using cadaveric material and injection techniques, followed by exhaustive dissection [9, 10]. Experience indicates that these findings have translated well into clinical practice. Due to the importance of preservation of perforating blood vessels and adequacy of surgical decompression in compartment syndrome, a new technique is proposed for anterior and peroneal compartment fasciotomy.

In the emergency clinical setting, simple hand-held ultrasound devices are regularly used for the safe provision of nerve blocks for pain relief. Similarly, hand-held Doppler devices are also used to check both peripheral circulation and the location of perforator vessels in severe lower limb trauma.

By using these techniques in the clinical setting it should prove possible to safely identify, mark and incise the skin directly over the anterolateral inter-muscular septum, while avoiding compromising perforators and unnecessary skin edge undermining.

Hypothesis:

The inter-muscular septum can be reliably identified using hand-held ultrasound, and confirmed with MRI.

METHOD:

A non-invasive study normal active volunteers was conducted. Medical students were approached after agreement from the College of Medicine, Swansea, and confirmation from the South West Wales Research Ethics Committee that formal ethical approval was not required. Exclusion criteria were all the conventional contra-indications for MRI, plus previous compartment syndrome, previous surgery to the left lower limb below the knee, and any congenital anomalies of the lower limb (e.g. talipes, fibula hemimelia etc). Prior to undergoing imaging, volunteers were required to read the standard Swansea University Volunteer MRI Information Sheet and complete the MRI Procedure Volunteer Safety Questionnaire. The study was conducted in the Clinical Imaging Facility in the Institute of Life Sciences 2 Building, Singleton Campus, Swansea University.

All examinations were made on the volunteers' left lower limbs. Using an indelible pen, the lateral maleolus, fibular head and the tibial crest were marked, the line of the fibula indicated, and the position of the BOA/BAPRAS recommended direct anterior fasciotomy drawn, 1.5-2cm lateral to the tibial crest.

Doppler ultrasound was used to identify the relevant perforator blood vessels. Subjects lay supine on an examination couch with their leg in a neutral position. Perforators were identified using a

Huntleigh Mini Dopplex D900 (Huntleigh Health Care Ltd, Cardiff, UK) handheld doppler, with a 8Mhz probe and a peak sensitivity at 20mm tissue penetration. First the dorsalis pedis artery was located in the foot and tracked proximally into the leg. At points where the signal became significantly louder a mark was placed to indicate a perforator from the anterior tibial artery. Next, the probe was positioned just posterior to the line of the subcutaneous border of the fibula proximal to the lateral malleolus. A "lawnmower" type action was used to detect and mark the most distal perforator. This mark was then used to identify more proximal perforators in the same coronal plane in a similar fashion. The perpendicular distance of each perforator from the marked fasciotomy line was then measured and recorded. These perforators were marked using MRI visible markers (cod liver oil capsules). Anterior perforators have a simple intra-muscular path. Perforators running in the inter-muscular septum between the anterior and peroneal compartments were identified as septocrural perforators. Those which traversed the peroneal muscle bellies were muscular perforators. More posteriorly still, posterior septal perforators were identified in the inter-muscular septum between the peroneii and the posterior compartment. These relationships were recorded.

Ultrasound of the anterior compartment was performed by a trained ultrasound operator, whose practice consists mostly of cardiac and vascular ultrasound. The operator reviewed local and published training material for lower limb ultrasound lower limb prior to commencement of the study [11]. A Sonosite® S-Nerve point-of-care portable ultrasound scanner with an HFL38x 6 - 13MHz linear transducer (FUJIFILM-Sonosite Ltd., London EC4A 3TW, United Kingdom), was used to scan the anterior and lateral aspects of the lower leg. Acoustic shadowing caused by the tibia was used as the marker of the medial borders of the anterior compartment (Figure 1a). Starting proximally, just below the tibial tubercle, the ultrasound transducer was moved laterally towards the fibula, to acquire an axial cross-sectional view of the antero-lateral aspect of the proximal lower leg, and to identify the muscles of the anterior compartment and the inter-muscular septum between anterior and peroneal compartments. The inter-muscular septum was followed distally, keeping the junction of the septum and the deep fascia in the centre on the scanning image, until the septum disappeared just above the level of the lateral malleolus. Marks on the skin, aligned with the centre of the ultrasound transducer, were made with indelible marker pen at 4 – 5cm intervals.

The volunteers limbs were then photographed from an antero-lateral view, to include the markings of the lateral maleolus and fibular head, with the fasciotomy incision line just visible (Figure 2). These images were used to compile a composite picture of the distribution of the alignment of the inter-muscular septum and perforators for all of the volunteers (Figure 3). The distances of each perforator from the lateral maleolus (anterior, septocrural, peroneal muscular or posterior septal) was then determined and expressed as a percentage of the length of the fibula (from the lateral maleolus to the fibular head).

The MRI images were acquired on a Siemens 3T Magnetom Skyra (Erlangen, Germany) system using two-dimensional fast spin echo sequences were performed to provide different contrasts. The T1-weighted axial 4mm slice thickness repetition time was (TR)=681, echo time (TE)=17 and 2 signal average. The T2-weighted axial 4mm slice thickness was TR=5590, TE=98 and 2 signal averages.

Various cod-liver oil type dietary supplements were purchased at a local pharmacy. These capsules were taped to a water phantom and the contrast investigated using the two sequences. The ones showing the best contrast were used as fiducial markers.

