# Fasciotomy Improvement Through Recognition of Errors Course: A Focused Needs Assessment for Error Management Training for Lower Extremity Fasciotomy Performance

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**BACKGROUND:** Many injuries from recent wars involve extremity trauma secondary to blasts, which predispose patients to developing extremity compartment syndrome. In military studies, 17% of fasciotomies required revision on arrival to a Role 4 hospital, and 41% of these had missed compartments, which is similar to that seen in civilian centers. While training has decreased this rate to 8%, this number is still too high. We conducted a focused needs assessment to guide the development of lower-extremity fasciotomy training.

**METHODS:** In a predeployment assessment, 42 military surgeons performed a 2-incision, 4-compartment, lower-extremity fasciotomy on simulated lower leg models. Models were assessed for standardized and objectively-assessed major (inadequate skin or fascial incisions, missed compartments) and minor (failure to make an H-shaped incision over the lateral compartments, division of the greater saphenous vein) errors based on joint Trauma System clinical practice guidelines and approved training curricula.

**RESULTS:** Four of 42 (9.5%) models contained no errors. Models averaged 4.3 ± 2.6 major and 0.3 ± 0.5 minor errors. 11 models (26.2%) had at least one missed compartment. The most common missed compartments were the deep posterior (17%) and anterior (14%). 29 (69%) had inadequate or poorly-placed skin incisions, with the most common being inadequate distal extension of the medial (10, 24%) and lateral (14, 33%) incisions, inadequate proximal extension of the lateral incision (6, 14%), medial incision too close to the tibia (7, 17%), and lateral incision over or behind the fibula (12, 29%). A total of 36 (86%) had inadequate fascial incisions. Inadequate fasciotomies were seen in the anterior (57%), lateral (55%), superficial (52%), and deep (34%) posterior compartments

**CONCLUSIONS:** Performance on the models approximates what has been seen in military and civilian settings. This needs assessment will inform development of a simulation curriculum based on error-management and mastery learning theory to reduce the morbidity of lower-extremity compartment syndrome. (J Surg Ed 76:1303−1308. Published by Elsevier Inc. on behalf of Association of Program Directors in Surgery.)

**KEY WORDS:** Fasciotomy, Error-management training, Error-recognition training, Education

**COMPETENCIES:** Patient Care, Medical Knowledge, Practice-Based Learning and Improvement

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## BACKGROUND

In the recent conflicts during the Global War on Terror, the majority of battlefield wounds involved extremity


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trauma.[1,2] Of the wounded from these conflicts, up to 62% presented with trauma to the lower extremities, and the majority presented with wounds due to gunshots or blast (39% and 31%, respectively).[1] These injury mechanisms can lead to fractures, vascular injury, burns and substantial muscle damage, all of which can put these patients at high risk for the development of extremity compartment syndrome (ECS). In the civilian population, the majority of compartment syndromes seen at a major Level I trauma center (77%) were caused by penetrating wounds, including gunshot wounds, stab wounds, and lacerations. The remainder were due to crush injuries (16%) and closed fractures (7%).[3] ECS is defined by Pearse et al., as "a surgical emergency [characterized] by raised pressure in an unyielding osteofascial compartment."[4] In the context of lower ECS due to trauma, the standard of care is the 2-incision, 4-compartment fasciotomy.[5] In this procedure, the anterior and lateral compartments are accessed through a lateral incision extending from the fibular head to the lateral malleolus and the superficial and deep posterior compartments are accessed through a medial incision extending from the tibial plateau to the medial malleolus.[4,6]

As a result of these typical wounding patterns from the recent conflicts, 15% of all limb trauma required fasciotomy, with the rates of fasciotomy increasing during the course of the conflicts.[7] Despite the procedure's prevalence in combat trauma, a recent review of graduating US general surgery residents showed that the average graduating resident only performed 0.8 lower extremity fasciotomies for trauma during the course of residency.[8] Given that most deployed military surgeons and many civilian surgeons at smaller hospitals do not have subspecialty training in trauma or vascular surgery, further training in fasciotomies will rely on targeted courses.

