texas orthopaedic journal®

ORIGINAL RESEARCH

Skin Pressure Measurements under a Bivalved Cast Stabilized by Utilizing a Knob-Wire System: A Cadaver Model Study

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ABSTRACT

Introduction: Elastic bandages are usually applied to hold a bivalved cast in place, but this has proven to be inconsistent and unreliable as well as subject to easy patient modification. We asked the following questions: (1) Are skin pressure measurements under a bivalved cast stabilized with a new device (CastFit™) comparable to elastic bandage use? (2) Are cadaver specimens suitable substitutes for human subjects for measuring skin pressure change under a cast?
Methods: Ten cadavers were casted and bivalved after placing a 100 mL fluid bag on the dorsum of the wrist and attaching its distally protruding ends to a pressure transducer. To record a baseline pressure, 10 mL was infused, and 50 mL more was added to simulate maximum pressure edema. After bivalving, 2 more pressure readings were taken, 1 after elastic bandage and another after CastFit™ application. The variance between the 2 interventions was assessed using Levene's test. Paired Student *t*-test was performed to assess significance of pressure changes throughout the experiment to determine if cadavers are suitable for testing.
Results: Levene's test of ACE™ wrap versus CastFit™ showed equal variability in both interventions ($p=0.222$). Pressure changes throughout experimental stages were consistently significant ($p<0.0001$) alluding to acceptability of a cadaver model.
Discussion: CastFit™ is a safe alternative given its similar pressure profile to elastic bandages. The cadaver model tested was a suitable alternative to studying skin pressure under casts of live subjects.
Level of Evidence: Experimental cadaveric study.
Keywords: Bivalved cast; Skin pressure; Cast models.

INTRODUCTION

Applying casts to stabilize fractured bones is a routine orthopaedic procedure; however, posttraumatic edema, which can last up to 3 weeks, may occur with definitive nonoperative treatment using circumferential casts [1]. Creating longitudinal cuts through the cast, ie *valving*, is an acceptable practice for managing edema associated with fractures and preventing detrimental

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complications, such as Volkmann's contracture [2], compartment syndrome [3-6], and pressure-related skin necrosis [3,4,6]. Furthermore, *univalving* is the process of creating a single longitudinal slit and *bivalving* is the process of creating 2 longitudinal slits along the length of the cast.

The orthopaedic care provider has the option to also release more pressure by cutting the underlying cast padding to allow for further soft tissue expansion. An elastic bandage may then be applied to prevent the bivalved cast from being easily removed. Zaino et al. found that bivalving a cast and cutting the underlying cast padding was the most effective method to eliminate all skin pressure in human subjects [7]. The authors also noted that the addition of an elastic bandage increased the skin pressure after application. Though there are no clinical studies that specifically address the properties of elastic bandages, it is intuitive that elasticity produces variable skin pressure changes based on the tightness of the wrapping. Moreover, the bandage may be easily removed and potentially compromise the fracture reduction within the bivalved cast.

The authors investigated a new method for stabilizing bivalved casts that utilized a knob-wire system (CastFit™, Clickmedical, Inc.; Denver, CO). The device has been available as a substitute to the traditional elastic bandage method for stabilizing bivalved casts. It is intended to allow for sufficient cast reinforcement while allowing practitioners and patients to adjust the tightness of the construct without compromising fracture reduction. The practitioner wraps the wire around the cast and its length can be adjusted through a center knob to tighten or relax the cast to the patient's comfort. (Figure 1). We therefore asked the following questions:

1. After bivalving a short arm cast, is the skin pressure better reduced after stabilization with CastFit™ or an elastic bandage?
2. Can a cadaver be an acceptable substitute for human subjects for measuring skin pressure changes under a short arm cast?

