TITLE: Verification of a standardized method for inserting intramuscular EMG electrodes into uniquely oriented segments of gluteus minimus and gluteus medius.

Original communication

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Abbreviated title: Gluteus minimus and medius EMG guidelines

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Guidelines for assessing the function of gluteus minimus and gluteus medius with electromyography (EMG) traditionally offer one electrode placement site per muscle. However, anatomical studies suggest that there are two uniquely oriented segments within gluteus minimus (anterior and posterior), and three within gluteus medius (anterior, middle and posterior) with potential for independent function. Assessment of these muscles with one electrode may therefore provide only a limited account of their role. Thus, the aim of this cadaveric study was to verify guidelines for placing intramuscular electrodes into two uniquely oriented segments of gluteus minimus, and three segments of gluteus medius. The guidelines were developed with reference to anatomical reports, cadaveric observation and real-time ultrasound imaging in-vivo. Five cadaveric gluteal regions were marked for intramuscular electrode insertions based on these guidelines. Intramuscular electrodes were inserted into the marked regions of gluteus minimus (x2) and gluteus medius (x3) with the aid of a 15 cm biopsy needle. Systematic dissection revealed that electrodes were successfully inserted into uniquely oriented segments of gluteus minimus and medius. The orientation of fascicles surrounding each electrode was also consistent with segmental descriptions in past anatomical research. The findings of this research suggest that the guidelines described may be used to assess the functional role of segments within gluteus minimus and medius in health and dysfunction using EMG. Finally, electromyographers intent on investigating the role of posterior gluteus minimus must be cautious of the superior gluteal neurovascular bundle.

Key words: Hip; buttocks; electromyography; gluteal; abductor.
INTRODUCTION

The concept of “muscles within muscles” implies that there are segments within a muscle with different functional characteristics and potential for independent control from the central nervous system (Wickham and Brown, 1998). Pertinent to this concept is that these segments have unique anatomical or fascicular arrangement (Segal et al., 2002; Wickham and Brown, 1998; Woodley and Mercer, 2005). Anatomical studies, texts and reviews have described three uniquely oriented segments within gluteus medius (GMed) (Al-Hayani, 2009; Flack et al., 2011; Gottschalk et al., 1989; Palastanga et al., 1989) and two within gluteus minimus (GMin) (Al-Hayani, 2009; Beck et al., 2000; Flack et al., 2011; Standring et al., 2005), supporting previous notions of functional differentiation within these muscles (Beck et al., 2000; Gottschalk et al., 1989; Grimaldi et al., 2009b; Soderberg and Dostal, 1978).

Electrode placement guidelines for assessing the function of GMin and GMed with electromyography typically offer one placement site per muscle, thus detecting myoelectric activity from a small sample of muscle fibres (Perotto et al., 2005). To study these muscles with one EMG electrode may provide only a limited account of their function.

Electromyographic research into GMin function is surprisingly scarce. In fact, the only published EMG investigation uses outdated processing and analysis techniques (Wilson et al., 1976). Moreover, Wilson and colleagues explored GMin with only one fine wire electrode, inserted two inches posterior to the anterior superior iliac spine (ASIS). Whether this electrode was functionally representative of the entire GMin, and perhaps more importantly, whether the electrode was actually in GMin was not confirmed.

