ELECTROMYOGRAPHY-RELATED PAIN: MUSCLE SELECTION IS THE KEY MODIFIABLE STUDY CHARACTERISTIC

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ABSTRACT: *Introduction:* The aim of this study was to estimate the effects of patient, provider, and study characteristics on electromyography (EMG)-related pain. *Methods:* Patients undergoing EMG rated their EMG-related pain after each muscle was studied on a 100-point visual analog scale (VAS). Investigators recorded the order in which the muscles were sampled, the total time spent with the needle in each muscle, and whether electrical endplate noise was noted. *Results:* A total of 1781 muscles were studied in 304 patients. Eleven muscles were associated with significantly more or less pain than the others. Endplate noise was associated with more pain (5.4 mm, 95% CI 2.8–7.0). There was a small, but significant effect from needling time (0.02 mm, 95% CI 0.00–0.04). *Conclusions:* Among factors that electromyographers can control, muscle selection has the greatest impact on pain. Our data include an extensive list of muscle-specific EMG-related pain scores. Provider and other study characteristics have little or no impact on EMG-related pain.

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Needle electromyography (EMG) is painful.[1,2] Concern about needle-related pain may prevent patients from participating in potentially useful electrodiagnostic studies. Electromyographers frequently alter their studies because of their perception of patient pain and sometimes avoid specific muscles or even abort an examination early because of perceived patient pain.[3] Although reducing pain is a major goal in and of itself, it may also improve the diagnostic utility of EMG by obviating the need to alter or abort studies. It is therefore important to identify the factors most strongly associated with EMG-related pain, with particular attention to factors that can be controlled by the electromyographer.

Although a number of methods have been studied to reduce pain, the efficacy of these methods is limited, and none are used commonly.[3–12] Consequently, alternate approaches to reducing EMG-related pain should be considered. Electromyographers control at least 1 potentially pain-related factor: the choice of which muscles to study. Few data exist as to which muscles are more or less painful. The abductor pollicis brevis has been shown to be more painful in EMG than both the biceps brachii and the extensor digitorum communis, but little is known about other muscles.[5,13] Electromyographers can also determine the order in which muscles are sampled and the time spent needling each muscle, but the influence of these factors on patient discomfort has not been studied. EMG-related pain may also be mediated, in part, by variables over which the electromyographers have no control, such as demographic factors of patients. Gender, age, and baseline anxiety have been shown to influence pain experienced during EMG.[14–18] Although these variables are outside the electromyographer's control, they may inform patient selection in patients with an uncertain need for EMG.

Our aim was to estimate the effects of patient, provider, and study characteristics on pain, with a focus on elements within the electromyographer's control. These data may then be used to determine strategies that electromyographers can use at the bedside to minimize patient pain.

METHODS

Patient Population. Three-hundred-four adult subjects undergoing EMG at a single academic institution were recruited to participate. Patients with severely impaired vision or cognition were excluded.

Standard Protocol Approvals, Registrations, and Patient Consents. All patients and electromyographers provided informed consent. The study was approved by the institutional ethical standards committee on human experimentation of the University of Michigan Health System.

Data Collection. Prior to the study, patients completed a demographic survey of patient-level characteristics including age, gender, height, weight, race, and ethnicity; baseline and expected level of pain (visual analog scale); and whether they had ever undergone EMG. EMG was performed by 1 of the 26 faculty, fellow, or resident electromyographers (including authors Z.L., B.C., and M.H.) at our institution. Each physician performing the EMG was documented.

Additional Supporting Information may be found in the online version of this article.

Abbreviations: EMG, electromyography; VAS, visual analog scale
Key words: complications; electromyography; EMG; muscle selection; pain

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Patients rated their pain on a 100-mm visual analog scale (VAS) immediately after each muscle was studied.[19,20] Investigators recorded the order in which the muscles were sampled and the total time spent with the needle in each muscle. They also reported whether electrical endplate noise was noted, an indicator that the needle was inserted into the endplate zone. Needle insertion into the endplate zone has been hypothesized to produce more pain than other sites, because pain fibers are more densely situated at the endplate and needle insertion causes muscle fiber contraction, which irritates pain fibers.[21]

After the study was complete, electromyographers revealed whether they used any of the common techniques to limit pain, such as pre-examination verbal or written explanation of what to expect, conversational distraction, verbal encouragement, a simultaneous finger slap next to the insertion site with the first insertion, or a minimal insertion technique (∽1 mm per insertion).