Coronal sections were imaged at the level of each perforator and the data acquired saved for analysis. Measurements of the distance of each perforator from the tibial crest were made, along with the distance between the MRI demonstrated septum, and the marked position determined by ultrasound was recorded. As the inter-muscular septum was easily identified on MRI distally where it becomes continuous with the periosteum of the distal fibula, this was then adopted as the starting point for measurements. On each consecutive MRI coronal section, the line of the inter-muscular septum was extended out to the skin, and taken as a reference point and ascribed a value of zero (the zero line). The location of each capsule representing the ultrasound position of the septum was determined, by measuring the distance from the zero line to the point where the radius of capsule meets the skin. Capsules to the fibula side of the zero line were recorded as “plus millimetres” and those to the tibial side “minus millimetres”. The relative position of the perforator markers was also noted (Figure 4).

RESULTS:

Ultrasound data was acquired in 14 subjects, with complete MRI data available in 13. There were 6 male and 8 female subjects. The mean age (range), of the subjects was 25 (22-30) years, median height 2 (1.53-1.94) metres, median weight 65 (49-113) kg and median body mass index 21 (18-32).

No anterior perforators were detected in one subject, and no peroneal perforators in another. A total of 41 anterior perforators were detected in the subjects giving a median (range) of 3(0-6) per volunteer. Septo-crural perforators were detected in only 4 subjects, totalling just 5 perforators with one volunteer having 2 and the remaining three volunteers having a single perforator each. Peroneal muscular perforators were detected in only 6 subjects, but totalling 14 perforators, with three volunteers having 3 perforators, two having 2 and one having a single detectable perforator. A total of 24 posterior septal perforators were detected in 8 volunteers, with three having 4 perforators, three having 3, and the remaining volunteers having 2 and a single perforator respectively.

The anterior and peroneal compartment muscles and the inter-muscular septum between anterior and peroneal compartments were identified on ultrasound in all subjects (Figure 1b). The ultrasound appearance of the septum was found to be characteristic, with little variation between subjects, having a slight convex bulge towards the peroneal compartment. The interosseous membrane, forming the posterior border of the anterior compartment was identified in all subjects, and clearly identifiable as attached to tibia and fibula. Anterior compartment muscles, extensor digitorum longus (EDL), tibialis anterior (TA) and extensor hallucis longus (EHL) were identified in all subjects, and movement within the body of EHL was visible on ultrasound with passive dorsi-flexion and plantar-flexion of the great toe.

Intra-muscular septation made clear identification of the inter-muscular septum difficult in some subjects. This was resolved by slight 'up and down' angulation of the transducer at each level, which showed continuity of the inter-muscular septum, in contrast to intramuscular septae, which were discontinuous. At the distal end of the leg, the inter-muscular septum became less distinct, as the edge of the ultrasound transducer came into increasing contact with the distal fibula (Figure 1c).

Measurements made on using a simple ruler corresponded well to the findings of the MRI studies of the subjects. In every case, the anterior perforators were found to lie lateral to the direct decompression incision line, a median distance of 22mm (range 20-29) from the tibial crest. The median distance of the peroneal perforators from this incision line was 62mm (42-90). The median difference between the ultrasound marked position of the inter-muscular septum compared to that demonstrated by MRI was +4mm (range -8.4mm to +13.1mm) with a tendency to mark the septum slightly closer to the fibula than was demonstrated on ultrasound. In the composite illustration figure 3, the relative position of anterior muscular, septucrural, peroneal muscular and posterior septal perforators are shown, with their location distal to proximal in the illustration being representative of their position in the MRI scan. The location of the MRI and ultrasound demonstrated inter-muscular septum are shown in red and blue respectively with the shaded area indicating the spread of the results.

DISCUSSION:

Since compartment syndrome was first recognised, its surgical management has steadily evolved. It is important to understand that compartment syndrome is a final common pathway which may arise from a host of potential causes. While commonly associated with high energy tibia fractures, the syndrome may arise as a result of arterial occlusion and reperfusion, acute myositis, exertion, crush injuries to name but a few (Bradley EL 1973). A range a fasciotomy techniques have been described with a single common goal, restoration of adequate muscle perfusion to prevent, at best, ischaemic contracture, or at worst whole-sale death of the muscle compartment. Seddon compared and contrasted the unpredictable findings in established ischaemic contracture in the lower limb with the characteristic elipsoid muscle infarct of the upper limb [12]. In the lower limb, the author commented "anything can happen" in terms of the pattern and distribution of the muscle infarct and contracture.

Matsen presented a useful synthesis of available data relating to the pathogenesis, presentation and treatment of compartment syndrome, much of which is still highly relevant today [13], in particular the detrimental effects of elevating the limb in the established syndrome. In both civilian and military spheres relatively small cases series were published using either a single parafibula approach, or more commonly medial and lateral incisions to decompress all four compartments. The double incision technique was widely advocated from the early 1970's onwards, , with a variety of landmarks used to position the skin incision for decompression of the anterior and peroneal compartments including a line 2cm anterior to the line of the fibula, to one halfway between fibula and tibia [3, 14, 15]. Short surgical incisions followed by "subcutaneous fasciotomy" were superseded by longer open incisions supported by clinically relevant reduction in compartment pressures [15]. The use of surface anatomical landmarks to place incisions could become less reliable in acutely injured, swollen and deformed limbs. Simple physical techniques such as the *poke test* can help answer the first vital question "which compartment am I in?" [16] However, only clinical judgement can assure the answer to the second vital question "have I decompressed the compartment sufficiently, in anticipation of further swelling? " In a series of over 600 fasciotomies in military casualties, the adequacy of fasciotomy and its consequences were studied [2]. At "second-look", when fasciotomy was judged to be inadequate (i.e. not all intended compartments were in fact fasciotomised, or the decompression was inadequate in terms of extent) rates of muscle excision, amputation and also death increased dramatically. These findings reinforce the current practice of making incisions the whole length of compartment, stopping (or deviating) only to avoid exposure of bone or tendon.