Electromyographic research into GMed function is not as scarce, yet is quite heterogeneous. As identified in a recent systematic review, at least six different electrode placement sites have been used by different investigators in reports of GMed function (French et al., 2010). It may not be possible to qualitatively pool or compare results between
studies, given that each investigator may be recording activity from structurally and functionally unique regions of GMed. Furthermore, limitations exist when less than three electrodes are used to assess entire GMed function (Earl, 2005; Philippon et al., 2011), or when surface electrodes are placed over anterior or posterior segments (Gottschalk et al., 1989; O'Sullivan et al., 2010). Surface electrode signals may be contaminated by additional myoelectric activity from surrounding muscles (gluteus maximus and tensor fascia lata) or segments (Bogey et al., 2000; Chapman et al., 2010; Perry et al., 1981). Fine wire electrodes would offer greater specificity for investigating the three segments, however only posterior GMed insertions have previously been verified (Hodges et al., 1997), and the only fine-wire study into multiple GMed segments is again outdated (Soderberg and Dostal, 1978). Furthermore, the latter investigators confirmed electrode location by palpation and the depth of electrode insertion was not specified. The proximity of gluteus maximus (GMax) and tensor fascia lata (TFL) to the posterior and anterior regions of GMed respectively (Moore et al., 2010; Standring et al., 2005) make confirmation of these segments by palpation difficult and the accuracy of the electrode locations questionable. The purpose of the present study was therefore to provide anatomical evidence for a standardized method of inserting fine wire electrodes into three regions of GMed and two regions of GMin based on fascicular orientation.
MATERIALS AND METHODS

Materials

Cadaveric material. Gluteal regions from five separate embalmed cadavers (4 right and 3 left limbs; 3 female and 2 male) aged 81 to 97 years (mean, 88.6; SD, 6.0) were used in this study.

Other materials. Real-time ultrasound (RTUS) imaging (Aquilia Pro, Esaote, Genova) was used to confirm locations of bony landmarks. Electrodes were inserted into each cadaver with a needle and electrode unit. The design of the electrodes was consistent with that used in vivo and consisted of bipolar, stainless steel, teflon coated wire electrodes which were inserted into the lumen of a 22 gauge, 15 cm Chiba biopsy needle (Bloodline S.p.A, Medolla). The tip of the wire electrode was bent back over the needle to form a 3 mm hook (Basmajian and Stecko, 1962). The hook enabled wire electrodes to remain in situ when the needle was removed.

Methods

The lateral surface of each specimen was placed uppermost on a dissection table. This position (side lying) is used in vivo so that all segments of GMin and GMed can be accessed without repositioning and thus minimises participant disturbance.

Insertion sites. These were developed with reference to anatomical texts and papers (Al-Hayani, 2009; Beck et al., 2000; Gottschalk et al., 1989; Sparks, 2011; Standring et al., 2005), cadaveric examination and RTUS imaging in vivo. For example, observations of GMin on cadavers revealed that it was positioned within the anterior two thirds of a line taken directly from the ASIS to the posterior superior iliac spine (PSIS). The anterior segment of GMin (vertical fascicles) was located in the first third and the posterior segment (posterior fascicles) was located in the second third. The centre of these segments therefore
corresponds to 1/6 and 3/6 (half) respectively along the line from the ASIS to the PSIS. Moving 3 cm inferiorly towards the GT enables placement of an electrode within the belly of the segment. A similar approach was taken for identifying anterior (anterior fascicles), middle (vertical fascicles) and posterior (posterior fascicles) segments of GMed. However, in this instance, a line along the length of the iliac crest was used as a reference.

For each specimen, the following bony landmarks were located and marked with pins; iliac crest (entire length), ASIS, PSIS and the cranial tip of the greater trochanter. Locations of bony landmarks were confirmed with RTUS imaging. Segmental EMG electrode placements were subsequently marked as illustrated in Figure 1.

*Insert Figure 1 here*

**Electrode insertion.** For each insertion site described above, the needle and electrode unit were inserted vertically until met with bony resistance. Accurate insertion to a desired depth with RTUS assistance was unable to be performed as the visual acuity of fascial planes in cadaver specimens is poor (Hodges et al., 1997). Needles were therefore inserted all the way to the ilium. Each needle was removed and wires remained in situ.

In order to compare the posterior GMed electrode placement site of Hodges et al. (1997) with our posterior GMed insertion, a further electrode was inserted into all cadavers based on the description in Hodges et al (1997).

