A comparison of surface and fine wire EMG recordings of gluteus medius during selected maximum isometric voluntary contractions of the hip

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Abstract

Electromyographic (EMG) studies into gluteus medius (GMed) typically involve surface EMG electrodes. Previous comparisons of surface and fine wire electrode recordings in other muscles during high load isometric tasks suggest that recordings between electrodes are comparable when the muscle is contracting at a high intensity, however, surface electrodes record additional activity when the muscle is contracting at a low intensity. The purpose of this study was to compare surface and fine wire recordings of GMed at high and low intensities of muscle contractions, under high load conditions (maximum voluntary isometric contractions, MVICs). Mann-Whitney *U* tests compared median electrode recordings during three MVIC hip actions; abduction, internal rotation and external rotation, in nine healthy adults. There were no significant differences between electrode recordings in positions that evoked a high intensity contraction (internal rotation and abduction, fine wire activity >77% MVIC; effect size, ES<0.42; p>0.277). During external rotation, the intensity of muscle activity was low (4.2% MVIC), and surface electrodes recorded additional myoelectric activity (ES=0.67, p=0.002). At low levels of muscle activity during high load isometric tasks, the use of surface electrodes may result in additional myoelectric recordings of GMed, potentially reflective of cross-talk from surrounding muscles.

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1 Introduction

Gluteus medius (GMed) is a broad, fan shaped hip abductor (Flack et al. , 2014) that is believed to have a major role in hip joint and pelvic stability (Gottschalk et al. , 1989; Retchford et al. , 2013). Electromyography (EMG) research has contributed to much of our understanding of this muscle's association with injury and pathology. Such research has established a link between GMed dysfunction and injury not only locally at the hip joint (Dwyer et al. , 2013), but also more proximally at the lumbar spine (Nelson-Wong et al. , 2008), and distally at the knee (Barton et al. , 2013) and ankle joints (Smith et al. , 2014). This knowledge has also had a large influence on informing current clinical practice (Grimaldi, 2011; Philippon et al. , 2011; Retchford et al., 2013).

With an increasing awareness of GMed dysfunction in a wide array of clinical conditions, clinicians are naturally seeking the most effective targeted intervention options for GMed rehabilitation. Research using EMG has also been pivotal in the attempt to identify the most optimum targeted rehabilitation program (Ayotte et al. , 2007; Barton et al., 2013; Bolgla and Uhl, 2005; French et al. , 2010; Philippon et al., 2011; Reiman et al. , 2012; Selkowitz et al. , 2013). For example, a recent systematic review identified four studies that assessed GMed EMG activity during twenty commonly prescribed lower limb rehabilitation exercises and categorised them according to level of EMG activity (Reiman et al., 2012). While the results of the review are helpful in enabling clinicians to choose the most appropriate exercises to achieve a targeted level of GMed activity for a particular condition or phase of GMed rehabilitation, there is some speculation as to the validity of the majority of GMed EMG data that has been informing clinical practice to date (Selkowitz et al., 2013; Semciw et al. , 2013c). That is, most have assessed GMed activity with surface EMG electrodes.

Surface EMG electrodes are commonly used to record muscle activity because they are non-invasive; do not expose participants to pain or discomfort; are easily applied to the skin; do not require specialist training for application; and with their relatively large inter-electrode distance, are able to capture muscle activity from a significant proportion of motor-units that is likely representative of whole muscle activity (Basmajian and De Luca, 1985). Despite these benefits, there are some disadvantages that would potentially result in the recording of invalid or misleading data. In the context of GMed EMG research, these disadvantages are primarily related to the inability of surface electrodes to detect activity from deeply situated muscles; and the vulnerability of surface electrodes to record additional myoelectric activity (cross-talk) from surrounding muscles or muscle segments (Chapman et al. , 2006; 2010; Johnson et al. , 2011; Waite et al. , 2010).

