Quality of Care Assessment in Forward Detection of Extremity Compartment Syndrome in War

David R. King, MD; John F. Kragh Jr., MD; Lorne H. Blackbourne, MD

ABSTRACT

Background: Recent efforts to improve the quality of care in the Afghanistan theater have focused on extremity compartment syndrome, a common, disabling, and costly problem. To identify opportunities to improve care, the present survey was undertaken to observe the use of two standard methods—the traditional, improvised method and the common, off-the-shelf method—for determining intracompartmental pressures in the lower extremities of combat casualties. **Methods:** As part of a quality of care improvement effort during Operation Enduring Freedom, all combat casualties presenting to a forward surgical team at Forward Operating Base Shank from August to November 2011 with lower-extremity major trauma were evaluated for signs and symptoms of compartment syndrome. **Results:** Ten casualties had pressure measurement surveyed simultaneously using both methods. A two one-sided test analysis demonstrated a mean difference of –0.13 (90% confidence interval, –0.36 to 0.096), which indicated that the methods were similar. A repeated-measures analysis yielded a *p* value of .72, indicating no statistical difference between the methods. The receiver operating characteristic curve demonstrated excellent agreement within the prespecified limits (±2mm Hg, area under the curve 1.0), which indicated that the methods were similar. **Conclusion:** The main finding of the quality of care effort was that clinicians received similar information from use of two standard methods for far forward measurement of pressures to detect extremity compartment syndrome. This finding may help clinicians improve the quality of care in the theater in detecting, diagnosing, and monitoring compartment syndrome.

KEYWORDS: *fascia, wounds, injuries, emergency medical services, Afghan Campaign 2001–present, military medicine*

Introduction

Extremity compartment syndrome, an abnormal rise in physiological pressure of an anatomic osteofascial space, among casualties of the current war in Afghanistan is controversial, common, disabling, and, if managed poorly, lethal.[1,2] Early detection of compartment syndrome onset after trauma appears essential to best care, but measurement of intracompartmental pressures can be challenging, particularly on the battlefield.[3] Evacuation (e.g., casualty transfer from Level II to Level III, from a forward surgical team [FST] to a combat support hospital [CSH], respectively) complicates compartment syndrome diagnosis and monitoring and thereby risks delayed detection, limb ischemia, amputation, and death.[1] Recent evidence implies that difficulties in measuring may cause surgeons to bypass measurement and to overuse fasciotomy (i.e., perform many prophylactic fasciotomy operations).[2] The small FST, having few supplies and moving to austere sites, has no compartment pressure–monitoring devices on its unit allowance list, so manometer values are routinely absent. To fill that detection gap at the point of care, forward surgeons can improvise pressure measurement by using the transducer of a vital signs monitor that normally measures central venous pressure.[4] This improvised method was popularized decades ago and soon became traditional and stimulated development of handheld manometers.[5] Today, commercial, off-the-shelf methods of determining pressures are common in civilian care. To focus on an opportunity to improve the quality of care, the present survey was conducted to observe use of the two standard methods—the traditional, improvised method and the common, off-the-shelf method—for determining intracompartmental pressures in the lower extremities of combat casualties.

Methods

As part of a quality of care improvement effort during Operation Enduring Freedom (OEF) , all combat casualties presenting to an FST at Forward Operating Base (FOB) Shank from August 2011 through November 2011 with critical lower-extremity injuries were evaluated for signs and symptoms of compartment syndrome.

The period of observation lasted until supplies ran out, which in this case was first with the off-the-shelf method. In the normal course of clinical care, each at-risk lower extremity had compartment pressures measured with the two standard methods—the improvised method and the off-the-shelf method. Pressures were measured by the treating surgeon (military occupational specialty 61J, general surgeon; or 61M, orthopedic surgeon). The present work was conducted to improve clinical performance at one institution without intent originally to generalize knowledge or publish results. However, after the usefulness of the findings became clear, we applied for an oversight review.

The traditional, improvised compartment pressure measurement method utilized a standard vital signs monitor that was available at the FST. A standard 20 gauge needle/intravenous pressure tubing/transducer setup was connected to the input normally used for central venous pressure waveform measurement.[4] The needle was then inserted in each compartment to measure compartment pressures. This setup was improvised, awkward, slow, and bulky; it consumed numerous supplies and occupied a waveform channel of the sole monitor during compartment pressure measurements. Although cumbersome, the traditional improvised method can be made reliable by knowledgeable hands with adequate supplies.[4]

The commercial, off-the-shelf method of determining pressures included a small, handheld manometer, the Compass™ Compartment Pressure transducer (Mirador Biomedical, Seattle, WA). The disposable manometer has an integrated digital display for direct measurement of physiological pressure; it was cleared by the U.S. Food and Drug Administration (FDA) in 2011 (510k number K112203). The manometer was used to simply and rapidly determine pressures as it required few supplies and little setup time in contrast to the improvised method. The handheld manometer in the present survey was used as indicated by the FDA labeling.