The angiosomal blood supply to the anterior compartment appears to make it particularly vulnerable to wholesale tissue death. Thus an argument could be made in favour of using "constant" anatomical landmarks which will ensure direct entry to the anterior compartment. Hence the current recommendation to make the anterior fasciotomy wound 2 cm lateral to the tibial crest. The other potential advantage of this incision is to avoid peroneal perforators, which may be jeopardised with a more posterior incision. The primary reference for this technique has proven elusive, and no series specifically reporting outcome using this approach has been identified. When the muscle of the anterior compartment then bulges in the manner usually seen, then access to the inter-muscular septum to decompress the peroneal compartment will be difficult. Injury to the superficial branch of the common peroneal nerve is a recognised complication. Variability in the path of the superficial branch of the common peroneal nerve does place it at risk of division particularly if the peroneal compartment is decompressed in this manner [6]. It's most common path is for the nerve to run in the peroneal compartment and pierce the inter-muscular septum, emerging into a superficial position 12cm proximal to the ankle joint, and dividing into its terminal branches 4 cm proximal to the joint. However, in up to a quarter of individuals, it or one of its major branches runs within the anterior compartment itself. Thus, if the crural fascia itself is divided, the superficial branch of the peroneal nerve is likely to be divided too. It is inevitable that septal peroneal perforators will be divided, and the fate of anterior perforators is never considered.

From the data presented in this study, it can be seen that in the uninjured, young, active subject, the inter-muscular septum can be reliably identified using portable ultrasound machines of the type readily available in operating theatres in United Kingdom. The marked position of the septum corresponded well with that demonstrated on MRI however the position of the septum is variable from one individual to another, suggesting that the use of surface landmarks would not result in accurate placement of the wound over the septum.

The position of the anterior, septal and peroneal muscular perforators, in relation to decompression is of interest. Whatever technique is employed the septal perforators will not survive. The peroneal perforators lie in a position significantly posterior to the line of an incision located over the septum. In the subjects examined in this study, the number and distribution of anterior compartment perforators demonstrated using hand-held Doppler is extremely variable. If the direct anterior fasciotomy incision had been used, all of these perforators would have been sacrificed in every case. Significant soft tissue problems may then occur compromising the skin over the subcutaneous border of the tibia.

After concluding this study, two patients have under-gone fasciotomy for acute compartment syndrome of the leg after this techniques was employed to aid in placing the antero-lateral fasciotomy. A male patient developed signs of acute compartment syndrome within three hours of a tibial osteotomy and reamed intramedullary nailing to correct a malunion. The ultrasound technique was described to the consultant anaesthetist on duty who agreed to undertake the examination and mark the septum accordingly. After general anaesthesia, compartment pressures were confirmed to be elevated.The consultant anaesthetist used hand-held ultrasound to define and mark inter-muscular septum, starting at the distal fibula working proximally. The incision was placed over this line deviating 1.5 cm anterior to the lateral maleolus distally, to avoid exposure of bone. The planned incision was found to lie immediately over the septum and the peroneal and anterior compartments were decompressed to separate fashion incisions (Figure 5). The superficial branch of the common peroneal nerve was identified easily preserved. The medial fasciotomy was performed in the conventional manner. At 48 hours the medial wound was closed using delayed primary closure, and the lateral with a combination of delayed primary closure and split skin graft. The patient went on to make a full recovery. In the second case, a female patient in her mid-sixties developed acute compartment syndrome in a 2 hour interval, the morning after her admission with a displaced spiral segmental distal tibial fracture sustained in a fall at home. Identifying the inter-muscular septum proved a little more difficult than in the first case, but this was accomplished without delay. The gliding of muscles elicited by passive flexion and extension of the digits as described above proved very helpful. All 4 compartments were decompressed and then a reamed tibial nailing performed. Both wounds were closed uneventfully at 5 days, and full weight-bearing mobilisation commenced.

Conclusions.

This study has demonstrated that hand-held ultrasound can reliably be used to mark the position of the inter-muscular septum in a group of healthy active volunteers. Placing the incision over the septum wouldn't jeopardise muscular perforators traversing anterior and peroneal compartments. The technique has been used successfully in two cases of acute compartment syndrome to date.

There are limitations to this study. In the absence of any pre-existing data, conducting this study in volunteers was essential. How reliable the technique will prove in the presence of acute trauma remains to be seen. Clearly, soft tissue trauma may make the structure of the septum less distinct, but applying the principle of "go to normal" may minimise this problem. While the distal fibula may help in locating the septum at its distal end, is vitally important to avoid exposing bone with the surgical incision hence deviation anteriorly is described.

Ultrasound is a highly operator dependent technique, and very careful liaison between the surgeon executing the fasciotomies and the anaesthetist assisting them with the ultrasound examination is vital. As the technique is new, the surgeon must be present to support and confer during the ultrasound examination.

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Our thanks.