MATERIALS & METHODS

Ten cadavers intact from the elbow were used in this study (mean age 66.7; mean BMI 24.8). Each cadaver served as its own control. Casting and elastic bandage wrap application were done by one registered orthopaedic technologist to minimize technique variability. Pressure readings under the cast were recorded using a similar method implemented by Zaino et al. [7] in a study using an empty intravenous fluid bag (100 mL) with its 2 ends pointing distally. The bag was placed on the dorsal side of the cadaver wrist with its distal end aligned with the metacarpal heads and were not covered by the cast. One layer of stockinette (Performance Stockinette™, Carolina Narrow Fabric Medical; Winston-Salem, NC) was used to hold the bag in place, 4 layers of 3 inch (7.6 cm) cast padding (Performance Padding™, Carolina Narrow Fabric Medical; Winston-Salem, NC) and 4 layers of 2 inch (5.1 cm) fiberglass cast (Performance Casting®, Carolina Narrow Fabric Medical; Winston-Salem, NC) were applied to the cadaver arm using a stretch-relax technique.

After the cast was dried completely, a calibrated pressure transducer (Deltran®, Utah Medical Products Inc.; Midvale, UT) was attached to 1 of the 2 valves of the bag (Figure 2). The same inlet valve was used to infuse fluid to simulate edema and read pressure.

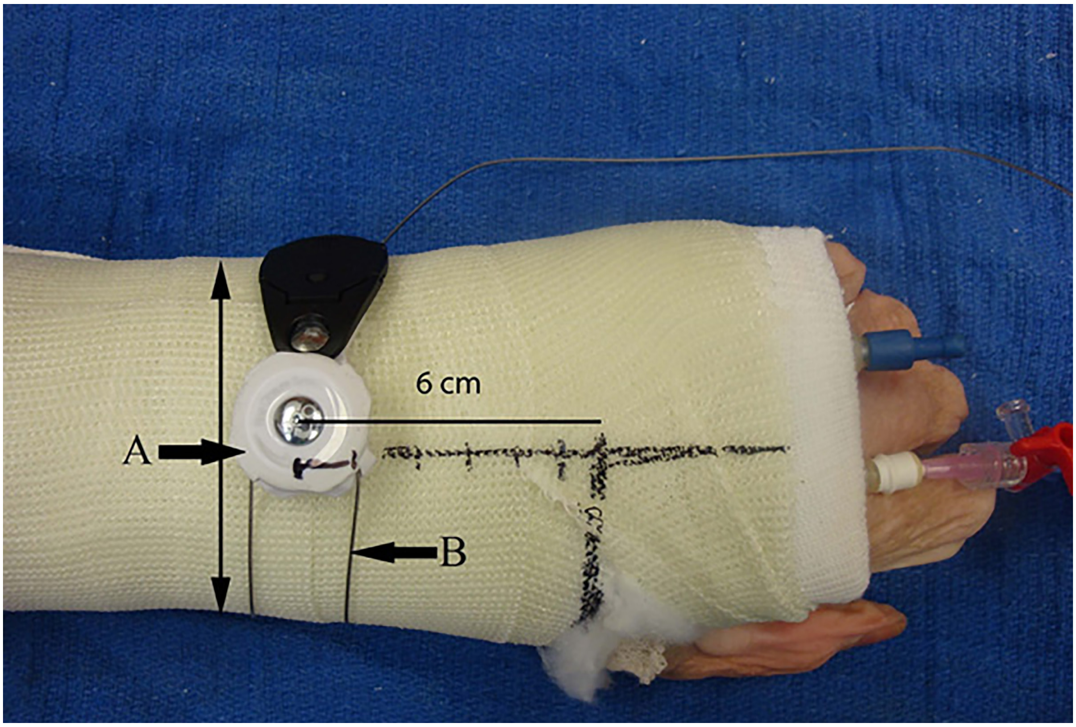

Figure 1. Castfit™ device for stabilizing bivalved casts utilizes a 2 way knob (**A**) and a wire system (**B**) for adjusting the tightness of the construct. The device was placed in line with the third metacarpal and 6 centimeters proximal to the carpometacarpal joint of the thumb.