As certain portions of GMed lie deep to surrounding musculature, the use of a surface electrode over these areas to detect activity in GMed may not be justifiable. Posteriorly, GMed is completely sheltered by gluteus maximus (GMax) (Hodges et al. , 1997; Semciw et al. , 2013a), while anteriorly, it is covered by tensor fascia lata (TFL) (Flack et al., 2014; Semciw et al., 2013a). Surface electrode recordings from either of these GMed regions would therefore be invalid (Gottschalk et al., 1989). The middle portion of GMed is situated deep to the gluteal aponeurosis (Flack et al., 2014; Semciw et al., 2013a). It could be argued that EMG recordings can validly be taken from this portion of the muscle. In fact, it is the middle GMed position that is recommended as a surface electrode placement site by SENIAM (n.d.) and others (Cram, 1998). However, the broad attachment of GMax means that its anterior border encroaches upon, and on occasion may cover middle GMed (Semciw et al. , 2013b). Therefore, prior investigations using surface electrodes over middle GMed may actually be recording data from the overlying GMax (Ayotte et al., 2007; Bolgla and Uhl, 2005; Dwyer et al., 2013; Philippon et al., 2011).

Fine wire EMG electrodes can overcome many of the pitfalls faced by surface electrode data collection (Basmajian and Stecko, 1962), and this technique has been used for GMed research previously (Selkowitz et al., 2013; Semciw et al., 2013c). With the aid of a hypodermic needle, the electrodes can be inserted directly into deep muscles; and the small inter-electrode distance (2-3 mm) ensures greater specificity for recording the desired muscle activity with minimal contamination from surrounding muscles (or segments) (Chapman et al., 2006; 2010). Furthermore, although seemingly considered an invasive technique, participant discomfort while recording data from GMed with fine wire electrodes is rated as mild (Semciw et al., 2013b). Despite these advantages, surface electrode recordings are still commonly used in contemporary GMed EMG research (Dwyer et al., 2013; Philippon et al., 2011). It is important then, to determine if surface electrode recordings are comparable to fine wire recordings of GMed muscle activity. Discrepancies may become clinically meaningful when clinicians are seeking to prescribe GMed exercises at a targeted level of activity, based on research using surface (Reiman et al., 2012) or fine wire recordings (Selkowitz et al., 2013).

Activities under high load (e.g. maximum voluntary contractions) provide a unique opportunity for comparing activity from surface and fine wire recordings. Previous studies on other muscles suggest that the electrode recordings are comparable when the muscle is contracting at a *moderate to high intensity* (>60% maximum voluntary isometric contraction, MVIC) (Johnson et al., 2011). However, when a muscle is contracting at a *low intensity* (<10% MVIC) under high load (e.g. in a task where the target muscle is not considered a prime mover), surface electrodes are vulnerable to recording additional myoelectric activity from surrounding muscles when compared with fine wire electrodes (Chapman et al., 2010; Johnson et al., 2011). The aim of the current study was therefore to compare surface and fine wire recordings of GMed at high and low intensities of muscle contractions, under high load conditions (MVICs). Previous fine wire research of GMed during MVICs illustrate that it is highly active during hip abduction (≈80% MVIC) and hip internal rotation (≈75% MVIC) (Semciw et al., 2013c); while it is active at low intensities during hip external rotation (≈5% MVIC) (Semciw et al. , 2011). The hypothesis of the current study was therefore that surface and fine wire recordings would be similar during hip abduction and hip internal rotation MVICs (high intensity contractions), and that surface electrodes would record additional myoelectric activity during hip external rotation MVICs (low intensity contractions).

2 Methods

2.1 Participants

Ten healthy participants (4 female) with a mean (SD) age, height and weight of 23.8 (1.6) years, 177.5 (10) cm and 79.9 (18.5) kg respectively volunteered for this study. Participants represented an active population, having a Tegner Activity Score (Tegner and Lysholm, 1985) of greater than 3; and performed deliberate exercise for an average (SD) of 8.0 (6.6) h/week. Participants were excluded from the study if they had lower limb and lumbar spine pain, disease or injury. Informed written consent was provided by all participants and approval was obtained from the University Human Ethics Committee (UHEC 13-005).

