The Pressure Is on: Dorsal Versus Volar Univalves for Long-arm Casts

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Background: Fiberglass casts are routinely used to treat fractures of the upper extremity. When posttraumatic edema is anticipated, the cast is often valved to hopefully prevent potential complications, especially compartment syndrome. Due to volar forearm compartments being most involved with upper extremity compartment syndrome, volar skin surface pressures (SSP) are paramount. Despite past literature showing that a univalved cast will retain a 3-point mold better than a bivalved cast, there is a paucity of information analyzing the effects of univalving on the volar SSP. We hypothesized that a volar univalve technique would have a greater decrease in the volar skin surface pressures compared to a dorsal univalve in long-arm casts.

Methods: A 100-mL saline bag attached to an arterial line pressure transducer was placed between a long-arm cast and the skin along the volar forearm of a single adult volunteer. Fourteen casts were applied by a single certified orthopaedic technologist with 30 years of experience and assigned randomly to receive either a volar or dorsal univalve. We calculated the change in volar forearm SSP on each cast in 4 stages: isolated univalve, with a 3-mm cast spacer, with a 6-mm spacer, and with bivalve. Statistical analysis of the data was performed using a Mann-Whitney U test.

Results: When comparing volar versus dorsal univalve, volar SSP significantly dropped by a mean of 32.00 versus 20.43 mm Hg (P value = 0.001) in stage I, 45.14 versus 38.00 mm Hg in stage II (P value = 0.026), and 56.53 versus 49 mm Hg in stage III (P value = 0.001). There was no significant difference between the 2 groups after a bivalve was performed at stage IV (P value = 0.318).

Conclusion: Our findings support that a volar univalve with a 6-mm spacer will provide the greatest reduction of skin surface pressure while theoretically maintaining the cast's structural integrity and biomechanical properties when compared to a bivalved cast.

Level of Evidence: Level II, prospective comparative study.

Key Words: bivalve, univalve, volar, dorsal, compartment syndrome, cast spacers, long arm cast, skin surface pressure

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Every year, patients present to healthcare providers for upper extremity fractures, often requiring some form of immobilization during their treatment. Patients with injuries near or above the elbow are routinely placed into long-arm casts. Despite their near-ubiquitous use in fracture care, they are not without complications. Complications of casting can include skin infections, pressure sores, dermatitis, thermal injuries, and joint stiffness.[1,2] These complications then cause clinic and emergency room visits, occupying valuable medical resources and costing patients and their families.[3]

In settings where posttraumatic edema is anticipated, the cast is often opened or valved in hopes of preventing potential complications of an excessively tight cast with the most clinically significant being compartment syndrome. There are several studies in the literature focusing on different methods for valving casts[4–7], how they affect structural stability, and the utilization of cast spacers. However, there are no studies, to our knowledge, analyzing the difference of a volar and dorsal univalve on the cast and its effect on the volar skin surface pressures of the patient. These volar skin surface pressures are of utmost importance due to the volar forearm compartments being the most involved in forearm compartment syndrome.[8] We hypothesize that a volar univalve technique would have a greater decrease in the volar skin surface pressures compared to a dorsal univalve in a long-arm cast.

METHODS

This was an Institutional Review Board exempt prospective randomized comparative study. Our institutional review board categorized our study as "exempt" due to the minimal risk involved with applying and removing long-arm casts to a single adult volunteer. The volunteer did not receive any financial compensation for their participation. A certified orthopaedic technologist with over 30 years of clinical experience performed all cast applications, modifications, and cast removals throughout the experimental procedure.