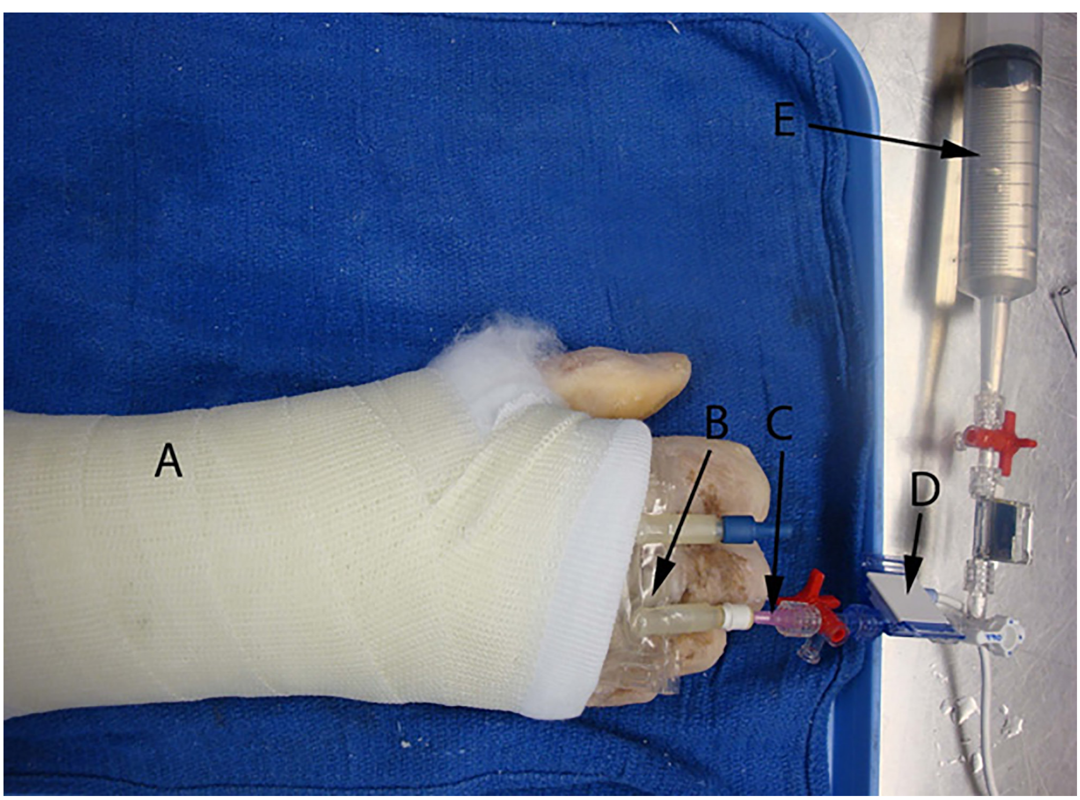

Figure 2. Test set up for pressure measurements. **A.** fiberglass cast, **B.** saline bag under the short-arm cast, **C.** 15 gauge needle, **D.** pressure transducer, **E.** 60 mL syringe.

Pressures were recorded on a digital pressure monitor (PCU-2000, Millar Inc.; Houston, TX), and data were acquired from the monitor using WinDaq Data Acquisition and Playback Software (DATAQ Instruments, Inc., Akron, OH). Ten milliliters of water were infused in the bag through 1 of the 2 ends using a 60 mL syringe to record a baseline pressure. An additional 50 mL of water were added to reach a total of 60 mL and record a maximum pressure of simulated edema. The cast was then bivalved by cutting the fiberglass on 2 sides along with the padding underneath and spread, and the pressure reading was recorded. Two more pressure readings were taken, 1 after elastic bandage (3 inch ACE™ Elastic Bandage, 3M®; St. Paul, MN) application and another after CastFit™ applications. The Castfit™ was maximally tightened on all samples for consistency.