2.2 Instrumentation and electrode insertions

Data were recorded from the stance limb (6 x left leg) of all participants (Bullock-Saxton et al. , 2001). The position of the intramuscular and surface EMG electrodes were marked by having participants lay on their side (stance leg upper-most), with their hips and knees in 45° flexion. The middle portion of GMed was marked by finding the mid-point of a line along the length of the iliac crest (IC), and directing that point 3 cm towards the proximal tip of the greater trochanter (GT) (Semciw et al., 2013a). This became the insertion site for the intramuscular electrode, which consisted of 75 µm bi-polar stainless steel, Teflon® coated fine wires (A-M Systems, Washington, USA), and were prepared as described by earlier reports (Basmajian and Stecko, 1962; Semciw et al., 2013b). The electrode was then inserted into middle GMed with the aid of a 5 cm spinal needle (Terumo, Tokyo, Japan), and real-time ultrasound (HDI 3000; Advanced Technology Laboratories, Washington, USA) was used to ensure the electrode was inserted into the belly of GMed. Surface EMG electrodes consisted of Trigno (Delsys Inc., Boston, USA) wireless sensors with a single differential configuration, and a four bar (99.9% silver) contact area, with an inter-electrode distance of 10 mm. The surface electrodes and the skin contact area were prepared following SENIAM recommendations (SENIAM, n.d.). The surface electrode was positioned immediately beside (≈1cm posterior) the intramuscular electrode, close enough to be in a similar recording area, without making direct physical contact with the fine wires (see Fig 1).

[*Insert Figure 1 here*]

2.3 Experimental protocol

To secure the fine wire electrodes within the muscle belly, participants were asked to walk comfortably within the testing laboratory for 5 minutes. Open chain hip abduction manoeuvres were also performed in standing to ensure clear signals were obtained from each electrode. Participants then returned to the testing plinth, and were asked to perform three maximum voluntary isometric contractions (MVICs) across three different actions. All MVICs were performed in side-lying, with the testing leg upper-most, and a pillow positioned between the participants knee’s for comfort. The three actions tested were hip internal rotation (IR; hip neutral, knee 90° flexion, resistance applied by investigator on the lateral aspect of the foot); hip abduction (Abd; hip and knee neutral, resistance applied by a Velcro® strap secured around the plinth and the participants testing leg at the knee) and hip external rotation (ER; positioned as per knee internal rotation with resistance applied by an investigator at the medial border of the foot). For each MVIC action, participants were instructed to slowly increase muscle contraction against the resistance, and sustain maximum effort for three seconds. The three second maximum effort was recorded for analysis. Participants were given a three minute rest in between each contraction. Consistent verbal encouragement was provided by the investigators and the order of MVIC testing was randomly assigned.

2.4 *EMG data acquisition, processing and statistical analysis*

Raw EMG signals were collected using a Trigno Wireless 16-Channel EMG system (Delsys® Inc., Boston, USA; CMRR >80 dB @60Hz; gain of 1000; band pass filtered at 20-450 Hz for surface electrodes and 20-900 Hz for intramuscular electrodes) and sampled at 2000 Hz. Delsys® EMGworks version 4.0 signal analysis software was used to further process the EMG data and acquire the dependant variable. The EMG signals were full wave rectified and filtered with a low-pass 4th order Butterworth filter, at a cut-off frequency of 6 Hz to generate a linear envelope (Semciw et al., 2013c).

Within each testing position (Abd, ER, and IR), a mean amplitude was calculated from the middle 1 second of each trial, and the highest mean amplitude from the three trials was recorded for analysis. This value was then normalised to the highest amplitude recorded from the nine trials across all three testing positions (Abd, ER or IR) (normalised amplitude, %MVIC).