Setup for Pressure Transducer System

A pressure transducer system was designed and created to measure the interval changes of volar skin surface pressures throughout our experiment. An empty 100-mL IV saline bag (VIAFLEX Container; Baxter Healthcare Corporation, Deerfield, IL) was modified using 2 female Luer lock connectors (Tyco Healthcare Group LP, Mansfield, MA), which were secured in place with super glue (Gorilla Super Glue Gel; The Gorilla Glue Company, Cincinnati, OH) and zip ties (HDX, Atlanta, GA). To protect the saline bag from damage by the cast saw, a protective strip (Saw Stop DE-FLEX; AquaCast, Newark, DE) was placed over the length of the bag. This saline bag was then connected to a pressure transducer (PXVMP160; Edwards Lifesciences Corporation, Irvine, CA) using extension tubing (B2033; ICU Medical Incorporated, San Clemente, CA). The transducer was then connected to a portable digital patient monitoring system (Philips IntelliVue X2; Philips Medical System, Andover, MA). The other access point to the IV bag was connected to a stopcock (BD Connecta REF 394910; Bector Dickinson, Franklin Lakes, NJ) using extension tubing (B2033; ICU Medical Incorporated, San Clemente, CA). The stopcock was then attached to 2 standard syringes with Luer lock tips that would be used to introduce saline into the saline bag to simulate increasing edema. The stopcock allowed for a closed system to be established after the saline was introduced into the saline bag, and the desired starting skin surface pressure was obtained. Setup before casting is reflected in Figure 1. We then primed the system to remove any air in the lines.

Cast Application

The long-arm cast was applied with the wrist in a neutral position and the elbow at 90 degrees of flexion with neutral forearm rotation. The materials used to construct the long-arm cast consisted of a 4-inch Tubular Cotton Stockinette (McKesson, Irving, Texas), 4-inch Webril Cotton Undercast Padding (Kendall brands; Covidien, Mansfield, Massachusetts), and 4-inch Scotchcast Plus Fiberglass Cast Tape rolls (3M, St. Paul, Minnesota). The empty 100-mL saline bag was then placed along the volar aspect of the forearm, directly over the bulk of the volar forearm muscle mass (Fig. 2A). This bag was held in place with the cotton stockinette. With the saline bag in place, we then applied the 4-inch Webril undercast padding in the standard fashion. Next, the 4-inch fiberglass casting material was applied in the standard fashion (Fig. 2B). Care was taken to leave the inlet/outlet lines for the saline bag accessible along the lateral aspect of the upper arm and unkinked to maintain their patency. Adequate time was allowed for complete drying and setting of the cast, as determined by the OTC with the approximate time being 3 to 5 minutes. The pressure in the system was subsequently tarred. To simulate increasing edema, a saline column was then added to the bag to create volar skin surface pressure of 85 to 90 mm Hg. Once this pressure was reached, the stopcock was adjusted to create a closed system. The pressure was then recorded as the initial pressure for our experiment.

FIGURE 1. The setup used for measuring pressure includes a Philips IntelliVue X2 patient monitor, an arterial line transducer setup connected to a 100-mL saline bag, protective strip on the saline bag, and 2 syringes filled with saline connected to the saline bag with a stopcock to allow for creating a closed system after the initial column of saline is added.

Cast Valving

Each cast that was applied was randomized to receive either a volar or dorsal univalve. Seven casts received an initial dorsal univalve, whereas the other 7 received an initial volar univalve (Fig. 2C) using a cast saw (940 Cast Cutter; Stryker, Kalamazoo, MI). Once the univalve was complete, the volar skin surface pressure was recorded. Next, 3 cast spacers were placed at the 3-mm setting. They were placed at the level of the wrist, just distal to the elbow flexion crease, and proximally on the upper arm (Fig. 2D). The volar skin surface pressure was then recorded. The 3 cast spacers were then changed from the 3-mm setting to the 6-mm setting (Fig. 2E). The volar skin surface pressure was then recorded. Finally, the cast spacers were removed and the cast was bivalved leaving the Webril and stockinette intact. The volar and dorsal valves were then spread to 1 cm using a standard 3-pronged cast spreader (Fig. 2F, G). The skin surface pressure was then recorded. At this time, the experimental procedure was deemed complete and the cast was removed and discarded. After each completed trial, we inspected the saline bag and lines for any damage sustained during the casting/valving process. There was no violation of or damage to the saline bag or lines throughout the duration of this study. This procedure was then repeated for 7 dorsal univalves and 7 volar univalves, resulting in a total of 14 long-arm casts in our study.