All pressure readings were taken after 1 minute to achieve a stable baseline. Analysis was done using Minitab® software (Minitab Inc.; State College, PA) by comparing the variance of the 2 intervention samples. This process allowed comparison of the spread of data around the mean in 1 sample to another, leading to a legitimate comparison between a maximally tightened CastFit™ and a standard elastic bandage technique. Levene's test was used to assess hypotheses of equal variance. A paired Students *t*-test was performed to assess significance of pressure changes throughout the experiment. A 2-sample Student *t*-test was performed to compare this study's results with those by Zaino et al. [7]. Statistical significance was defined as a p-value less than 0.05.

RESULTS

The average pressure under the cast at 10 mL infused water was 13.7±3.47 mmHg, and the average pressure increased at 60 mL infused water to 73.9±16.58 mmHg ($p<0.0001$) (Figure 3). After cutting the cast, the pressure dropped to an average of 9.6±3 mmHg ($p<0.0001$). Elastic bandage application caused the pressure to increase to an average of 24.4±6.6 mmHg, and the CastFit™ at its maximum tension resulted in an average pressure increase to 33.9±9.44 mmHg ($p<0.0001$; $p<0.0001$).

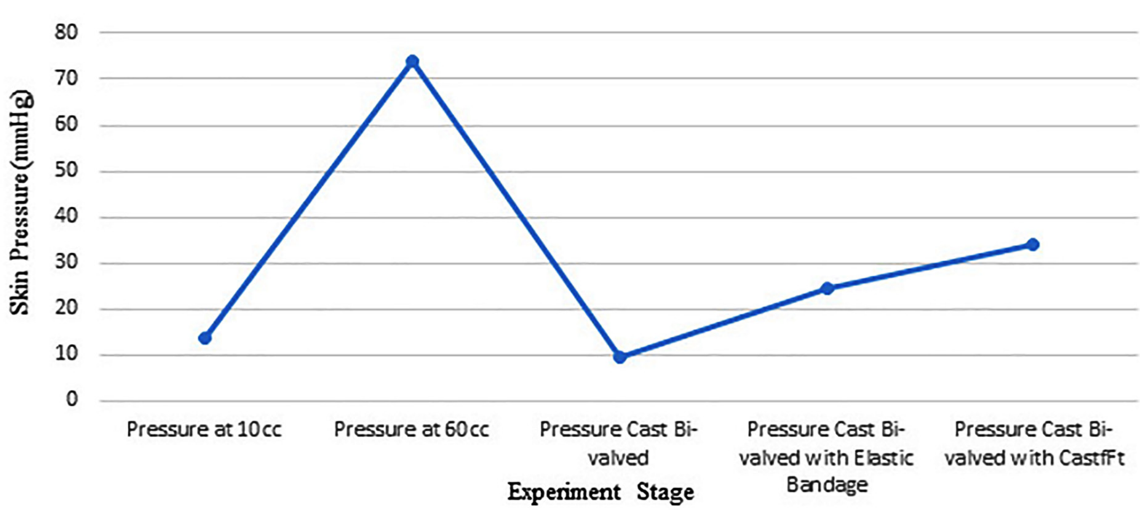

Figure 3. Line graph showing average skin pressure changes under the cast during various stages of the experiment.

The increase in pressure in the 2 interventions was significantly higher than the baseline, (Elastic Bandage, p<0.0001; CastFit™, p<0.0001). Levene's test of elastic bandage versus CastFit™ demonstrated equal variability in both interventions (p=0.222).

Results from this cadaver model study were then compared to the human study by Zaino et al. as a measure of validity (Table 1). Baseline and maximum simulated edema pressures were significantly lower than human trials (p=0.033 and p=0.046, respectively). No significant difference was found when comparing pressure under bivalved casts wrapped in elastic bandage (p=0.134).

Table 1. Pressure Data Obtained from Cadaver Specimens versus Human Subjects.