**Dissection, wire electrode location and fascicle orientation.** Gluteus medius: An incision was made through the skin along a line from the anterior aspect of the greater trochanter in a cephalad direction towards the ASIS. Another incision was made from the greater trochanter in a transverse plane, medially along the posterior aspect of the gluteal region. The skin was then reflected to expose the attachments of GMax, GMed and TFL.
along the iliac crest. Care was taken so as not to dislodge the wire electrodes in situ by leaving a ‘button’ of tissue until the wires were located at the next fascial plane (e.g., a button of skin and superficial fascia until the wire could be located passing through GMax). The location of GMed electrodes relative to GMax and TFL were qualitatively described. Gluteus maximus and TFL were subsequently removed to expose the entire GMed muscle. The entry point of each wire electrode into GMed was located, and the orientation of fascicles (anterior, vertical or posterior) surrounding each electrode was recorded and compared to descriptions in past anatomical research (Al-Hayani, 2009; Gottschalk et al., 1989).

*Gluteus minimus:* The overlying GMed was removed carefully by detaching its proximal origin from the gluteal surface and lip of iliac crest. The proximal attachment along the iliac crest was excised laterally towards the ASIS. At this point, GMed could be reflected distally and removed with further excision of its tendinous insertion at the greater trochanter. The entry point of each wire electrode into GMin was located, and the orientation of fascicles (posterior or vertical) surrounding each electrode was recorded and compared to descriptions in earlier research (Al-Hayani, 2009; Beck et al., 2000; Nazarian et al., 1987).
RESULTS

Gluteus Medius

*Electrode position and fascicle orientation.* The three electrodes successfully penetrated GMed (Fig. 2). Fascicles surrounding anterior, middle and posterior GMed electrodes were directed anteriorly, vertically and posteriorly respectively (Fig. 2), and were consistent among all five cadavers. Anterior and middle electrodes entered directly into GMed, while the posterior electrode initially penetrated GMax (Fig 3). The arrangement of electrodes in relation to superficial musculature is illustrated in Figure 3. The additional Hodges electrode was closely positioned to our posterior GMed electrode, in fascicles directed posteriorly (Fig. 2).

*Insert Figure 2 and Figure 3 here*

Gluteus Minimus

*Electrode position and fascicle orientation.* Anterior and posterior electrodes successfully penetrated the GMin muscle belly (Fig. 4). Fascicles surrounding anterior and posterior electrodes coursed vertically and posteriorly respectively. The posterior electrode was closely positioned to the superior gluteal neurovascular bundle (NVB), and a large postero-superior portion of GMin was observed to lay deep to the NVB and piriformis. The anterior electrode penetrated GMed prior to GMin, while the posterior electrode pierced GMax and GMed before entering GMin (Fig. 3). These findings were consistent in all 5 cadavers.

*Insert Figure 4 here*
DISCUSSION

Gluteus Medius

Previous cadaveric research and anatomical texts have described the anterior fibers of GMed as being oriented obliquely anteriorly (almost vertical) as they ascend from the greater trochanter, middle fibers being vertical and posterior fibers directed posteriorly (Al-Hayani, 2009; Gottschalk et al., 1989; Palastanga et al., 1989). The fine wire electrode placement sites in this study have successfully been inserted into regions of GMed with comparable fascicular arrangements in five cadavers. This is the first study to offer and confirm fine wire EMG electrode placement sites for three regions of GMed with independent fascicular orientation.