Statistical methods included descriptive statistics and three comparison methods. First, to compare the diagnostic methods, a two one-sided test (TOST), the most basic form of equivalence testing to compare two groups, was used to compare the two methods. Routinely in TOST analysis, the confidence intervals are made at $(1 - 2\alpha) \times 100\%$ and as $\alpha = .05$ or 5%; the 90% confidence intervals were constructed in order to observe equivalence or difference. Second, repeated-measures analysis was conducted. Third, receiver operating characteristic (ROC) curves were used. In comparison, noninferiority of the off-the-shelf method to the traditional, improvised method was determined by boundaries of ±2mmHg; the reference was the improvised method and the comparator was the off-the-shelf method.

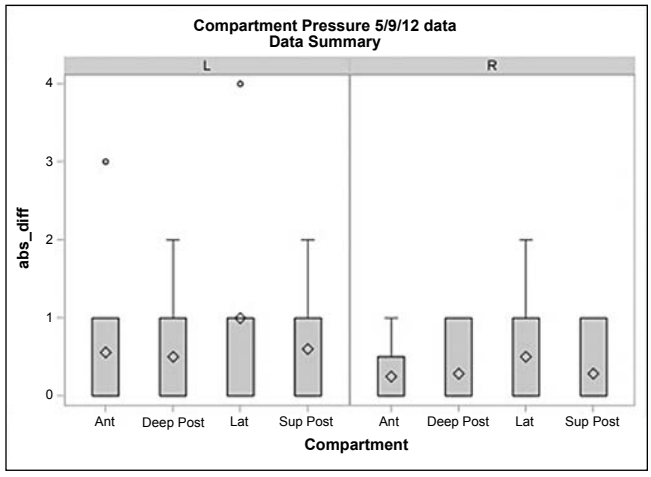
Results

In this quality of care effort, 10 casualties had pressure measurement surveyed simultaneously using both methods. All casualties sustained explosion injuries that caused soft tissue damage and destruction. Fragment wounds or associated vascular lesions were neither excluded nor required for inclusion. The 10 casualties had 20 lower-extremity injuries involving 68 compartments below the knee, all of which were surveyed.

For the first quality of care comparison of the diagnostic methods, the total sample size of 68 was used to conduct a TOST analysis; it demonstrated a mean difference of –0.13 (90% confidence interval, –0.36 to 0.096). This –0.13 difference was within the predefined tolerance limits of ±2mmHg, and so the methods were similar. The absolute differences in compartment pressures, by method, are described in Figure 1, while the distributions of pressures are described in Figure 2. Figure 3 demonstrates the paired pressure differences between the two methods are very narrow.

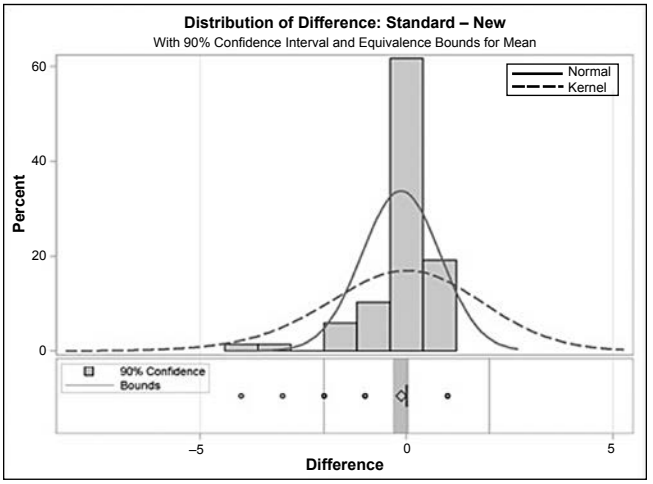
For the second quality of care comparison, repeated-measures analysis revealed a *p* value of .72, indicating no statistical difference between the methods. When the analysis was repeated using the absolute differences, the *p* value was .25, which also indicated no statistical difference between the methods. Figure 4 demonstrates the granularity of data points and means between the two methods.