Figure Legends

Figure 1: Ultrasound images showing (1a) Acoustic shadowing caused by the tibia was used as the marker of the medial border of the anterior compartment (AC). The intermuscular septum (dotted line), peroneal compartment (PC) and the tibia are indicated (triangular arrow). (1b) The ultrasound appearance of the septum (dotted line) was found to be characteristic, with little variation between subjects, having a slight convex bulge towards the peroneal compartment. Extensor hallucis longus (EHL), tibialis anterior (TA) and extensor digitorum longus (EDL) are indicated. (1c) At the distal end of the lower leg, the inter-muscular septum became less distinct, as the edge of the ultrasound transducer came into increasing contact with the distal fibula indicated with a triangular arrow.

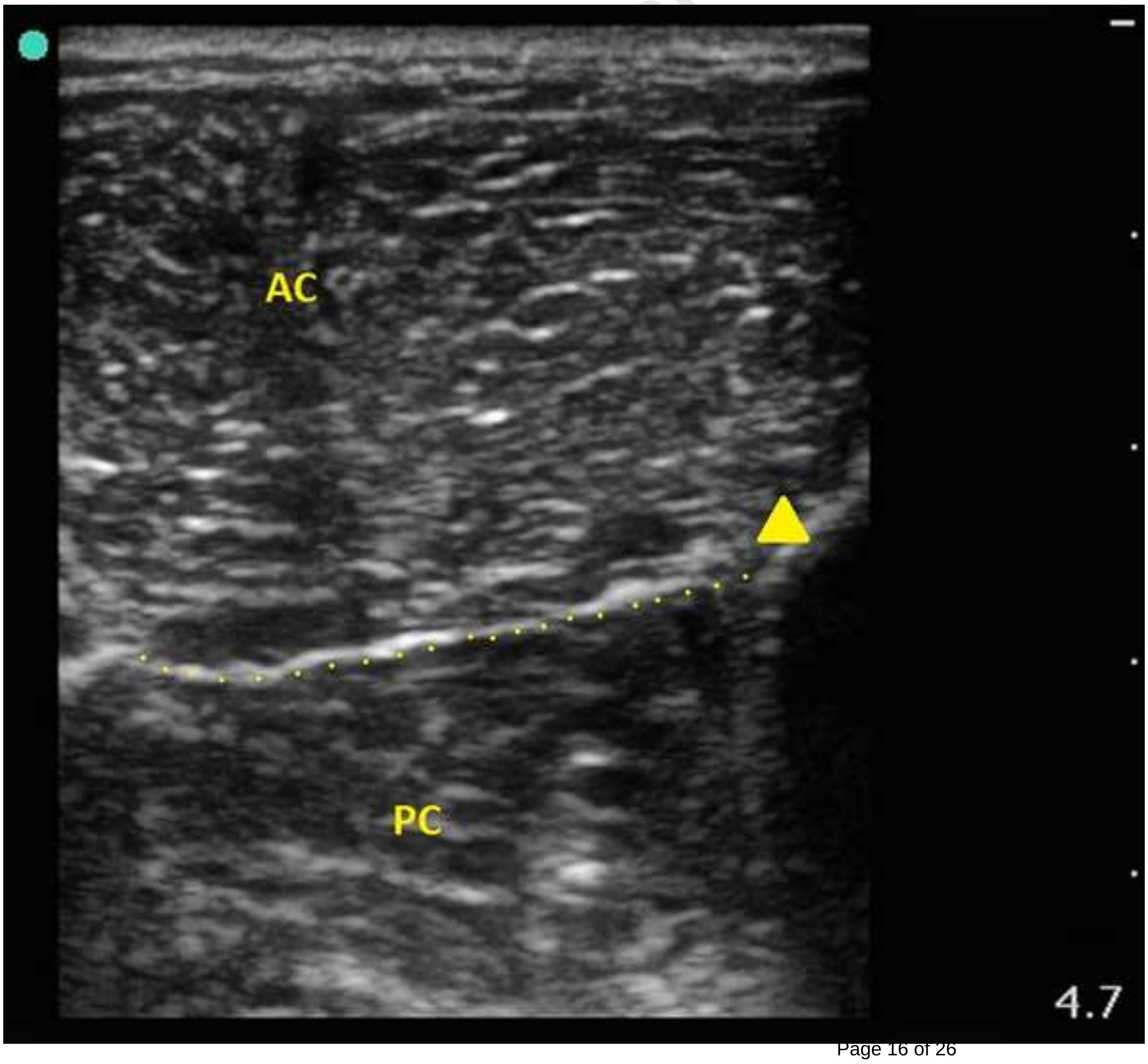
Figure 2: A volunteer's limb from an antero-lateral view, to include the markings of the lateral maleolus and fibular head, with the fasciotomy incision line just visible, with oil capsules marking the position of perforator blood vessels (small, round, light coloured) and the intermuscular septum (dark oval).

Figure 3: A composite illustration derived from a previous patient's CT scan rendered in 3D as the basis. The relative position of anterior muscular (green), septucrural (red), peroneal muscular (blue) and posterior septal (purple) perforators are shown, with their location distal to proximal in the illustration being representative of their position in the MRI scan. The location of the MRI and ultrasound demonstrated inter-muscular septum are shown in red and blue respectively with the shaded area indicating the spread of the results.

Figure 4: MRI coronal sections of the same volunteer's leg showing the position of oil capsule positioned using ultrasound indicating the intermuscular septum (dark marker with lighter circumferential ring) at 3 levels and small, round, light coloured markers indicating (4a) an anterior muscular perforator, (4b) a posterior septal perforator and (4c) a peroneal muscular perforator.

Figure 5: Clinical images of the example case showing (5a) ultrasound identification of the intermuscular septum. (5b) marking of the skin incision compared to the line of the septum – note the anterior deviation at the distal end to avoid exposure of the lateral maleolus. (5c) the skin and fascial incisions at completion of the procedure.