Statistical Analysis. Our analysis sought to answer 2 specific questions: (1) What proportion of variance in patient pain was explained by the study characteristics vs. patient characteristics vs. provider characteristics? (2) What is the association between specific study characteristics and patient pain? We developed an empty 3-level model (muscle within patient within electromyographer) with random intercepts at the provider and electromyographer level to characterize the proportion of variance at each level using the intraclass correlation coefficient (ICC). In the empty model, the ICC was 0.502 at the patient level and 0.017 at the electromyographer level, meaning that 50% of the variance explained by the model is explained at the patient level, 1.7% at the electromyographer level, and the remainder at the muscle level. To define the association between specific study characteristics and pain, we developed a model that included major patient and study characteristics as well as electromyographer as fixed effects while allowing for a random patient-level intercept.

Our primary linear regression model specifically included pre-specified study characteristics (the specific muscle studied, amount of time in the muscle, whether endplate noise was detected and the order the muscle was studied [quartiles], and patient-level characteristics.) The linear regression model was estimated using *xtreg* in Stata statistical software (Stata, release 12, 2011; StataCorp LP, College Station, Texas). An adjusted pain score for each muscle, accounting for all muscle features, was estimated using average marginal effects from the primary model.

To determine how specific EMG studies may be designed to reduce pain, we performed a series of secondary analyses. First, we added a series of covariates to the primary model describing whether pre-examination explanation of the procedure, conversational distraction, verbal encouragement, finger slapping with needle insertion, or a minimal insertion technique were used. We then explored variants of our primary model using slightly different parameters, including determination of whether a muscle was first vs. non-first (as opposed to order quartiles). Finally, we sought to determine whether certain variables (time in the muscle, whether endplate noise was detected, and the order in which the muscle was studied) influenced painfulness differently for some muscles than for others by exploring a series of interaction effects.

Application to Root Screens. Prior studies have suggested needle examination of 5 limb muscles and a paraspinal muscle when screening for cervical or lumbar radiculopathy.[22,23] In those studies the investigators offered several protocols that included different combinations of limb muscles, each of which had a similar sensitivity for the diagnosis of radiculopathy. We compared the average marginal pain from the primary model associated with all of the muscles in those protocols to identify the least painful cervical and lumbar root screens.

RESULTS

A total of 1781 muscles were studied in 304 patients. The mean age was 52.7 years; 49.5% were female; 85.5% were Caucasian; and 53.5% had undergone prior EMG. The mean baseline pain on VAS was 21.6 mm (SD 24.8 mm), and the mean expected pain was 47.8 mm (SD 24.7). The overall correlation between model predictions and patient-reported pain was 0.79. The ICC was 0.47 for the baseline model, indicating that 47% of the variance explained by the model was explained by the patient-level random intercept. Physician-level variables accounted for only about 2% of the overall variance in pain explained by the model. Given the low variance at the electromyographer level, we did not pursue the effect of level of training or other variables.

Primary Analysis: Association between Specific Muscle Features and Patient-Reported Pain. In the primary model, the muscles significantly associated with higher levels of pain were rectus femoris, extensor digitorum brevis, abductor hallucis, extensor hallucis longus, abductor pollicis brevis, opponens pollicis, vastus lateralis, medial gastrocnemius, and thoracic paraspinals. The muscles significantly associated with lower levels of pain were the deltoid and gluteus medius. Table S1 (see Supplementary Material available online)

Table 1. Effects of time, order, endplate, and patient demographics factors.