Figure 1 *Difference in compartment pressures betweeen the two methods.*



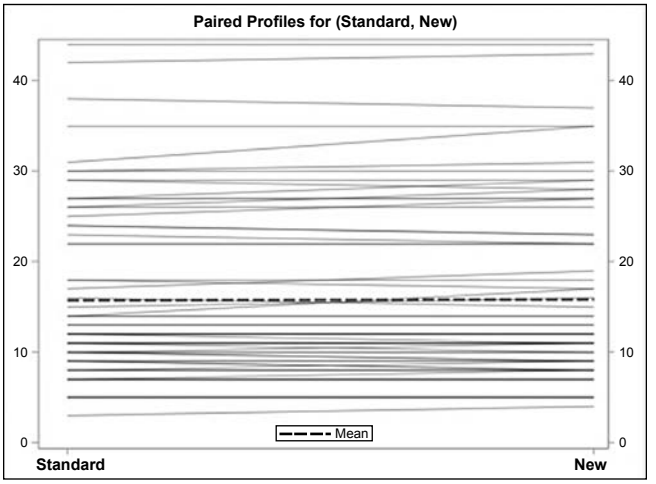
Notes: The absolute (abs) difference (diff) in compartment pressure measured by the two methods was often at or near zero. The absolute difference is the vertical (y) axis and is in mmHg units. The horizontal (x) axis is the abbreviated names of the anatomic leg compartments (anterior [Ant], deep posterior [Post], lateral [Lat], and superficial posterior [Sup Post]). L represents left leg, and R represents right. The box top is the 75th percentile, the bottom is the 25th percentile, the whisker is the 90th percentile, and circles are outliers beyond the whisker. Diamonds are means.

Figure 2 *Distribution of difference in pressures between the two methods.*



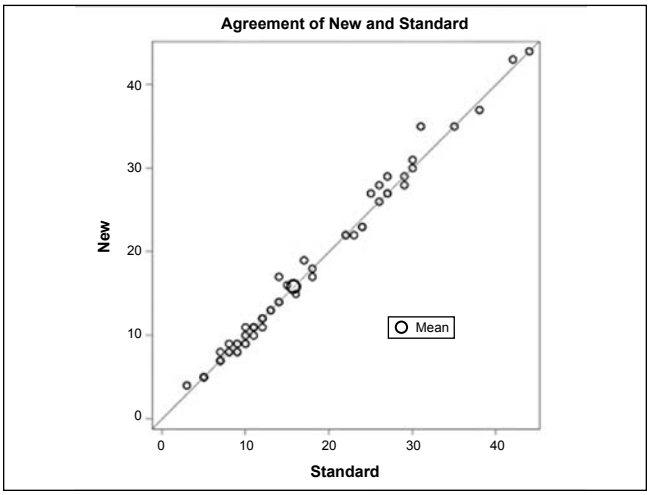
Notes: The data distribution of pressure differences between the two methods was centered closely to zero, indicating little to no difference. The vertical (y) axis is the percentage of all pressure measurements. The horizontal (x) axis is the differences in mmHg. The differences also have 90th percent confidence bounds shown on the axis as a narrow, gray-shaded area over which the diamond represents the mean. Circles represent outlier values beyond the 90th confidence bounds. A referent normal distribution is shown as a solid line in its characteristic bell-shaped curve so that the reader can see that the data are distributed narrower than normal (similarly, the data distribution is narrower than a Kernel distribution).

Figure 3 *Profiles of paired pressures measured by the two methods.*



Notes: When data are paired for the traditional, improvised (standard) method and for the for the off-the-shelf (new) method, the differences are small or zero. The points at the ends of the paired lines represent the data points of the two respective methods. The two vertical axes (y-axes, left and right) are in mmHg for the differences. Minor differences among paired measurements are seen as sloped lines; no difference is a flat line. The mean difference, the dashed line, is nearly flat. The two methods generated similar paired measurements.