Figure



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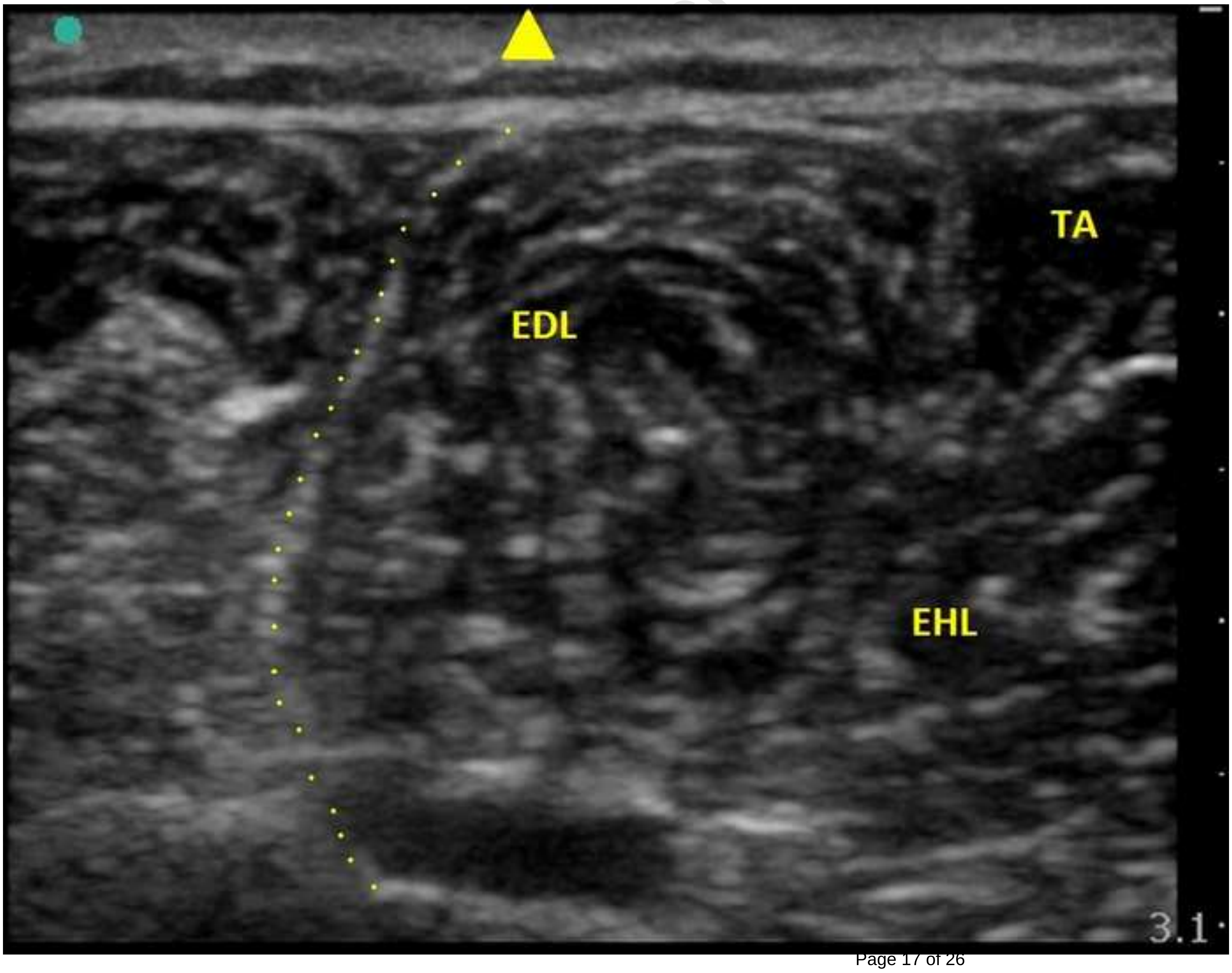

