A pilot study of surgical telementoring for leg fasciotomy

Max Talbot,1,2 E J Harvey,1 G K Berry,1 R Reindl,3 H Tien,2,4 D J Stinner,5,6 G Slobogean,2,7 Compartment Release in Austere Locations (CORAL) Collaborators

ABSTRACT

Introduction Acute extremity compartment syndrome requires rapid decompression. In remote locations, distance, weather and logistics may delay the evacuation of patients with extremity trauma beyond the desired timeline for compartment release. The aim of this study was to establish the feasibility of performing telementored surgery for leg compartment release and to identify methodological issues relevant for future research.

Methods Three anaesthetists and one critical care physician were recruited as operators. They were directed to perform a two-incision leg fasciotomy on a Thiel-embalmed cadaver under the guidance of a remotely located orthopaedic surgeon. The operating physician and the surgeon (mentor) were connected through software that allows for real-time supervision and the use of a virtual pointer overlaid onto the surgical field. Two experienced orthopaedic traumatologists independently assessed the adequacy of compartment decompression and the presence of iatrogenic complications.

Results 14 of 16 compartments (in four leg specimens) were felt to have been completely released. The first evaluator considered that the deep posterior compartment was incompletely released in two specimens. The second evaluator considered that the superficial posterior compartment was incompletely released in two specimens. The only complication was a large laceration of the anterior compartment which occurred during a period of blurred video signal attributed to a drop in bandwidth.

Conclusions This study suggests that surgical telementoring may enable physicians to safely perform two-incision leg fasciotomy in remote environments. This could improve the chances of limb salvage when compartment syndrome occurs far from surgical care. We found interobserver variation in the assessment of compartment release, which should be considered in the design of future research protocols.

INTRODUCTION

Acute extremity compartment syndrome requires rapid decompression. Compartment syndrome occurs in up to 11% of patients with a tibia fracture, while 19% of all military orthopaedic trauma casualties require at least one fasciotomy.1–6 Once intracompartamental pressure reaches a critical threshold, fasciotomy should be performed as soon as possible, as irreversible tissue necrosis occurs within hours.7–9 Delayed or incomplete compartment release has been associated with increased mortality and need for amputation.10–12

In remote locations, distance, weather and logistics may delay the evacuation of patients with extremity trauma beyond the desired timeline for compartment release. This may occur during military operations and exercises, notably those conducted at sea or in polar regions. In such situations, a physician on location could dramatically improve patient outcomes by performing fasciotomy under telemedicine guidance.

The aim of this study was to assess the utility of non-surgeon physicians performing extremity fasciotomy while being telementored by an orthopaedic surgeon. We sought to evaluate the feasibility of this procedure and identify surgical, technical and methodological issues relevant to future research and practice.

METHODOLOGY

The study protocol was approved by our local research ethics board. Written informed consent was obtained from all participants. Three military anaesthetists and one military critical care physician were recruited as operators. They were directed to perform compartment release on a Thiel-embalmed cadaver leg under the guidance of a remotely located military orthopaedic surgeon, who mentored all four procedures consecutively.13–15 A two-incision fasciotomy technique was used, as taught on the American College of Surgeons’ Advanced Surgical Skills for Exposure in Trauma (ASSET) course.16 Briefly, this technique involves a full-length medial incision slightly posterior to the medial edge of the tibia. This incision allows decompression of the superficial and deep posterior compartments, the latter being accessed after detaching the soleus muscle from the tibia. The second incision is located slightly anterior to the fibula. After the lateral intermuscular septum is identified, a small transverse incision crossing the septum is performed in the
fascia. This incision allows the clear identification of the anterior compartment, the septum and the lateral compartment. This small incision is then extended longitudinally over the full length of both the anterior and lateral compartments, resulting in an h-shaped incision in the fascia. Care is taken to preserve the superficial peroneal nerve throughout its course.

Participants had no advanced knowledge of the procedure they would be asked to perform. The operating physician (operator) and the surgeon (mentor) were connected through Reacts Lite (Innovative Imaging Technologies, Montréal, Canada) software running on iPad Air2 (Apple, Cupertino, California, USA) which allows for real-time supervision and the use of a virtual pointer overlaid onto the surgical field. The tablet used by the operator was fixed to the operating table in a manner that allowed the operator to look through or around the tablet during surgery. Looking ‘through’ the tablet allowed the operator to see the mobile pointer overlaid on the surgical field in real time (Figure 1). The mentoring surgeon also used hard copy diagrams of the leg compartments, which were transmitted to the operators over the live video at important points of the procedure.