There is only one other study that verifies fine wire electrode placement for any region of GMed (Hodges et al., 1997). A location of 3 cm lateral and 2 cm inferior to the PSIS was confirmed by Hodges and colleagues and has been used in subsequent EMG studies into posterior GMed (Cowan and Crossley, 2009; Cowan et al., 2009; Crossley et al., 2011). This location was developed by identifying the boundaries of posterior GMed through RTUS imaging in vivo, while our locations were developed by partitioning the entire GMed into three equal segments (Soderberg and Dostal, 1978) and identifying their relevant positions to bony landmarks in cadaver specimens. Both studies were able to insert an electrode into fascicles of GMed that were oriented posteriorly (described as almost horizontal by Hodges et al. (1997)). The difference in location between the two sites is marginal and may not be clinically relevant, as fascicles surrounding both electrodes are posteriorly oriented (Fig. 2). Signals recorded from two different sites of a muscle segment with similar morphological characteristics have previously been reported as comparable (Bogey et al., 2000; Chapman et al., 2006), although this would need to be verified for these electrode locations.
The posterior line of pull created by the posterior fascicles of GMed is hypothesised to assist with load transfer, or resist ground reaction forces during the initial stage of gait (Anderson and Pandy, 2003; Gottschalk et al., 1989). Additionally, the parallel arrangement of these fibers to the neck of femur may help to draw the head of femur towards the acetabulum, facilitating hip joint stability (Al-Hayani, 2009; Earl, 2005; Gottschalk et al., 1989). There are a number of studies that attempt to quantify the role of posterior GMed during functional tasks (Cowan and Crossley, 2009; Cowan et al., 2009; Crossley et al., 2011; Gottschalk et al., 1989; O'Sullivan et al., 2010; Soderberg and Dostal, 1978). However, posterior GMed is deep to GMax (Fig. 2) and can only be accessed with intramuscular electrodes. Only three studies have applied a technique that ensures accurate location of intramuscular electrodes into posteriorly directed fascicles (Cowan and Crossley, 2009; Cowan et al., 2009; Crossley et al., 2011). The results of the studies suggest that posterior GMed activity is comparable between males and females during a step task (Cowan and Crossley, 2009); is significantly delayed during a poorly performed single leg squat (Crossley et al., 2011) and also delayed in the presence of patello-femoral pain (Cowan et al., 2009). There are no other investigations that attempt to confirm independent fascicle orientation surrounding electrodes positioned in anterior and middle regions of GMed. The morphological differences between these two regions may be minimal, however some authors speculate that the difference is enough to partition unique functional roles between them (Al-Hayani, 2009; Earl, 2005; Gottschalk et al., 1989). For example the vertical nature of the middle and anterior fascicles place them in a position to maintain vertical femoro-pelvic alignment in the coronal plane during the middle stage of the gait cycle; and the additional oblique or anteriorly directed anterior fascicles may contribute to forward contralateral pelvic rotation in the transverse plane from the mid to late stage of the gait cycle (Gottschalk et al., 1989; Soderberg and Dostal, 1978). The culmination of these roles together with the posterior
region would potentially result in independent, phasic activation of three regions of GMed within a gait cycle (Gottschalk et al., 1989; Soderberg and Dostal, 1978). Previous investigations that aimed to define the roles of anterior or middle regions either consider the two regions as one (Cowan and Crossley, 2009; Cowan et al., 2009; Crossley et al., 2011), use surface electrodes (Cowan and Crossley, 2009; Cowan et al., 2009; Crossley et al., 2011; Earl, 2005; Gottschalk et al., 1989; O'Sullivan et al., 2010) which may be subject to additional segmental myoelectric activity (Chapman et al., 2010), or fail to confirm adequate placement in GMed or its regions (Soderberg and Dostal, 1978). Our study offers three sites that can be used to insert fine wire electrodes into regions of GMed with potential for unique functional roles based on their fascicular orientation. This is the first study to offer such locations for anterior and middle regions and supplements that of Hodges et al. (1997) for the posterior region. Further research is needed to build on previous work, in particular to compare the roles of the three segments of GMed.