The normalised amplitude of GMed muscle contractions recorded from each electrode was not normally distributed across participants, so non-parametric statistical comparisons were performed. Mann-Whitney *U* tests compared the normalised amplitude recorded between each electrode (intramuscular vs surface) within each testing position (ER, Abd and IR). Differences were considered significant where $p < 0.05$. To provide an indication of the magnitude of difference between each electrode type, a standardised effect size (ES) was calculated by dividing the *z*-score of the Mann-Whitney *U* test by the square root of the total sample size (Field, 2009). An ES threshold of 0.2, 0.5 and 0.8 was considered small, medium and large respectively (Cohen, 1988). All statistical comparisons were performed using the SPSS statistical software package (version 19, IBM SPSS Inc., Chicago, IL, USA)

3 Results

The intramuscular electrode was dislodged during testing for one participant, and artefact affected the intramuscular electrode data during abduction for one participant; and the surface electrode data during abduction for another participant. Data were therefore acquired from the intramuscular electrodes in eight participants during abduction, and nine participants during external and internal rotation; and data were acquired from surface electrodes in nine participants during abduction, and ten participants during external and internal rotation.

Table 1 outlines the number of participants whose highest EMG amplitude was recorded during each test position, for subsequent use in amplitude normalisations. The comparisons between electrode types across the three testing positions are presented in Figure 2. According to the fine wire recordings, GMed is active at very high intensities during maximum resisted abduction and internal rotation; and active at a very low intensity during maximum resisted external rotation. Within the high intensity conditions, there were no significant differences between intramuscular and surface electrode recordings during abduction (U=24.0, ES=0.42, p=0.277) or internal rotation (U=52.0, ES=0.13, p=0.604). However, in the low intensity condition of maximum resisted hip external rotation, surface electrodes recorded significantly higher EMG activity when compared with intramuscular electrodes (U=81.0, ES=0.67, p=0.002).

[*Insert Table 1 here*]

[*Insert Figure 2 here*]

4 Discussion

This is the first study to compare data recorded from intramuscular and surface EMG electrodes positioned over the middle segment of GMed; and adds to our understanding of the direction specific actions of middle GMed. The results suggest that EMG amplitudes recorded from surface electrodes are comparable when middle GMed is active at a very high intensity (e.g. during maximum resisted abduction, or internal rotation). However, when middle GMed is active at a low intensity under a high load condition (maximum resisted external rotation), surface electrodes record additional myoelectric activity.

4.1 Direction specific action of middle GMed

The normalised amplitudes reported in this study are consistent with those reported in previous fine wire EMG research into GMed (Semciw et al., 2011; Semciw et al., 2013c). In the anatomical position, middle GMed is highly active during maximum resisted internal rotation and abduction, but only active at very low intensities during maximum resisted external rotation (according to intramuscular recordings). In the sagittal plane, the fibres of middle GMed are predominantly vertical in orientation (Flack et al., 2014; Gottschalk et al., 1989; Semciw et al., 2013a), and it has a relatively large moment arm in the coronal plane (Dostal et al. , 1986). This would facilitate its role as a prime hip joint abductor, and thus explain the high intensities recorded during maximum resisted abduction in the current study. However, the high intensity recorded during internal rotation is in contrast to its unfavourable moment arm for internal rotation torque production (Dostal et al., 1986). It is likely that the position of testing during maximum resisted internal rotation in the current study (side-lying, with resistance applied to the lateral border of the foot) did not encourage isolated internal rotation torque production, but rather, a combination of internal rotation and abduction. The current findings also indicate that middle GMed is only active at a small intensity during maximum resisted external rotation as measured by intramuscular electrodes. This is consistent with middle GMed’s unfavourable moment arm for external rotation torque production (Dostal et al., 1986), suggesting it is not a prime mover for external rotation in the anatomical position.