A Critical Care Nursing Officer without prior surgical experience acted as the first assistant. Branches of the saphenous nerve encountered in the medial incision were ligated and divided when necessary to advance dissection.

The primary outcome was adequacy of compartment release. Therefore, each anatomic specimen yielded four separate reportable events: quality of decompression of the anterior, lateral, superficial posterior and deep posterior compartments. Two experienced orthopaedic traumatologists independently assessed the adequacy of decompression in each compartment as fully released, partially released or not released. The distinction between a partial release and a full release was left up to each assessor’s clinical judgement. Secondary outcomes included the duration of surgery and the presence of iatrogenic complications. These included injuries to the saphenous vein, saphenous nerve, superficial peroneal nerve, posterior tibial artery, tibial nerve or popliteal vessels. The only complication was a large laceration of the soleus that occurred during a period of blurred video signal attributed to a drop in bandwidth. This resulted in the operator straying from the correct tissue plane while attempting to access the deep posterior compartment. Once the video signal returned to normal, the deep posterior compartment was released adequately. For the mentoring surgeon, the most challenging aspects were visualization of the superficial peroneal nerve and release of the deep posterior compartment. Both at baseline and after the index procedure, none of the participants stated that they would be confident in performing fasciotomy unassisted. However, three of the four participants said they would feel confident or very confident to perform this procedure under the video guidance of a surgeon.

DISCUSSION

While current North Atlantic Treaty Organization (NATO) guidelines call for initial damage control surgery within 1 to 2 hours during combat operations, extremity trauma can occur during low-intensity conflict, training missions, naval and arctic operations in which the low probability of injury does not warrant the deployment of a surgical force package. In such circumstances, casualties with extremity compartment syndrome may experience prolonged evacuation to a surgical facility. Delayed fasciotomy may lead to adverse outcomes, including amputation, sepsis and death.

Our study explored the use of surgical telementoring for compartment release, which is one possible solution to lengthy evacuation delays. This procedure could allow immediate treatment of compartment syndrome, which would routinely be followed by evacuation to higher echelons for comprehensive care, including fracture fixation and soft-tissue coverage. All four operators were Royal Canadian Medical Service anaesthetists and intensivists who regularly practise in remote locations, notably during aeromedical evacuation. Our results suggest that telementoring may allow physicians without surgical training to safely perform leg fasciotomy. From the surgical perspective, the posterior compartments were the most challenging to release. The depth and complexity of the proximal aspect of the deep posterior compartment and the proximity of major vessels make it particularly difficult to fully release without tactile feedback. The mentoring surgeon erred on the side of caution, which accounts for the incomplete release of the proximal soleus fibres (‘soleus bridge’) in two cases. Although current recommendations

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**Table 1** Results. The two evaluators independently assessed the four leg specimens and rated each compartment as fully released or partially released.

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Evaluator 1</th>
<th>Evaluator 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior compartment</td>
<td>4/4 fully released</td>
<td>4/4 fully released</td>
</tr>
<tr>
<td>Lateral compartment</td>
<td>4/4 fully released</td>
<td>4/4 fully released</td>
</tr>
<tr>
<td>Superficial posterior compartment</td>
<td>4/4 fully released</td>
<td>2/4 fully released</td>
</tr>
<tr>
<td>Deep posterior compartment</td>
<td>2/4 fully released</td>
<td>4/4 fully released</td>
</tr>
</tbody>
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**Figure 1** View of a simulated lower extremity from the operator’s perspective.

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call for release all four compartments in a combat environment, recent civilian data suggest that release of the anterior and lateral compartments often results in a significant increase in posterior compartment perfusion pressure. In far-forward locations, a limited anterolateral release may be a safe compromise until the patient reaches a fixed surgical facility. In the current study, the anterolateral release was complete and without complications in all cases.