Statistical Analysis

Averages and standard deviations were calculated. Data was analyzed using a nonparametric Mann-Whitney U test conducted for each of the volar univalved casts in comparison with the dorsal univalved casts at each individual stage. Data were analyzed using SPSS v. 27 (IBM Corp. Released 2020. IBM SPSS Statistics for Windows, version 27.0.; IBM Corp, Armonk, NY). For this study, the level of significance was $P<0.05$.

RESULTS

Before valving, the mean SPP was 87.7 mm Hg (range, 85 to 90 mm Hg) among all casts. The mean

FIGURE 2. Our experimental setup of right long-arm cast including (A) the position of the 100-mL saline bag on the volar forearm, (B) the arm with the long-arm cast applied over the saline bag, (C) the volar univalve present without any cast spacers, (D) the cast spacers applied at the number 1 position providing a 3-mm gap, (E) the cast spacers applied at the number 2 position provider a 6-mm gap, (F) the volar aspect after a bivalve was performed, and (G) the dorsal aspect after a bivalve was performed.

pressure before valving was 87 mm Hg for the volar univalve group, and 88.4 mm Hg for those included in the dorsal univalve group. In the volar univalve group, the pressure dropped by a mean of 32.00 mm Hg (36.78%) after the univalve, 45.14 mm Hg (51.91%) after 3 mm cast spacer application, 56.43 mm Hg (64.87%) after 6 mm cast spacer application, and 65.71 mm Hg (75.50%) after a bivalve. In the dorsal univalve group, the pressure dropped by a mean of 20.43 mm Hg (23.12%) after the univalve, 38.00 mm Hg (42.98%) after 3 mm cast spacer application, 49.00 mm Hg (55.43%) after 6 mm cast spacer application, and 63.29 mm Hg (71.56%) after a bivalve.

Analysis showed that between the 2 groups, a significant reduction occurred in volar forearm skin surface pressures at stages I, II, and III (P value = 0.001, P value = 0.026, P value = 0.001, respectively). At stage IV, no statistical difference was noted (P value = 0.318). These pressure differences and the corresponding significance are displayed graphically in Figure 3.

DISCUSSION

Fiberglass casts are routinely used to treat fractures of the upper extremity, often selected over plaster cast material due to its adequate combination of setting time, structural integrity, ease of application, robust weight:strength ratio, less intensive exothermic reaction, and near-ubiquitous presence among emergency room and orthopaedic providers.[9,10] Edema is often expected and may be profound after traumatic injuries due to the resulting soft tissue and bone damage. While proper reduction and cast application is essential, these casts are often valved in hopes of preventing potential complications of an excessively tight cast with the most clinically significant being compartment syndrome. This is especially important as Garfin et al demonstrated via an animal model that even after cast removal, intracompartmental pressures can still be artificially elevated.[11]

Despite the simplicity and importance of valving in the setting of acute trauma and edema, there continues to be a paucity of literature regarding pressure recordings after casting and valving. Recent literature[4,6] has examined the effect of casting and valving on skin surface pressures. However, there is minimal literature on this topic, specifically to the difference, if any, between volar and dorsal univalve techniques. This is especially important due to the volar forearm compartment's propensity to develop compartment syndrome.