**Gluteus Minimus**

Anatomical texts and studies have described two regions of GMin with unique fascicular orientation (Al-Hayani, 2009; Beck et al., 2000; Nazarian et al., 1987; Standring et al., 2005). The anterior fibers course vertically and the posterior fibers run posteriorly (Al-Hayani, 2009; Beck et al., 2000; Nazarian et al., 1987) as they ascend from the greater trochanter. The orientation of fascicles surrounding the anterior and posterior electrodes in our study is consistent with those described above.

Many authors support the notion that GMin has a leading role in hip joint stability (Al-Hayani, 2009; Beck et al., 2000; Gottschalk et al., 1989). This theory is strengthened by a magnetic resonance imaging (MRI) investigation that demonstrated a dramatic increase in signal intensity of GMin following five minutes of loaded single leg standing (Kumagai et al.,
The increase was significantly greater than that of GMed. Furthermore, analysis with proton emission tomography after 15 minutes of walking revealed that glucose uptake was significantly larger in GMin than the other gluteal muscles (Oi et al., 2003). These radiological measures however do not allow muscle activity to be assessed in real-time and limit the dynamic and temporal assessment of muscle activation patterns. The guidelines provided in the present study may be used to expand on the functional understanding of this theoretically important, yet understudied muscle.

Neurovascular bundle. The location of the superior gluteal nerve (SGN) and the deep superior gluteal vessels are of importance to an electromyographer intent on investigating GMin and GMed. The course of these nerves and vessels have been described in detail previously (Akita et al., 1993, 1994a, 1994b; Sparks, 2011). Collectively they offer neurovascular supply to GMed, GMin and TFL. There is a high concentration of these nerve branches and vessels forming a NVB superior to the greater sciatic notch and piriformis, in the facial plane between GMed and GMin (Collinge et al., 2005).

The posterior GMin electrodes in our study were closely situated to the NVB (Fig. 4). Damage to these nerves and vessels has been reported in some surgical procedures (Collinge et al., 2005; Eksioglu et al., 2003). Possible consequences include hip abductor weakness (Grisold et al., 1999), fatigue (Collinge et al., 2005), or cutaneous parasthesia over the anterolateral thigh (Akita et al., 1992). The needles used in fine wire research are much thinner than typical hip surgical instruments, however steering clear of these nerves and vessels is recommended at the very least to limit participant discomfort and avoid “shorting” the EMG signal from blood pooling (Basmajian and De Luca, 1985). In light of this information, we recommend the use of Doppler imaging under RTUS in order to define the clearest insertion path before inserting electrodes into posterior GMin (Fig 5A). Pilot trials in our laboratory
have demonstrated that careful insertion into GMin using this technique is possible in vivo (Fig. 5B).

Insert Figure 5 here.

A further consideration is that the NVB and piriformis cover a significant portion of posterior GMin (Fig. 4). These most posterior fascicles may have an important role in hip joint stability (Al-Hayani, 2009; Gottschalk et al., 1989) and capturing their EMG activity would be desired. However, like the neighboring obturators, gemelli and quadratus femoris, the proximity to neurovascular structures (Standring et al., 2005) mean that accessing these deep fascicles with EMG electrodes seems unfeasible.