Further highlighting the skill gap, Ritenour et al. studied combat-wounded patients who underwent fasciotomy for trauma in theater between 2005 and 2006 and found 51 of 294 (17%) required revision when arriving to a higher level of surgical care.[9] Of these revisions, 63% required extension of the fascial incisions and 41% required opening of an additional compartment. The anterior (40%) and deep posterior (37%) compartments were the most commonly missed in this study. More than subjecting patients to an additional surgery, patients who required revision had significantly higher rates of mortality (20% vs 6%) and muscle excision (35% vs 9%), while also having a trend toward increased rates of major amputation (24% vs 16%).[9]

In the civilian population, 19% of lower-extremity fasciotomies performed after vascular repair of traumatic injury occurred at a second operation between 2 and 48 hours later due to delayed diagnosis of ECS. Of those, 26% missed at least 1 compartment.[3] In the context of civilian burns, 44% of fasciotomies performed at outlying hospitals required revision upon transfer to the burn center.[10]

Following the Ritenour study, a didactic-based fasciotomy training curriculum was introduced throughout the Department of Defense (DoD) in 2007. Following implementation of this training, the rate of revision fasciotomy decreased from 17% to 8% (20 of 336 patients).[11] Additionally, mortality of patients who received fasciotomies in the post-training time period decreased to 3% from an overall rate of 8% in the pretraining period.

In addition to the DoD training course, the Advanced Surgical Skills for Exposure in Trauma (ASSET) course was introduced by the American College of Surgeons for both military and civilian surgeons during the same time period. Unlike the DoD course, the ASSET course relies on cadaveric or model-based dissection coupled with both real-time and video-based feedback. Following this training, 33% of general surgery residents were able to perform a successful 4-compartment decompression, compared with only 5% pretraining. When reevaluated in 12 to 18 months, 26% of those residents maintained their skills.[8] Currently, neither of these courses are required for the deploying military surgeon.

Although these courses have resulted in statistically-discernible improvements in fasciotomy performance in both the military and the civilian setting, continued high rates of errors in lower extremity fasciotomies and the sequelae of those errors show a persistent need for improvement in lower extremity fasciotomy instruction. Traditional training techniques center around error avoidance, where errors are associated with the negative side of the learning process. The purpose of training using this framework is an attempt to move toward an error-free environment.[12] Error-recognition and error-management training (ERT and EMT) present a different approach to fasciotomy training that may help to drive down further the error rates in fasciotomy performance.

ERT and EMT, on the other hand, approaches errors as inevitable aspects of training that serve an informative function for the learner. Errors are encouraged during training, thereby forcing the learner to engage in a deeper thought process to identify and to correct the error. Studies into error-management training suggest that this approach to learning results in favorable short- and long-term outcomes, particularly when learners are asked to transfer their skills to novel problems.[13] This study is a targeted needs assessment for specific errors in lower extremity fasciotomy in preparation for development of a simulation-based, ERT and EMT curriculum.[14]

## METHODS

This focused needs assessment was conducted at the Val G. Hemming Simulation Center of the Uniformed Services University of the Health Sciences. Fasciotomies performed on lower-extremity synthetic models (Operative

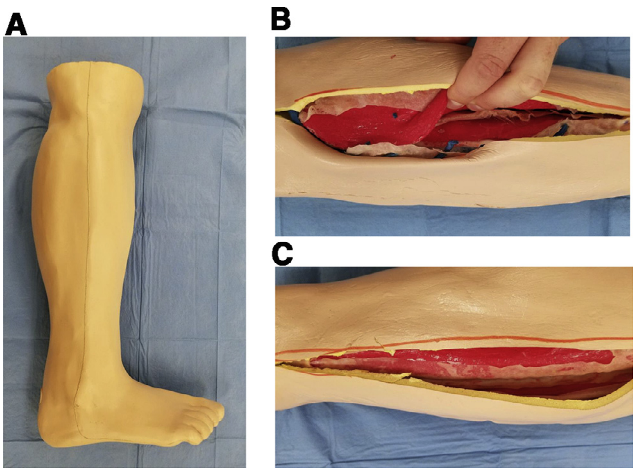

**FIGURE 1.** Lower extremity model. (A) External appearance, (B) dissected medial compartments, and (C) dissected lateral compartments.