Factor	Effect (mm) (95% CI)
Order (reference: first quartile)	
Second quartile	1.9 (−0.6 to 4.3)
Third quartile	1.2 (−1.6 to 3.9)
Fourth quartile	2.2 (−1.1 to 5.4)
Time, per second	0.02 (0.00 to 0.04)*
Presence of endplate noise	5.4 (2.8 to 8.0)*
Age, per year	−0.1 (−0.3 to 0.1)
Male gender	−0.7 (−6.9 to 5.5)
Race (reference: white)	
American Indian or Alaska Native	−10.1 (−36.9 to 16.7)
Asian	23.1 (6.1 to 40.1)*
African American	7.2 (−0.6 to 14.9)
Other	1.9 (−13.9 to 17.7)
Height, per inch	−0.4 (−1.2 to 0.4)
Weight, per pound	0.0 (−0.1 to 0.1)
History of previous EMG	4.4 (−0.3 to 9.1)
Baseline pain (VAS)	0.1 (0.0 to 0.2)*
Expected pain (VAS)	0.2 (0.1 to 0.3)*

CI, confidence interval; VAS, visual analog scale.

**Statistically significant at $P < 0.05$.*

lists all muscles tested and the adjusted pain score for each muscle.

When motor endplate noise was identified during needle examination of a given muscle, the pain associated with that insertion was increased (Table 1).

There was a very small association between pain and time spent needling. The order in which the muscles were studied had no significant effect on pain.

Self-identified Asians had significantly more pain than other individuals. Otherwise, age, gender, height, weight, race, ethnicity, baseline pain, and prior history of EMG had no significant effect on pain levels. There was a small but significant association between expectation of pain and EMG-related pain.

Secondary Analysis. There was no significant change in pain scores when electromyographers used an explanation of the procedure, conversational distraction, verbal encouragement, finger slapping, or a minimal insertion technique. When muscle order was parameterized as first vs. non-first muscle, as opposed to by quartiles of order, we found that being the first muscle needled was associated with a 4.3-mm (95% CI 1.9–6.6 mm) decrease in pain. None of the interaction effects between muscle (even when grouped by painfulness) and time, endplate, or order were significant.

Application to Root Screens. In Table 2, we show that adding the adjusted pain scores of the suggested muscles in these protocols could be used to estimate the least painful radiculopathy screen.

DISCUSSION

Among factors that the electromyographer can control, it is the choice of muscles that has the greatest impact on pain scores. Order of muscles, time needling, and techniques aimed at limiting pain have little or no impact. Therefore, the recipe for minimizing patient pain is to study the least painful muscles possible.

Our data provide an extensive list of pain scores for commonly studied muscles during EMG. Among the more painful muscles were the thenar and intrinsic foot muscles, which are notoriously sensitive. These areas are covered by glabrous skin, rather than hairy skin. It is thought that high-threshold mechanoreceptors with A-δ axons and polymodal receptor units with C axons are more numerous or react differently in glabrous skin.[5] The abductor pollicis brevis and the opponens pollicis were similarly painful, indicating that the choice between these 2 muscles has little effect on pain. Other distal lower extremity muscles (the medial gastrocnemius and extensor hallucis longus) were also unusually painful. The medial gastrocnemius may be a painful muscle because of the difficulty in activating a large portion of this muscle in the recumbent position, whereas the extensor hallucis longus is a small muscle near multiple tendons. The pain levels associated with large proximal muscles were variable. We cannot explain why the quadriceps and thoracic paraspinal muscles were among the more painful muscles based either on prior work or our personal

Table 2. Adjusted muscle pain scores applied to clinical scenarios.

Root screen	Sum of adjusted pain scores (*P*-value compared with lowest)
6 muscle root screens—cervical	
Deltoid, triceps, EDC, FDI, CPSM, FCU	189
Triceps, EDC, biceps, FDI, CPSM, FCU	196 (<0.01)
Deltoid, triceps, PT, EDC, CPSM, APB,	200 (0.08)
Triceps, biceps, CPSM, FCR, PT, APB	211 (0.02)
6 muscle root screens—lumbar	
TFL, PTIB, LPSM, ATIB, VMED, LGAS	145
TFL, PTIB, LPSM, ATIB, VMED, MGAS	160 (0.70)
TFL, LPSM, ATIB, SHBF, LGAS, VLAT	174 (0.20)
PTIB, LPSM, ATIB, SHBF, VMED, MGAS	178 (0.17)
PTIB, LPSM, SHBF, VMED, LGAS, MGAS	182 (<0.01)
PTIB, LPSM, ATIB, SHBF, ADD, MGAS	183 (0.12)
PTIB, LPSM, SHBF, ADD, MGAS, VLAT	195 (<0.01)