Limitations

Real-time ultrasound guided insertions were unable to be performed in this study because the visual acuity of fascial planes in cadaver specimens is poor (Hodges et al., 1997). The electrodes were consequently inserted to the ilium. In reality, the depth of insertion is an important consideration in order to ensure that the tip of each electrode rests in the desired muscle belly. For example, anterior GMed electrodes inserted to the ilium as described in the current cadaveric study would pass through GMed and eventually rest in GMin (Fig. 5 C). Real-time ultrasound guided insertions are a valid way of judging the depth of electrode insertions (Hodges et al., 1997), thus should be used in vivo for each of the locations described (Fig. 5 C). Inserting electrodes into forty to sixty per cent of a muscles cross sectional depth is considered adequate for obtaining clear EMG signals from fine wire electrodes (Chapman et al., 2010).
A further limitation is that our study has only considered fascicle orientation as a potential determinant of functional partitioning within a muscle. Other important considerations of partitioning are innervation patterns (English et al., 1993), and morphological differences between segments such as fibre length or volume (Becker et al., 2010; Lieber and Fridén, 2000; Woodley and Mercer, 2005). An additional morphological determinant, as described by Jaegers et al. (1992) with respect to GMed is the possible differentiation of segments according to distinct fascial partitioning. In particular, Jaegers et al. (1992) suggest that the middle and anterior compartments of GMed can be fascially differentiated into deep anterior, and superficial lateral segments based on MRI investigation. However, the most recent and comprehensive cadaveric study failed to identify a consistent fascial partition dividing regions of middle and anterior GMed (Sparks, 2011). The most consistently documented, morphological feature distinguishing regions of GMed is that of fascicle orientation (Al-Hayani, 2009; Gottschalk et al., 1989; Sparks, 2011), and therefore became the distinguishing morphological variant between segments in our study. It follows, that EMG signals detected from electrodes positioned according to the guidelines of our study may not represent muscle activity from segments of GMed that have been classified by other means (Jaegers et al., 1992).

Finally, Basmajian and Deluca (1985) suggest that electrodes be placed away from the innervation zone (IZ) of a muscle. The IZ represents an area of muscle with a large cluster of motor end plates and repeated placement of electrodes in or around this zone can result in great variability in EMG signals (Basmajian and De Luca, 1985; Rainoldi et al., 2004). This is due to the two electrodes of a bi-polar unit being positioned on either side of a motor endplate, detecting action potentials propagating in opposite directions, thus recording a lower potential difference between electrodes (Rainoldi et al., 2004). The IZ of GMed is
reportedly one third of the distance from the greater trochanter to the iliac crest (Rainoldi et al., 2004), and our GMed locations appear to be well enough away from this position. There are no reported accounts of the IZ of GMin, which may impact on the potential reliability of EMG signals from our locations. However, inter-electrode distances of bi-polar intramuscular electrodes are extremely small (around 1-2 mm) (Basmajian and Stecko, 1962), which would reduce the likelihood of electrodes being placed on either side of a motor endplate. Nevertheless, further work is required to establish the exact location of the IZ in GMin.

Clinical implications

These segmental electrode placement guidelines will assist with providing a more complete picture of the normal role or function of GMin and GMed. Pilot work using these electrode locations in vivo suggests that for a given task, segments within GMin, as well as GMed, are working at largely different intensities (Semciw et al., 2011). It follows that normal GMin or GMed function cannot adequately be defined without considering multiple segments. A further finding from pilot work is that anterior GMed is highly active during maximum resisted hip joint extension (Semciw et al., 2011) and highlights a possible stabilising role of anterior GMed during this manoeuvre (Lewis et al., 2007). Such findings would not be possible with traditional GMed electrode placements (Perotto et al., 2005). Finally, hip muscle dysfunction has been implicated in a range of hip (Bewyer and Bewyer, 2003; Casartelli et al., 2011; Grimaldi et al., 2009a; Grimaldi et al., 2009b) and knee disorders (Chang et al., 2005; Cowan et al., 2009; Heiderscheit, 2010; Hinman et al., 2010; Prins and van der Wurff, 2009). Some researchers have also highlighted a specific association between the strength or size of hip abductors with severity of hip (Grimaldi et al., 2009b) and knee (Hinman et al., 2010) osteoarthritis. It is of no surprise then that clinical assessment of hip abductor function has gained recent attention (Grimaldi, 2011). The guidelines described
in this paper will enable researchers to accurately define the role of these muscles, assess possible changes associated with lower limb dysfunction, and monitor progress of targeted rehabilitation programs.
CONCLUSION