Figure 4 *Graphic agreement in pressures measured by the two methods.*



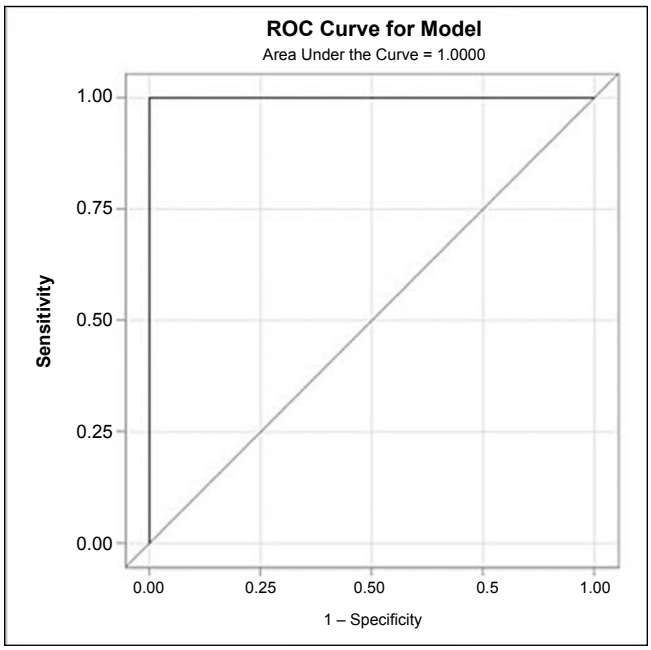
Notes: When data are graphed for the traditional, improvised (standard) method and for the off-the-shelf (new) method, the differences are seen as distance from the central diagonal line representing no difference. The circles are the pressure measurements; the large circle is the mean. The vertical ax=is (y-axis, left) is the pressure in mmHg by the off-the-shelf (new) method. The horizontal axis (x-axis) is the pressure in mmHg by the traditional, improvised (standard) method. Differences were small or zero, indicating that the two methods are similar.

For the third quality of care comparison, the ROC curve demonstrated excellent agreement of the off-the-shelf method with the improvised method within the prespecified limits (±2mmHg). The area under the curve was 1.0, which also indicated that the two methods were similar (Figure 5).

Discussion

The main finding of the present effort to improve quality of care in theater was that two standard methods used for far forward measurement of extremity pressures to detect compartment syndrome were similar to one another. Rarely are battlefield assessments of extremity compartment syndrome evidenced well, and the present survey describes the results of both a traditional, improvised method and the recently cleared off-the-shelf manometric method. The methods performed similarly in measuring physiological pressures at the FST (Level II) in the Afghanistan war. Although it is no scientific surprise that the off-the-shelf method and improvised method had similar results, as they both were to measure extremity compartment pressures, the ease of use of the off-the-shelf method is of plain practical value to forward clinicians such as surgeons, emergency physicians, and physician assistants. The value is extra if expertise or time is limited. By increasing awareness of detection of a common, disabling, and occasionally lethal condition, the present survey offers specific evidence of the diagnostic equivalence of two common methods. Therefore, users may now make a better informed decision among them, perhaps concerning other factors such as convenience or cost, depending on the user's individual needs. A key to improving care of the syndrome is its early detection, the focus of the present effort.

Figure 5 *Receiver operating characteristic (ROC) curve of the two methods.*



Notes: The ROC curve of the two methods of measuring compartment pressures showed that the two methods are similar. The vertical axis (y-axis) is the sensitivity of the off-the-shelf method compared with the improvised method. The horizontal axis (x-axis) is the specificity of the off-the-shelf method compared to the improvised method. Differences between the two methods were zero, indicating that the two methods are similar. The curve is represented as a dark line; in this case, it rises vertically and turns horizontally at the top. Given a ±2mm tolerance, the area under the curve is 1.00, indicating that the two methods are similar.

In the present quality of care effort, diagnostic processes at the base were improved by the focused attention on compartment syndrome detection. By deconstructing the task of detection into pressure manometry, the focus became clear to the clinicians, which improved clarity of diagnosis.

Regarding quality of care efforts on compartment syndrome in theater, routine war surgery often includes liberal four-compartment fasciotomies for lower-extremity wounds with any clinical suspicion of compartment syndrome. At-risk limbs include those with wounds prone to swelling such as with reperfusion after vascular repair and soft tissue injuries with long evacuation and little monitoring. Fasciotomy with compartment syndrome present is therapeutic, and fasciotomy with compartment syndrome absent is prophylactic[1,2]; the latter is generally regarded as standard of care in combat operations. This common or liberal use of fasciotomy when the syndrome is absent, yet may develop soon, is in part largely due to the inability to assess compartments when casualties are moved from Level II to Level III and due to a lack of continuity in care because surgeons do not travel rearward with casualties. The new off-the-shelf method used in the present survey may have a role in filling that gap by providing a simple method for measuring compartment pressures and thereby detecting the onset of compartment syndrome reliably, easily, and early. Additionally, this method could be used without consuming other valuable supplies. Furthermore, the off-the-shelf method did not block the use of monitor channels for vital signs. Finally, this method was able to be used repeatedly on a single casualty and left in place for real-time ongoing measurements.