PT, pronator teres; EDC, extensor digitorum; CPSM, cervical paraspinal muscle; APB, abductor pollicis brevis; FDI, first dorsal interosseous of the hand; FCU, flexor carpi ulnaris; FCR, flexor carpi radialis; TFL, tensor fascia lata; PTIB, posterior tibialis; LPSM, lumbar paraspinal muscles; ATIB, anterior tibialis; VMED, vastus medialis; MGAS, medial gastrocnemius; SHBF, short head of the biceps femoris; LGAS, lateral gastrocnemius; VLAT, vastus lateralis; ADD, adductor longus.

experience. Of note, the vastus medialis was less painful than the vastus lateralis and rectus femoris, which could aid in study planning given the same innervation of these muscles.

Foremost, muscle selection must be based on the relative yield of different muscles for addressing the diagnosis in question. Because different muscles have overlapping innervations, there are clinical scenarios in which the electromyographer may select from among several without compromising the diagnostic utility of the study. It is these scenarios in which adjusted pain scores may be applied. A notable example of how these results can be used clinically is to apply the adjusted pain scores to established EMG protocols. For instance, it is possible to choose among various proposed cervical and lumbar root screens based on the adjusted pain scores of the included muscles (Table 2). In general, we found a wider range of pain scores among lumbar compared with cervical radiculopathy protocols, suggesting that there may be a greater opportunity to minimize pain in lumbar root screens. Prior studies have suggested that a difference of 13 mm on a visual analog scale represents, on average, the minimum change in acute pain that is clinically significant.[20,24,25] This analysis assumes that the sum of pain scores for individual muscles correlates with overall pain in the study. Therefore, further study and validation are needed to determine whether overall pain correlates with the sum of the individual muscle scores, the average of the scores, the presence or absence of particularly painful muscles, or other factors.

Among patient-level variables, Asian race was significantly associated with EMG pain, but only 5 Asians were included in this study, so the generalizability of this finding is unclear. A patient's expected pain was also associated with EMG pain, but the magnitude of the effect was small. Not surprisingly, the largest amount of variance came from patient-specific factors that were not directly measured in this model. This may include psychological factors, or factors pertaining to the patient's symptoms or underlying neuromuscular disease. Although these factors may be beyond the control of the electromyographer, there may still be value in being able to predict the patient population likely to have more EMG-related discomfort.

In our sample, individual electromyographers had surprisingly little effect on pain. Instead, most of the variance explained by the model was associated with patient characteristics (measured and unmeasured), with a significant contribution from individual muscles selected. Therefore, investigating detailed electromyographer characteristics, such as years of experience and certification, and their association with EMG pain is unlikely to uncover major modifiable factors influencing pain.

This study has some major limitations. As with all observational studies, unmeasured variables that influence pain may lead to a bias in the estimates of things we did measure. In addition, we did not collect data on the diagnoses of patients referred for study. It is possible that patients with centralized pain syndromes or certain neuromuscular conditions may perceive more pain than others, or that pain may diminish in patients with diseases that cause neuropathic sensory loss. The electromyographers were not blinded as to the intent of the study, which may have affected their performance. Also, the patients at our tertiary EMG laboratory may have a different distribution of diagnoses and responses to pain compared with the broader population undergoing EMG. Patients who declined to participate in the study may have differed in some aspects from those who agreed to participate. Finally, certain muscles were studied less often than others, limiting the power to detect an association with patient pain.

Limiting EMG pain is an important goal because of the potential to not only improve patient satisfaction but also to improve the diagnostic utility of the test itself. We found that the choice of muscles has the largest effect among factors within the control of the electromyographer. Future work to determine how the choice of specific muscles influences overall EMG-related pain may help in designing studies that maximize the diagnostic yield of the test while also minimizing pain.

Part of this study was presented as a poster at the annual meeting of the American Academy of Neurology, March 2013, San Diego, California.

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