4.2 Surface and fine wire electrode comparisons under high load conditions

In the current study, surface electrodes were comparable to intramuscular electrodes when the muscle was contracting at a *high intensity* (abduction, and internal rotation) under high load conditions. This is consistent with literature from some muscles, such as the infraspinatus, where comparable activity was recorded from each electrode type when the amplitude of activity was greater the 60% MVIC (Johnson et al., 2011). On the other hand, in a recent investigation on the serratus anterior muscle, surface electrode signals were significantly lower than intramuscular electrode signals during ramped isometric shoulder flexion and shoulder abduction, performed at 90° of elevation (Hackett et al. , 2014). The difference between electrode recordings in their study however, is likely due to the displacement of the surface electrodes as a result of moving participants from the initial electrode application position (60° of arm elevation) to the testing position (90° of arm elevation). The surface electrodes were presumably displaced, thus recorded from the superior intercostal space rather than serratus anterior.

When GMed was active at a *low intensity* (external rotation) under a high load condition, the current study identified additional myoelectric activity in surface electrode recordings. This is again consistent with the results of Johnson et al. (2011) on the infraspinatus muscle. During isometric shoulder extension performed across a number of submaximal and maximal loads, surface electrode recordings of infraspinatus continued to climb (>80% MVIC) as the loads approached maximum, while fine-wire recordings remained low (<10% MVIC) (Johnson et al., 2011). Infraspinatus is not considered an extensor of the shoulder joint and the low activity in fine-wire recordings of Johnson et al. confirmed this. The authors proposed that the additional activity recorded by surface electrodes at higher loads most likely reflected cross-talk from surrounding prime movers of shoulder joint extensors, such as the posterior deltoid (Johnson et al., 2011).

The additional activity from surface electrode recordings during isometric hip external rotation in the current study most likely represents cross-talk from surrounding prime movers. Given that middle GMed has an unfavourable fibre orientation and moment arm for external rotation torque production (Dostal et al., 1986), it was expected that EMG activity during this manoeuvre would be low. This was the case for intramuscular electrode data, however, surface electrode activity was significantly higher, and bordered on moderate intensity (moderate intensity indicated by 21%-40% MVIC; Reiman et al., 2012). It is possible that surface electrodes captured additional activity from neighbouring prime movers of external rotation, for instance, GMax (Dostal et al., 1986).

4.3 Implications

Accurate EMG data is essential to inform clinical practice. As identified by recent systematic reviews, there are a number of EMG studies on GMed that aim to evaluate the contribution of this muscle to commonly prescribed rehabilitation exercises (French et al., 2010; Reiman et al., 2012). However, all studies except one (Selkowitz et al., 2013) used surface electrodes to record EMG activity, thus should be interpreted with caution based on the current findings. For example, clinicians aiming to prescribe a moderate intensity exercise for GMed, could feasibly prescribe a bilateral bridge, according to the surface electrode results of Ekstrom et al. (2007) (mean activity ± SD = 28 ± 17% MVIC). However, GMed would be under-recruited according to a separate fine wire study on the same exercise (mean ± SD = 15 ± 11% MVIC) (Selkowitz et al., 2013). Based on the current findings, it is possible that surface electrodes were recording additional myoelectric activity from neighbouring prime movers, and if so, would potentially misdirect clinical interventions.

4.4 *Limitations and further research*

As outlined in a previous systematic review, there are at least six different placement sites that have been used to record EMG activity from GMed (French et al., 2010). The data from our study may therefore not be generalizable to all GMed surface electrode investigations. However, as with our protocol, most studies employ a position along a line between the greater trochanter and the midpoint of the iliac crest (Ayotte et al., 2007; Cynn et al. , 2006; Hertel et al. , 2005; Krause et al. , 2009). Investigators using a more distal position along this line (Ayotte et al., 2007; Cynn et al., 2006; Hertel et al., 2005; Krause et al., 2009) to that used in our protocol (3 cm from the iliac crest) are perhaps even more likely to be located within the borders of GMax (Semciw et al., 2013a); thus could be influenced by cross-talk from this muscle. Furthermore, EMG data was not deliberately collected from surrounding musculature. This would be necessary to verify whether cross-talk was a factor associated with additional EMG activity from surface recordings of GMed during ER.