We found disagreement between the two evaluators’ perception of a full compartment release, particularly in the posterior compartments. Both evaluators were fellowship-trained orthopaedic traumatologists with more than 10 years of experience working at a tertiary trauma centre. They each reported that 14 of 16 compartments were fully released, but disagreed as to which compartments needed a more extensive fascial incision (Table 1). This interobserver variability may be explained by differences of opinion and by the absence of compartment syndrome in our model. In a clinical situation, an experienced surgeon proceeds with release until there is no residual compression. Without tense muscle, it may be more difficult to assess the clinical relevance of remaining fascial bridges. A porcine study demonstrated that tissue pressure has a strong inverse correlation with the length of the incision, with release of 90% being suggested to restore tissue pressures to baseline in that model. In the two-incision technique, it is generally agreed that decompression of the deep posterior compartment should include a full release of the medial origin of the soleus muscle (the medial portion of the ‘soleus bridge’). In contrast, varied single incision fasciotomy techniques in which the soleus origin is not fully released have produced good clinical results. This includes a variation in which the deep posterior compartment is released through an incision in the interosseous membrane. These various techniques and the results of our study suggest that there is no universal agreement among surgeons as to what constitutes a full compartment release. Future research should include precise a priori criteria for a complete fasciotomy to ensure the surgical mentor and the assessors have a common understanding of the desired outcome.

We used commercially available tablets and software, making this system affordable and simple to reproduce. The software allowed audio and video communication and the use of a virtual reality pointer overlaid on the surgical field, which we found essential to improve communication. The tablet used by the operator was fixed to the operating table in a manner that allowed the operator to look through or around the tablet during surgery. During preliminary testing, we found that a fixed platform (as opposed to a head-mounted camera) improved spatial orientation and communication between the mentor and the operator. Andersen et al. reported that a similar set-up (STAR: System for Telementoring with Augmented Reality) decreases operator focus shifts and improves accuracy when performing port placement and abdominal incisions on a surgical simulator. Telementoring of trained surgeons learning new procedures appears to yield similar complication rates and surgical duration compared with on-site mentoring. This may not be applicable to operators with more rudimentary surgical skills.

The authors recognise that this current study has several limitations. The procedure was performed in pristine anatomic specimens, which facilitates identification of tissue planes. We simulated haemostasis by having the operators ligate branches of the saphenous vein encountered in the medial incision. However, we did not simulate bleeding from fracture surfaces and major vessels that is often encountered in cases of extremity trauma. In a real-life situation, haemorrhage control would likely be the most hazardous part of this procedure for an operator working without cautery and vascular instruments. In case of catastrophic bleeding, proximal control could be obtained with a tourniquet. In addition, we did not address clinical diagnosis, pressure measurement, anaesthesia and perioperative care. Bedside fasciotomy under local anaesthesia and sedation may be an option when resources are limited. Finally, the connection consisted of a solid local Wi-Fi network, which may not be representative of field conditions.

CONCLUSION

This study suggests that surgical telementoring may enable physicians to safely perform two-incision leg fasciotomy in remote environments. This could improve the chances of limb salvage when compartment syndrome occurs far from surgical care. We found interobserver variation in the assessment of compartment release, which should be considered in the design of future research protocols.

Correction notice

This article has been corrected since it was published Online First. Dr Rudolph Reindl has been reinstated in the author list after being removed by accident during editing.

Collaborators

Compartment Release in Austere Location (CORAL) Collaborators: Max Talbot; Edward J Harvey; Gregory K Berry; Rudolph Reindl; Homer Tien; Daniel J Stinner; Gerard Slobogean; Paul A Martineau; Valerie Weagle; Marie-Julie Levesque; Joanne Schmid; Wang-Chun Ip; Leilani Doyle; Chris Berger; Stephen Crummeny; Mathieu Couillard.

Contributors

MT, EH, GKB, RR, HT and GS contributed to study design. MT, EHJ, GKB, RR, HT and GS contributed to data analysis and interpretation. MT wrote the manuscript. EHJ, GKB, RR, HT, DS and GS critically reviewed the manuscript.

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Competing interests

Outside the submitted work: MT is a member of the Society of Military Orthopaedic Surgeons’ Board of Directors and of the Orthopaedic Trauma Association’s Military Committee. EHJ is a co-founder of NXSens, a biomedical company, GS received personal fees from Zimmer Biomet and grants from PCORI and the Department of Defence. GKB was a surgical educator for Stryker Inc.

Ethics approval

McGill University Faculty of Medicine.

Provenance and peer review

Not commissioned; externally peer reviewed.

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REFERENCES


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