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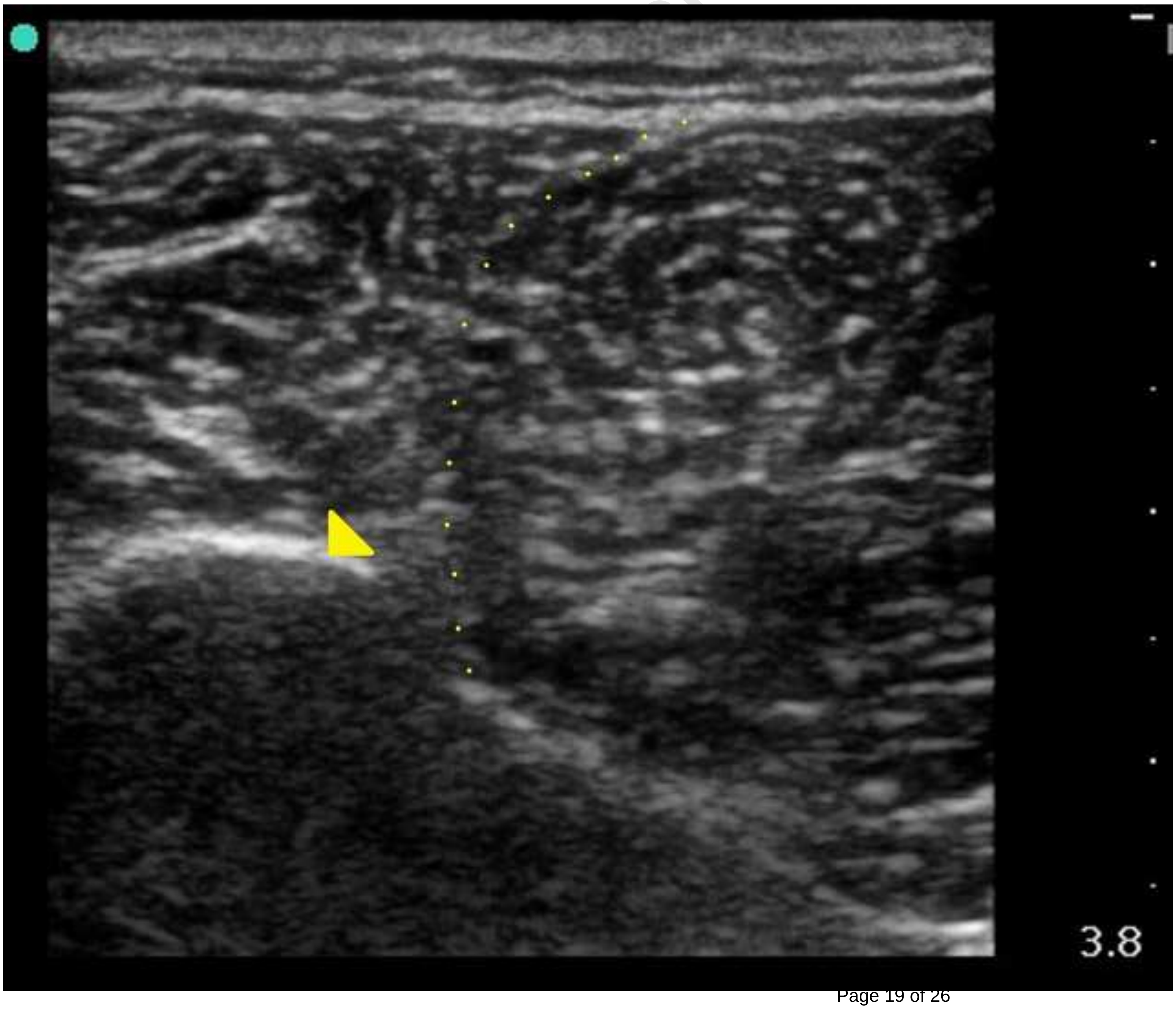

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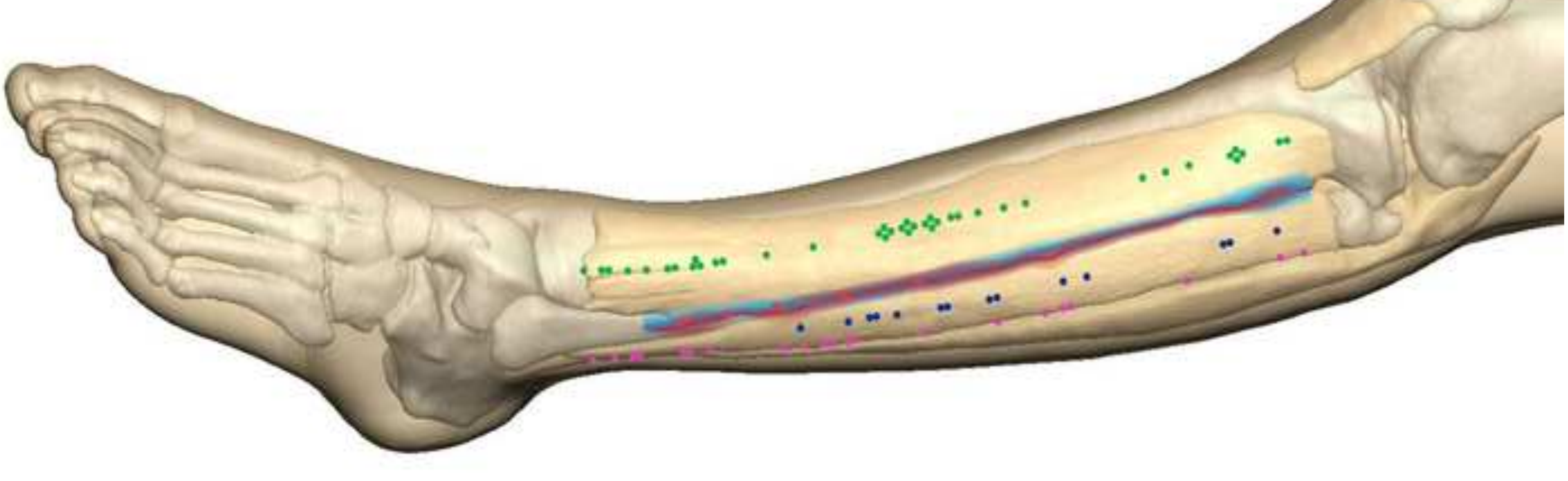