The size of the sample in the current study might be considered to be too small to detect a difference between the electrode types in the high intensity conditions. However, the magnitude of the difference was small and it was calculated that more than 95 participants would be required (β=0.80) to detect a difference if one truly exists. The sample size used in this study reflects similar literature on comparisons between surface and fine wire electrode recordings (Hackett et al., 2014; Johnson et al., 2011).

A concern with EMG data, particularly when recorded with intramuscular electrodes (Kadaba et al. , 1985), is whether they are consistently representative of a participants' actual EMG variables, i.e. are they repeatable within test sessions and between testing days (Kadaba et al. , 1989; Kadaba et al., 1985). Intramuscular EMG signals are considered to be less repeatable within participants than surface EMG signals because they may cause intramuscular bleeding, can move within the muscle, or may fracture during intense muscle contractions (Kadaba et al., 1985). Repeatability of fine wire data recorded from this muscle is yet to be established and therefore requires further investigation.

The comparisons between surface and fine wire electrodes in this study were performed during isometric high load conditions. Further comparisons in dynamic tasks will help evaluate any inaccuracy associated with movement of the skin over muscle (Hackett et al., 2014). Future work is also required to clarify the relationship between surface and fine wire recordings of GMed during submaximal loads (Hackett et al., 2014; Johnson et al., 2011; Waite et al., 2010). Finally, through fine wire EMG recordings, the current study has provided valuable information on the direction specific actions of middle GMed. Future research aimed at evaluating the direction specific action of all three GMed segments

(Semciw et al., 2013a) in different positions along the coronal and saggital plane (Delp et al. , 1999) will add to the dearth of literature on the segmental function of this muscle.

5 Conclusion

The current study suggests that surface EMG electrodes record additional myoelectric activity from middle GMed when it is active at low intensities, under high load, e.g. in actions where the muscle is not considered a prime mover. Caution should be used when interpreting prior surface electrodes studies; and we recommend the use of intramuscular electrodes in future studies that attempt to quantify muscle activity of middle GMed across a wide range of tasks.

Conflict of interest: none declared

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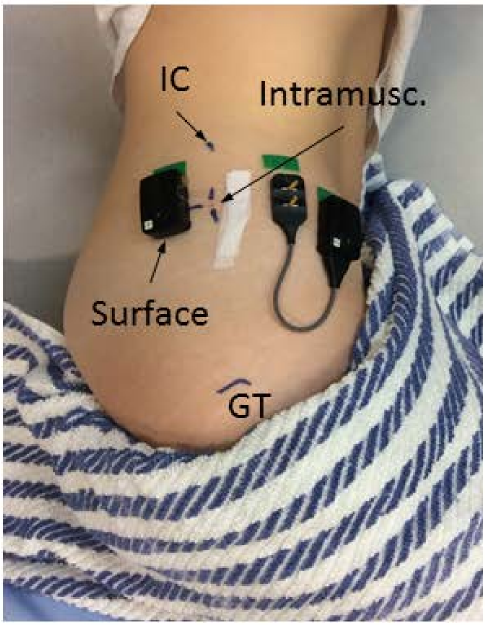
7 Captions to Illustrations

Figure 1. Photograph of the lateral hip and pelvis indicating surface and intramuscular electrode placement.

Figure 2. Box-plots illustrating comparisons between intramuscular (IM) and surface electrode recordings across the three testing actions. Box-plots represent median, inter-quartile range and range. *Significant differences between electrode recordings (α=0.05).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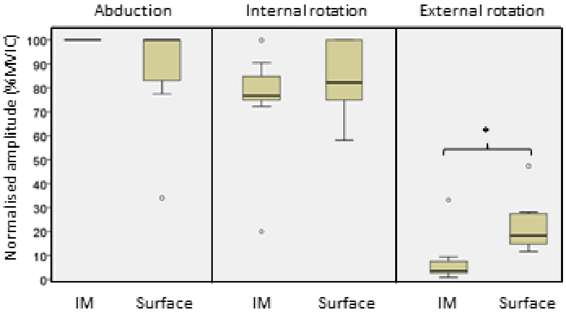
Abduction
Internal rotation
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Normalised amplitude (%MVIC)
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