	Baseline Pressure		Max Simulated Edema		Pressure Elastic Bandage	
	Cadaver	Human	Cadaver	Human	Cadaver	Human
Mean	13.7	18.2	73.9	92.5	24.4	21.1
STD	3.5	6.6	16.6	28.5	6.6	5.17
P-value	0.033*		0.046*		0.134	

All pressure values in mmHg; * denotes statistical significance

DISCUSSION

Applying plaster or fiberglass casts to fractured extremities comes with risks, those of greatest concerns being increased pressures that may cause skin necrosis [3,4,6] and the potential for compartment syndrome [3-6]. Capillary occlusion occurs at a critical closing pressure of 32 mmHg of external pressure, and skin necrosis occurs at 60-75 mmHg [8]. To avoid compartment syndrome in acute fractures where significant soft-tissue edema is expected, bivalving a cast, cutting the underlying cast padding, spreading open the cast, and overwrapping the cast with an elastic bandage comprise common practice. This study aimed (1) to examine CastFit™ as a novel alternative for stabilizing the cast after it has been bivalved, and (2) to evaluate a cadaver model for the assessment of skin pressure changes under a cast.

This study has limitations. As a cadaveric study, its results may not be generalized to all clinical encounters. However, as we demonstrated in our results, the cadaveric model is an acceptable re-creation of the human model described by Zaino et al. without significant variability [7]. Similar to the Zaino et al. study, the use of intravenous fluid bags may not be an accurate method for simulating edema under a cast. However, we used certain pressure measurements that have been previously reported to distinguish pressure changes necessary for both skin necrosis and compartment syndrome [2,8-10]. Though we used only 10 cadavers for this study, each 1 served as an internal control, and our study was powered sufficiently to detect significant results. Lastly, CastFit™ can be manipulated by a patient just as an elastic bandage can; unfortunately, in a cadaveric model, real-time patient compliance cannot be tested.

In regards to whether skin pressure is better reduced after stabilization with CastFit™ or an elastic bandage following bivalving of a cast, we found no statistically significant difference in the variability between the 2 methods. Our results demonstrate that following cast bivalving, elastic bandage application caused the pressure to increase to an average of 24.4±6.6 mmHg, and CastFit™ at its maximum tension caused an average pressure increase to 33.9±9.44 mmHg, a finding that resulted in no difference in variability ($p=0.222$). CastFit™ can be easily adjusted by the patient to his or her comfort by simply turning a knob, whereas adjusting an elastic wrap is more involved and usually requires assistance. Although CastFit™ average maximum pressure of 33.9 mmHg resulted in pressure levels in the range of arteriolar capillaries occlusion (32-60 mmHg) [9], patients are not expected to maximally tighten the device. Furthermore, this pressure is safely below skin microcirculation occlusion (60-75 mmHg) [8].

Our results indicate that skin pressure assessment under a cast is reproducible in a cadaver model as it is with human subjects. Our cadaveric study produced statistically significant changes in pressure throughout the experimental phases, a result previously seen in human trials [7]. Also, when comparing this study's average elastic bandage pressure reading (24.4 mmHg) to the human subject study average by Zaino et al. at the same conditions (elastic bandage triple cut group 21.1 mmHg)[7], no statistically significant difference was found. Although the average baseline of 10 mL water-infused pressure of 13.7 mmHg was statistically lower than that by Zaino et al., it was within the range published by other studies [2,6,10]. The maximum simulated scenario of 60 ml water-infused pressure of 73.9 mmHg was also lower than clinical data by Zaino et al. (92.5 mmHg)[7] but still high enough to be in the range of the pressure needed to occlude skin microcirculation causing skin necrosis (60-75 mmHg)[8]. Therefore, this study presents an acceptable cadaver model for measuring skin pressures under a short arm cast.

CONCLUSIONS

CastFit™ is a convenient and safe alternative for stabilizing bivalved casts given its pressure profile similar to an elastic bandage. Moreover, our cadaver model is a valid alternative for studying skin pressures under short arm casts. This model has several advantages to using a human model, including reproducibility and decreased costs and the avoidance of physical trauma to patients (eg, skin breakdown from inadequate cast padding, lacerations from cast saws).

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