From our data collected, we found that a volar univalve causes a statistically significant greater decrease in

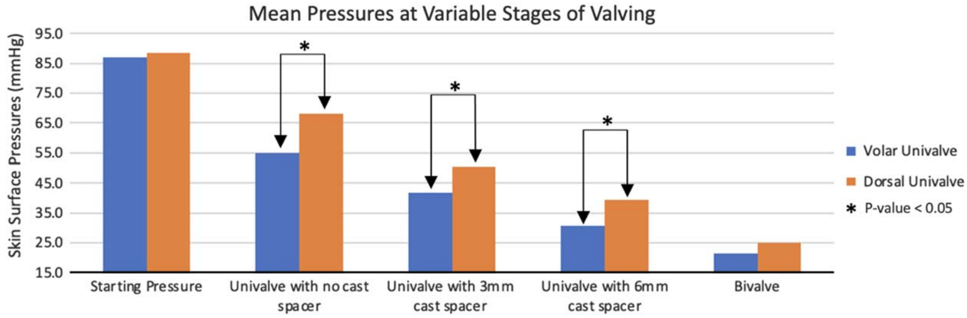

FIGURE 3. The mean pressures of each group at each stage of the experiment.

volar skin surface pressures, as compared to a dorsal univalve in long-arm casts. This relationship held at the initial univalve (P value = 0.001), after the 3-mm cast spacer (P value = 0.026), and after the 6-mm cast spacer (P value = 0.001). Spacers are a frequent addition to a univalved cast. Kleis and colleagues showed that the 6- and 9-mm cast spacers are reasonable options to reduce pressures within a cast in their experimental model.[6] In this study, we used a commercially available spacer that features both 3 and 6 mm settings. As expected, the 6-mm spacer provided greater pressure reduction as compared to its 3 mm counterpart. While at our institution a 6-mm position is routinely chosen, we feel that decision is best left up to the provider based on their concern for increased swelling, mechanism of injury, and possible soft tissue and vascular injury.

This experimental design is similar to that of Zaino et al[4] who used a similar pressure transducer system as well as human volunteers. However, they modeled tissue edema by infusing air into the saline bag as opposed to our utilization of saline. We used saline due its incompressible nature and closer characteristics to that of tissue edema. While similar results were obtained, this incorporation of a noncompressible substance such as saline in combination with a human subject corroborates Zaino and colleagues and other previous literature supporting the utility of a volar univalve. In addition, Zaino et al[4] suggested performing a bivalve technique, which included cutting the underlying Webril on both sides where severe swelling or concern arises. Our data did support that a bivalve demonstrated the greatest pressure reduction. As expected, no significance difference existed between groups (P value = 0.318) after bivalve, supporting that an initial volar or dorsal univalve is equivocal if a bivalve is desired.

With valving, there is a theoretical risk of reduced integrity and possible reduction loss; however, this was not specifically investigated during this study. Crickard et al[12] found that bivalved casts had the lowest bending stiffness and lowest failure threshold when compared to univalved and nonvalved casts. Despite this, Bae et al[13] reported that there were no differences between bivalved casts and nonvalved casts in terms of loss of reduction. Recently, Montgomery et al[5] showed that a short-arm cast with 3-point mold after either a volar or dorsal univalve retained its structural integrity.

In the setting of a clinically stable patient without significant concern for acute compartment syndrome at the time of intervention, we feel that a single volar univalve with a cast spacer set at 6 mm will provide the greatest reduction of skin surface pressure while better maintaining the cast's integrity and biomechanical properties when compared to a bivalved cast.

This study had several limitations. As only fiberglass long-arm casts were applied, the generalizability to short-arm casts and/or other casting material is unknown. However, Roberts et al[14] have shown the effectiveness of valving in multiple types of casting material. In addition, the additional use of a cast saw may cause a small but potentially significant chance of thermal burns. Finally, while this study supports univalving, the optimal time of the univalve was not assessed. Further investigations will need to be conducted to assess these limitations. In addition, this study only focuses on a neutral forearm position and does not account for alternative positions of the forearm in LAC that maybe necessary to treat unique fracture patterns.

In conclusion, long-arm casting is a simple yet effective way to protect a healing limb. However, it is not entirely without risk. Valving is an easy and potentially effective means to lessen the risk of severe complications such as compartment syndrome, with infrequent adverse outcomes. This study offers support for volar univalving due to its combination of pressure reduction with known better maintenance of the cast's structural integrity.

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