Despite evidence that segments within GMin and GMed are structurally and functionally independent, current EMG electrode placement guidelines only describe one site for the assessment of each muscle. This study offers guidelines for accurately inserting fine wire electrodes into regions of GMin and GMed with independent fascicle orientation. These guidelines will help to evaluate whether GMin and GMed are composed of “muscles within muscles” and if so, establish the role of these segments in health and dysfunction.
REFERENCES


Footnotes

1. *In-vivo* electrode insertions are best conducted with the participant in side lying, and their hips in 45° flexion. The photograph in Figure 1 has been modified with permission from Moore et al., (2010), Fig 5.46D pg 578. *This footnote is located in the legend of Figure 1*
Legends

Fig. 1. Segmental EMG electrode placement guide for gluteus medius and minimus. Bony landmarks are indicated with green circles. A: Gluteus medius. Measure the distance from ASIS to PSIS along the outer lip of the iliac crest (blue dashed arrow). Mark the locations 1/6, 1/2 and 5/6 along this line (black crosses). Direct these locations 3 cm towards the greater trochanter (blue circles). B: Gluteus minimus. Measure the direct distance from ASIS to PSIS (yellow dashed arrow). Mark the locations corresponding to 1/6 and half way along this line (black crosses). Direct these locations 3 cm towards the greater trochanter (yellow circles). ASIS, anterior superior iliac spine; EMG, electromyography; GT, greater trochanter; PSIS, posterior superior iliac spine.

Fig. 2. Gluteus medius electrode locations and fascicle orientation (lateral view). Gluteus maximus and tensor fascia lata have been removed to expose the entry point of anterior (a), middle (m) and posterior (p) electrodes into GMed. These have been marked with blue pins. Dashed black lines represent the fascicle orientation surrounding each electrode. The letter h marks the location of an electrode inserted as per the Hodges et al. (1997) protocol. ASIS, anterior superior iliac spine; GT, greater trochanter; PSIS, posterior superior iliac spine.

Fig. 3. Electrode locations through superficial musculature (lateral view). The three GMed electrodes have been marked with dark blue pins, and the two GMin electrodes marked with yellow pins. Dashed lines indicate the borders of TFL and GMax. Iliac crest is pinned with ‘C’ inscripted flags. ASIS, anterior superior iliac spine; GMax, gluteus maximus; GMed, gluteus medius; GMin, gluteus minimus; GT, greater trochanter; PSIS, posterior superior iliac spine; TFL, tensor fascia lata.
Fig. 4. **A:** Gluteus minimus electrode locations and fascicle orientation (lateral view). Gluteus maximus, tensor fascia lata and gluteus medius have been removed to locate the entry points of anterior (a) and posterior (p) electrodes into gluteus minimus. These have been marked with yellow pins. Dashed black lines indicate the fascicle orientation surrounding each electrode. A dotted white line courses the border of the superior gluteal neurovascular bundle. **B:** Schematic representation of the un-assessable zone of gluteus minimus (lateral view). Piriformis has been removed and the neurovascular bundle reflected posteriorly. Fibers posterior and inferior to the dotted white line are covered by piriformis and the neurovascular bundle. ASIS, anterior superior iliac spine; GT, greater trochanter; NVB, neurovascular bundle; Piri, piriformis; PSIS, posterior superior iliac spine; Sciatic n., sciatic nerve.

Fig. 5. Transverse RTUS image *in vivo* taken with a 7.5 MHz linear transducer. **A:** Posterior GMin electrode location with superior gluteal vessels (green box) observed under Doppler imaging. This image allows electromyographers to determine a clear path prior to electrode insertion. **B:** Posterior GMin electrode insertion with the aid of a 9 cm, 22 gauge spinal needle. **C:** Anterior GMed electrode insertion via a 5 cm, 22 gauge hypodermic needle. Imaging with RTUS allows correct judgment of needle depth, in this instance, to prevent the needle from entering GMin. GMax, Gluteus maximus; GMed, gluteus medius; GMin, gluteus minimus; RTUS, real-time ultrasound.