Experience; North East, Maryland; Fig. 1) were examined from an anonymous convenience sample of United States and allied military surgeons undergoing routine predeployment training. These models incorporate all 4-muscle compartments, the greater saphenous vein, and the posterior tibial neurovascular bundle. For the models utilized in this study, participants were instructed to perform a 2-incision, 4-compartment lower extremity fasciotomy based only on their prior experience with the procedure with no additional instruction. The ASSET curriculum and the current US Joint Trauma System Clinical Practice Guideline for lower extremity fasciotomy were used to develop a list of 18 possible major errors and 2 possible minor errors (Table 1).

Each of the models were examined twice, once each by 2 of the authors (WBK and MDN). At the outset of the study, any disagreements between these 2 authors were to be arbitrated by a third author (MWB). No disagreements arose during evaluation, however, and the inter-rater reliability was 100%. Individual and total number of errors were counted for each leg and recorded in Microsoft Excel version 16 (Microsoft Corp; Redmond, Washington). Descriptive statistics were used to define the average number of major and minor errors, as well as the rate of each individual error.

**TABLE 1.** Lower Extremity Model Fasciotomy Errors

| |
|---|
| Major errors |
| Inadequate skin incision |
| Distal end of medial incision greater than 5 cm proximal to medial malleolus |
| Distal end of lateral incision greater than 5 cm proximal to lateral malleolus |
| Proximal end of medial incision greater than 5 cm distal to tibial plateau |
| Proximal end of lateral incision greater than 5 cm distal to fibular head |
| Improperly placed skin incision |
| Medial skin incision less than 1.5 cm posterior to tibia |
| Medial skin incision greater than 6 cm posterior to tibia |
| Lateral skin incision over or posterior to fibula |
| Lateral skin incision over tibia |
| Missed compartment |
| Anterior |
| Lateral |
| Superficial posterior |
| Deep posterior |
| Inadequate fascial incision |
| Proximal end of incision greater than 3 cm proximal to malleolus or 3 cm from tibial plateau |
| Failure to open fascia over entire length of soleus |
| Failure to take soleus down from posterior tibia |
| Failure to expose the posterior tibial neurovascular bundle |
| Minor errors |
| Failure to make H-shaped fascial incision over anterior and lateral compartments |
| Division of the greater saphenous vein (GSV) |

## RESULTS

Forty-two models were examined. Four of the 42 models (10%) had no errors present (Table 2). Overall, the mean number of major errors present in each leg was 4.3 (SD = 2.6, range 0-9). When examining only the 38 legs with errors, there was a mean of 4.8 errors per leg (SD = 2.3, range 1-9). Twenty-nine of the 42 models (69%) had at least 1 inadequate or misplaced skin incision, with a mean of 1.2 skin errors per model (SD = 1.1). The most common skin incision errors were inadequate distal extensions of the lateral (14/42; 33%) and medial (10/42; 24%) incisions. The most common misplacement of the skin incisions was a lateral incision over or posterior to the fibula (12/42; 29%), followed by a medial incision less than 1.5 cm posterior to the border of the tibia (7/42; 17%).

Thirty-six of the 42 models (86%) had inadequate fascial incisions, with a mean of 2.0 inadequate fascial incisions per model (SD = 1.3). The anterior (24/42; 57%), lateral (23/42; 55%), and superficial posterior (22/42; 52%) compartments were inadequately opened in more than half of the models. Additionally, 15 models (36%) had a failure to take down the soleus muscle from the posterior tibia, 9 (21%) had an inadequate deep posterior fascial incision, and 3 models (7%) had an unexposed posterior tibial neurovascular bundle, all of which demonstrate inadequate decompression of the deep posterior compartment.