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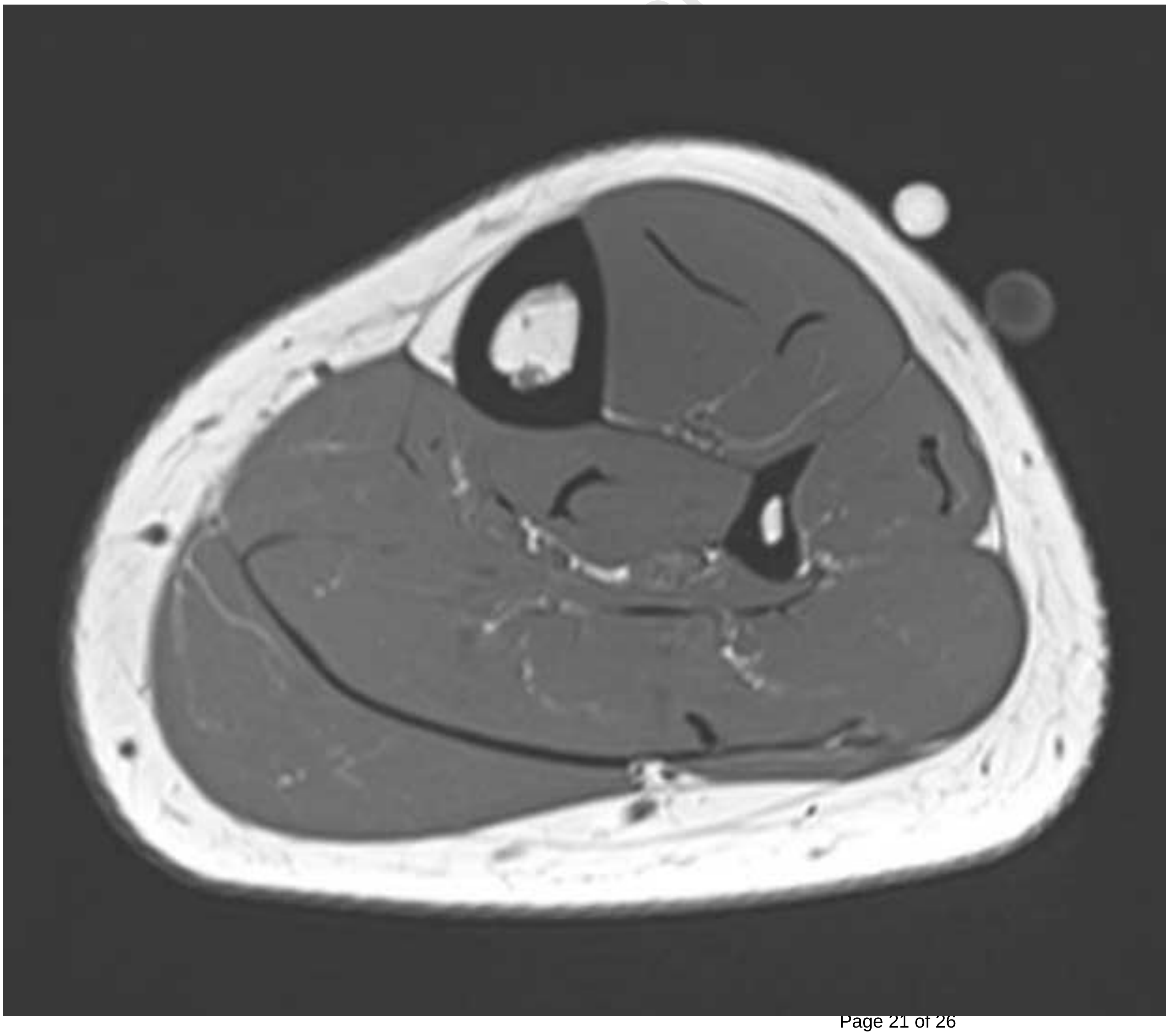

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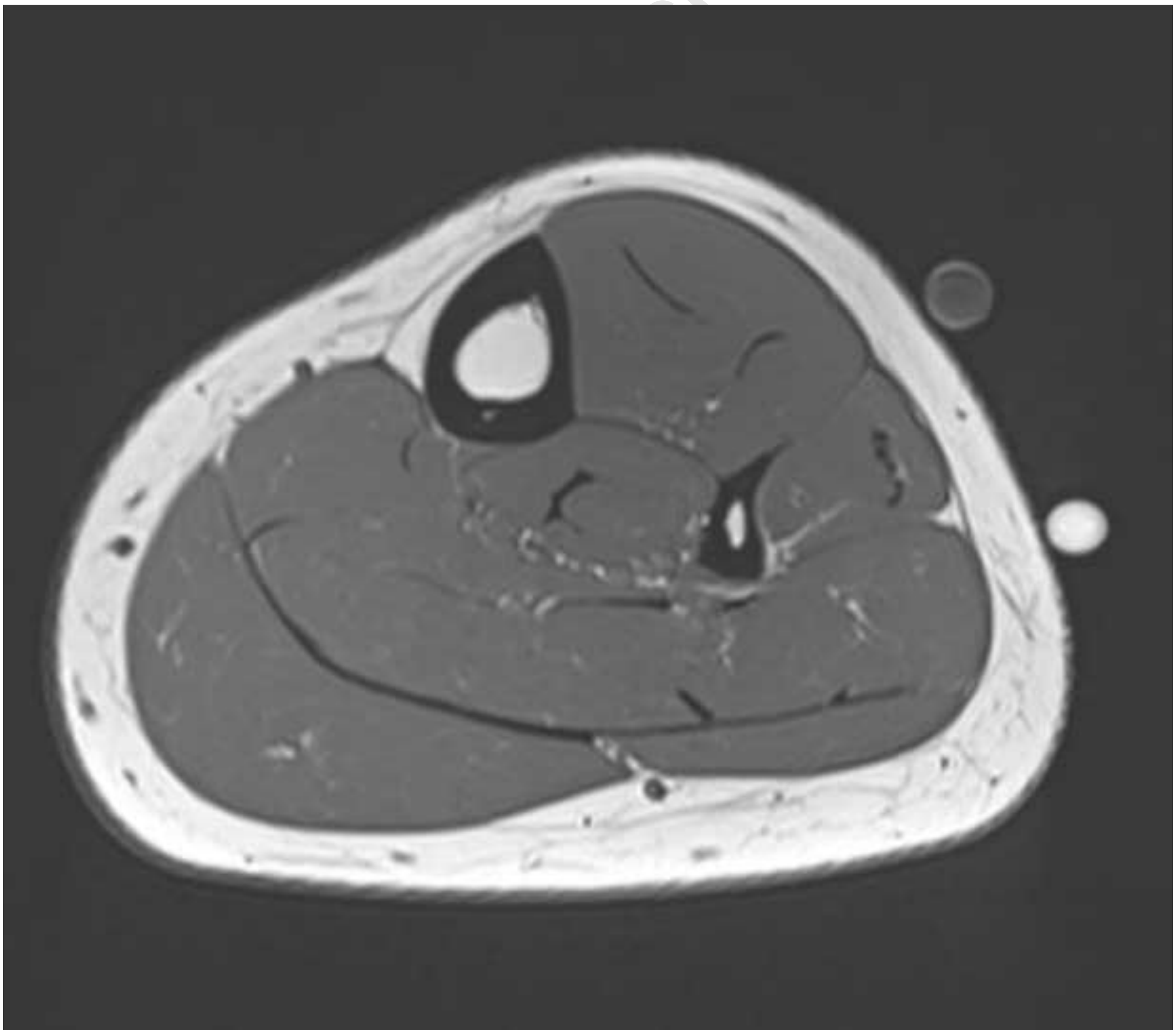