Limitations of the present quality of care effort in theater are numerous. By limiting this work to observation of normal care, no experiments, controls, or interventions were performed. Without more rigorous methods, the present work observing a small number of cases mainly increases awareness of the clinical syndrome and its early detection by two common methods.

Several future directions exist for further quality of care efforts in theater . Work that advances awareness of the difficult-to-detect compartment syndrome, improves diagnosis and monitoring, or provides equivalent answers faster may help move the trauma system from its current state to a level that provides the best possible care for all.

Acknowledgments

Otilia Sánchez aided in manuscript preparation. Yuchaio Chang provided statistical support.

References

1. Ritenour AE, Dorlac WC, Fang R, Woods T, Jenkins DH, Flaherty SF, Wade CE, Holcomb JB. Complications after fasciotomy revision and delayed compartment release in combat patients. *J Trauma.* 2008;64:S153–S161.
2. Kragh JF Jr, Wade CE, Baer DG, Jones JA, Walters TJ, Hsu JR, Wenke JC, Blackbourne LH, Holcomb JB. Fasciotomy rates in Operations Enduring Freedom and Iraqi Freedom: association with injury severity and tourniquet use. *J Orthop Trauma.* 2011;25:134–139.
3. Joint Trauma System. *Guideline for clinical practice, compartment syndrome (CS), and the role of fasciotomy in extremity war wounds.* Approved April 2009, updated annually thereafter.
4. Whitesides TE Jr, Haney TC, Morimoto K, Harada H. Tissue pressure measurements as a determinant for the need of fasciotomy. *Clin Orthop.* 1975;113:43–51.
5. McQueen MM, Court-Brown CM. Compartment monitoring in tibial fractures: the pressure threshold for decompression. *J Bone Joint Surg Br.* 1996;78:99–104.

LTC King is a U.S. Army Reserve trauma surgeon who has deployed with Forward Surgical Teams to Iraq and Afghanistan. He is also an academic trauma surgeon and surgical scientist/researcher, Division of Trauma, Emergency Surgery, and

Surgical Critical Care, Massachusetts General Hospital and Harvard Medical School, Boston, Massachusetts, with expertise in hemorrhage control and resuscitation. E-mail: bostontraumasurgeon@gmail.com.

COL (Ret) Kragh is currently a hemorrhage control researcher at the USAISR. He is an orthopedic surgeon who previously served at 3d Ranger Battalion from 1990 to 1993.

COL Blackbourne is located at the U.S. Army Institute of Surgical Research, Fort Sam Houston, TX. Lorne is a senior Army surgeon, experienced leader, trauma researcher, and educator with SOF experience.

D.R.K. was responsible for literature search, work organization, data collection, data analysis, and data interpretation, writing, and revision. J.F.K. and L.H.B. were responsible for data analysis, data interpretation, writing, and revision.

Disclosure

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense. Dr. Kragh is an employee of the U.S. Government and receives institutional support where he works, the U.S. Army Institute of Surgical Research. He has offered free advice on scientific matters at no cost to Operative Experience; M2, Inc.; Tiger Surgical, LLC; Tactical Medical Solutions, LLC; Combat Medical Systems, Inc.; Composite Resources Inc.; Delfi Medical Innovations, Inc.; North American Rescue Products LLC; H & H Associates, Inc.; Creative & Effective Technologies, Inc.; TEMS Solutions, LLC; Blackhawk Products Group; Hemaclear; Tactical Development Group; Compression Works, LLC; Tier-One Quality Solutions; Kforce Government Solutions; CHI Systems; Tactical Emergency And Medical Simulations Training (TeamsT); Athena GTX; Pélagique, LLC; Hawaii Product Development, Inc.; RevMedx, Inc.; SAM Medical Products; and Entrotech, Inc. He has received honoraria from the U.S. Food and Drug Administration for device consultation. He has received honoraria for trustee work for the nonprofit Musculoskeletal Transplant Foundation. He has worked as a technical representative to the U.S. government's contracting officer in agreements with Physical Optics Corporation; Resodyn Corporation; International Heart Institute of Montana Foundation; Daemen College; Noble Biomaterials, Inc.; Wake Forest Institute of Regenerative Medicine; National Tissue Engineering Center; Pittsburgh Tissue Engineering Initiative; University of Texas Southwestern Medical Center; Arteriocyte, Inc.; and Kelly Space and Technology, Inc.

The other authors have nothing to disclose.