Perhaps most importantly, 11 of 42 models (26%) had at least 1 completely missed compartment, and the mean number of missed compartments was 0.4 (SD = 0.8). The 2 most commonly missed compartments were the deep posterior (7/42; 17%) and anterior (6/42; 14%), although there were examples of missed superficial posterior (3/42; 7%) and lateral (1/42; 2%) compartments as well.

**TABLE 2.** Errors Identified ($n = 42$).

| | |
|---|---|
| Legs with no errors, *n* (%) | 4 (10) |
| Mean major errors, *n* (SD) | 4.3 (2.6) |
| Mean major errors in 38 erroneous legs, *n* (SD) | 4.8 (2.3) |
| Atleast 1 erroneous skin incision, *n* (%) | 29 (69) |
| Mean # erroneous skin incisions, *n* (SD) | 1.2 (1.1) |
| Insufficient medial distal incision, *n* (%) | 10 (24) |
| Insufficient lateral distal incision, *n* (%) | 14 (33) |
| Insufficient medial proximal incision, *n* (%) | 2 (5) |
| Insufficient lateral proximal incision, *n* (%) | 6 (14) |
| Anterior medial incision, *n* (%) | 7 (17) |
| Posterior medial incision, *n* (%) | 1 (2) |
| Anterior lateral incision, *n* (%) | 2 (5) |
| Posterior lateral incision, *n* (%) | 12 (29) |
| Atleast 1 inadequate fascial incision, *n* (%) | 36 (86) |
| Mean # of inadequate fascial incisions, *n* (SD) | 2.0 (1.3) |
| Inadequate anterior fascial incision, *n* (%) | 24 (57) |
| Inadequate lateral fascial incision, *n* (%) | 23 (55) |
| Inadequate superficial posterior fascial incision, *n* (%) | 22 (52) |
| Failure to take down soleus, *n* (%) | 15 (36) |
| Inadequate deep posterior fascial incision, *n* (%) | 9 (21) |
| Failure to expose neurovascular bundle, *n* (%) | 3 (7) |
| Atleast 1 missed compartment, *n* (%) | 11 (26) |
| Mean # of missed compartment(s), *n* (SD) | 0.4 (0.8) |
| Missed anterior compartment, *n* (%) | 6 (14) |
| Missed lateral compartment, *n* (%) | 1 (2) |
| Missed superficial posterior compartment, *n* (%) | 3 (7) |
| Missed deep posterior compartment, *n* (%) | 7 (17) |
| Mean minor errors, *n* (SD) | 0.3 (0.5) |
| Division of GSV, *n* (%) | 5 (12) |
| Failure to make H-shaped incision, *n* (%) | 6 (14) |

Participants made a mean of 0.3 minor errors ($SD = 0.5$). Failure to make an H-shaped incision over the lateral intramuscular septum (6/42; 14%) and division of the greater saphenous vein (5/42; 12%) being nearly equally represented.

## DISCUSSION

### Theoretical Framework

In both training and real-world cases, the published error rates in fasciotomy continue to be an area for improvement. The error rates and types seen in the deployment training precourse assessments are similar to those reported from combat operations during the Global War on Terror.[9,11] As a result, the lower extremity models from this study serve as a representative sample of common errors in lower-extremity fasciotomy. This needs assessment yielded a catalogue of possible errors that is being used to develop an ERT and EMT curriculum in an effort to decrease further the rates of inadequate fasciotomy.

Traditional educational models, including the DoD and ASSET courses, center on error-avoidance training. In these training models, learners are taught to eliminate errors, defined as "unintentional deviation from truth or accuracy," before they occur.[12,13] These curricula tend to focus on a step-by-step emphasis on correct procedure and view errors as negative events.