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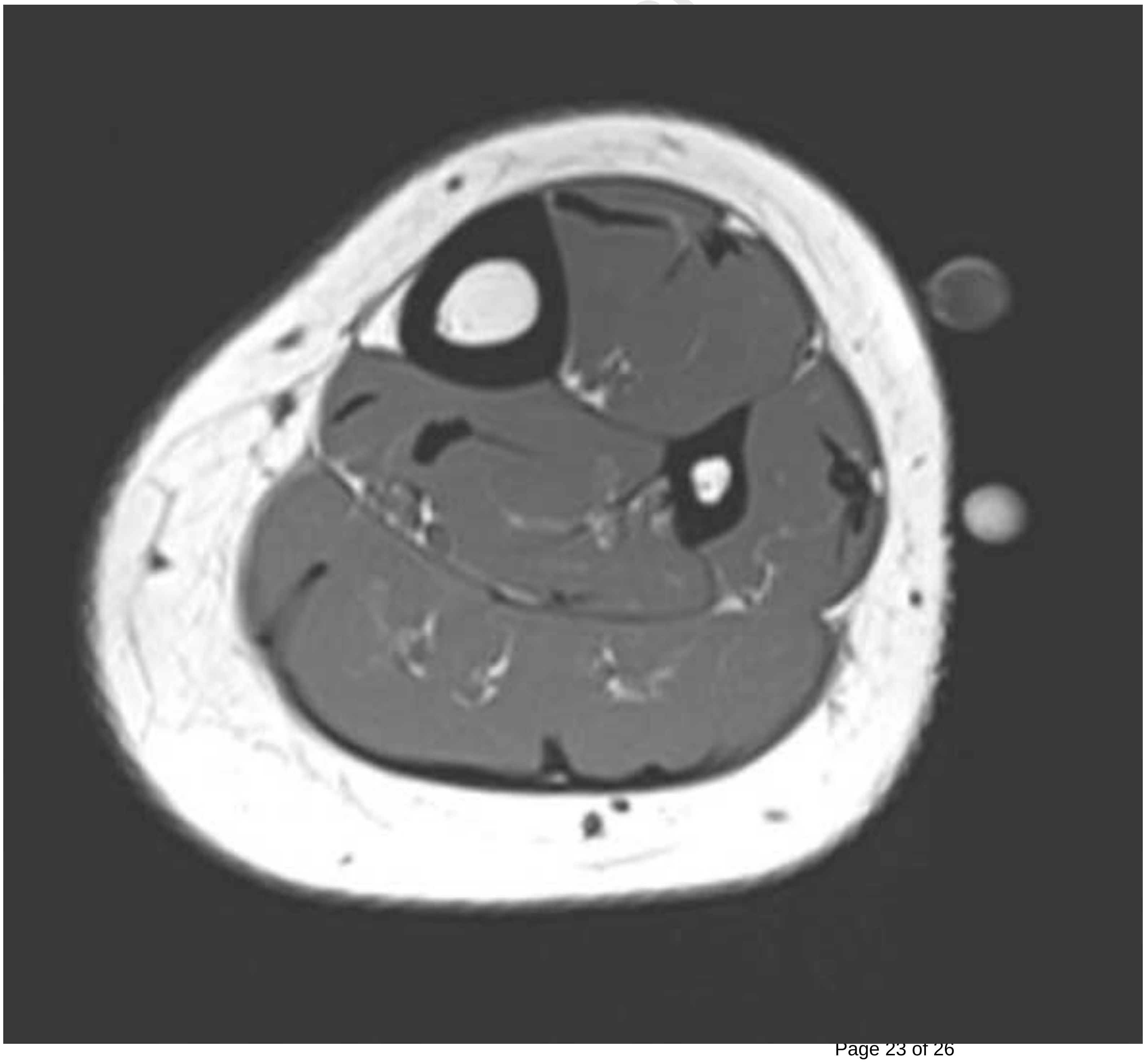

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