In contrast, EMT takes a positive view of errors. Instead of seeing errors as nuisances to be avoided, EMT frames errors as inevitable events that serve as necessary components for learning and growth.[12,13,15] As a part of this educational strategy, learners are provided a less-structured learning environment in which they explore a given task with minimal guidance. When errors are committed, the instruction shifts from open exploration of the task to identifying the error and learning how to correct that error. A 2008 meta-analysis of studies surrounding EMT found a positive and significant impact of EMT curricula (Cohen's $d = 0.44$) relative to traditional curricula, particularly when the knowledge was used for an adaptive transfer task, which is defined as applying a "learned skill to novel problems that require development of new solutions."[13] The benefit for adaptive transfer is especially important for the military trauma setting where the devastating nature of the injuries can result in massive distortion of the normal anatomy. Similar clinical factors of anatomic distortion also come into play when revising inaccurate fasciotomies that have been performed by other surgeons. In addition to adaptive transfer, EMT is also seen to result in greater skill retention when compared with traditional error avoidance training.[16] In a medical context, error management is increasingly being used in simulation-based training, leveraging simulation's low-risk environment.[15]

Fasciotomy training presents an ideal forum for error recognition and management as it is a simple psychomotor task with a relatively more difficult cognitive component. Additionally, rectifying fasciotomy errors requires simple corrective actions including making a new incision or extending a previously existing one, yielding significant clinical benefit for the patient. For the proposed curriculum, learners will undergo brief instruction of how and why to perform a fasciotomy. They will then be asked to identify independently the presence or absence of errors in multiple simulated leg fasciotomy models, propose a reason for the error, and take the appropriate action to resolve the error. Once the learner has demonstrated a predetermined level of proficiency in identifying the presence or absence of errors, they will then progress to performing a simulated fasciotomy, which can then itself be evaluated for errors. The learners will be reassessed at 6 months to evaluate for knowledge retention. The first iteration of the course is currently being rolled out at the Walter Reed National Military Medical Center and will be directed at evaluating the course's efficacy and cost. Although this course focuses on lower-extremity fasciotomy, ERT and EMT present an opportunity to train surgeons for a wide variety of procedures.

### Cost Effectiveness

In addition to providing a different theoretical framework for fasciotomy training, transitioning to a model-based EMT curriculum also can provide financial and regulatory savings for organizations. Based on a 2014 evaluation of cadaveric-based medical school anatomy courses, a single cadaver costs $1500 to $2000 and a single storage humidor for an individual cadaver can cost up to $50,000.[17] Even if only detached cadaveric legs are used, each leg costs about $250. In addition to the direct costs of procurement and storage, cadaver-based courses also require oversight from different regulatory bodies that, even without monetary costs, require time and administrative structure investments to meet all requirements.

Traditional, model-based, error-avoidance curricula, such as the predeployment training evaluated in this study, also have considerable recurring costs. Although simulated lower extremities avoid the same regulatory burdens, each model costs around $750 and is only usable for performance of a single fasciotomy. Assuming each course includes a precourse and postcourse assessment model, this curriculum has a recurring cost of $1500 per student per course. In contrast, a model-based EMT curriculum needs only 1 postcourse assessment model per student, leading to a 50% cost savings per course. We hypothesize that evaluation of 5 to 10 models, with a varying number of major and minor errors, per student will be sufficient for the error-recognition component of this new training program; however, future work in the curriculum development process will define the ideal number needed. Thus, while there is a moderate one-time cost to obtain the initial catalogue of training models for a new program ($7500 for 10 models), this catalogue has potential to expand and diversify with the postcourse assessment models of previous learners. The continued addition of new models following each course and the lack of specialized storage equipment will lead to substantially decreased course maintenance and material costs versus a cadaver-based structure.

## CONCLUSIONS

The lower extremity fasciotomy continues to present a challenge for surgeons, with significant implications for the patient. Despite multiple training programs, error rates continue to be near 10% for this low-volume procedure that carries a high risk when performed incorrectly. EMT presents a novel and promising educational framework for this procedure and should be explored as a method of model-based simulation training.

## DISCLAIMER

The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Department of Defense, the Uniformed Services University of the Health Sciences, or any other agency of the US Government

## AUTHOR CONTRIBUTION

Drs. Kucera and Nealeigh participated in the background literature research; study design; data collection, analysis, and interpretation; writing; and critical revision. Drs. Franklin, Bowyer, Sweeney, and Ritter participated in background literature research, study design, and critical revision.

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