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Biomechanical analysis of ridged dorsal wrist backslabs

Aiden Jabur [a,b,*], John Maunder [a,b], Alexander Mitrichev [a,c], Scott Sommerville [a]

[a] Princess Alexandra Hospital Orthopaedic Department, Brisbane, Australia
[b] Griffith University School of Medicine, Gold Coast, Australia
[c] James Cook University School of Medicine, Townsville, Australia

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ABSTRACT

Background: Loss of plaster integrity is linked to failure to maintain fracture reduction and pain. Adding plaster layers makes the construct more cumbersome. This biomechanical study applied the engineering principle of the reinforcement strut to pragmatically designed dorsal wrist backslabs to investigate the effect on flexural strength.
Methods: Ridged and non-ridged 8-layered casts were created using an investigator's wrist ($n = 24$). Failure load was recorded in simulated wrist flexion and extension. Failure of the cast was defined by the point of plastic deformation. Force was compared using student's t-test and effect size.
Results: There was no significant difference in backslab dimensions. Ridged casts had a 1.6 times greater failure load in extension compared to non-ridged casts ($p < 0.001$; Cohen $d = 3.42$). In flexion, ridged cast failure load was not significantly stronger than in non-ridged (1.15 times, $p = 0.16$). Variance in failure load was greater in ridged casts ($p = 0.003$).
Conclusions: Adding a longitudinal ridge to dorsal wrist backslabs increases its strength in wrist extension but not in flexion. The benefit conferred by the ridge likely varied due to minor random differences in ridge height. The present technique may be a simple, lightweight and cost effective method of increasing the strength of wrist backslabs without needing to layer additional reinforcement plaster.

1. Introduction

An orthopaedic cast functions as a structure that immobilises and maintains reduction of a fracture.[1] The two most commonly used materials for orthopaedic casts are plaster and fibreglass. Plaster casts are comprised of muslin coated in calcium sulphate hemihydrate, also termed plaster of Paris (PoP) or gypsum, which hardens when hydrated with water and allowed to dry.[2]

In the forearm and wrist, casts are used to temporise acute injury, treat various chronic conditions and promote postoperative comfort and healing. The backslab is a non-circumferential cast, one application being the dorsum of the wrist and forearm - commonly used in Colles fractures and scaphoid fractures.[1] Compared to a circumferential cast, the backslab cast offers a lower risk of ischaemia over the injured area and compartment syndrome.[1]

While variations in casting technique exist, forearm casts are typically constructed from 8 or 10 layers of plaster material. Several studies have investigated the elastic modulus of hardened plaster cast. Schenk et al.[2] determined this to be 6895 MPa, Schmidt et al.[3] found it to be slightly higher at 7584 MPa, and Mihalko et al.[4] found it to be 2579 MPa. Moulding reinforcement ridges in the longitudinal axis of the cast increases its yield strength and stiffness. The textbook description of volar hand slab construction recommends adding a ridge by pinching the wet plaster slab before applying it to the patient to increase the strength of the slab enormously.[5] Theopold and colleagues determined that the breaking point of a ridged backslab was 8.62 Nm compared to 3.66 Nm for the non-ridged backslab, representing a 2.4-fold improvement in strength with the ridge.[6] Counter-intuitively, the addition of a second ridge merely yielded a 2.1-fold strength increase compared to a non-ridged backslab.[6] Furthermore, Stewart et al. found that casts reinforced with a ridge exhibited a maximum load at failure of 126 N, compared to unreinforced casts at 66 N, representing a significant 1.9-fold strength improvement.[7] 8-ply volar casts of plaster bandage and a ridge are reported to perform similarly to 12-ply non-ridged plaster and fibreglass casts.[8] It remains to be seen whether or not a ridge incorporated on a dorsal wrist backslab provides a similar strength benefit.

This biomechanical study quantifying the effect on the yield strength of a reinforcement ridge constructed on a pragmatically designed dorsal wrist backslab will add to the growing evidence around this practice.

* Corresponding author. Princess Alexandra Hospital Orthopaedic Department, Brisbane, Australia.
E-mail address: aiden.jabur@health.qld.gov.au (A. Jabur).

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Ridge reinforcement may allow for less overall material use in each cast without compromising its ability to immobilise the forearm and wrist. Hence, a lighter-weight cast is achieved.

2. Materials and methods

A standardised custom-made mould of an investigator's forearm, wrist and hand was created using plaster of Paris. This served as the model on which all backslabs would be made. 12 plaster casts were made with a longitudinal ridge and another 12 without; half of each group was tested in wrist flexion and the remainder in wrist extension. A power analysis was performed using mean and standard deviation from existing literature.[9] Each cast consisted of a wrapped layer of Velband padding bandage (BSN Medical, Hull, UK) with 50 % overlap followed by the 8-layered 15 cm Gypsona PoP (BSN Medical, Hull, UK) backslab which was shaped to the mould (Fig. 1). Elastolite bandage (BSN Medical, Hull, UK) was then wrapped around the construct with 50 % overlap. One senior investigator created all of the casts to minimise inter-operator variability. Backslabs were dried for 48 h before testing to ensure complete curing. A template was used prior to water addition, to ensure uniform width, length, and ridge height. In addition to this, cast width, ridge thickness, and plaster thickness were each measured at three standardised points, then averaged, to determine any final variation in cast geometry after application. Casts were labelled 1–24.

The backslab was then fixated to a standardised forearm mould which allowed wrist articulation. A force was then applied that was distributed over a 5 cm^2 plate, 5 cm from the wrist articulation, creating a standardised moment arm. A random number generator was utilised to perform stratified randomisation, with 12 casts tested in flexion, and 12 tested in extension. Within each group, half were ridged. Force was applied, and measured with a digital force gauge (YaSao, Tokyo Japan) with an accuracy of ± 1 %. The maximum measured on the force gauge was considered the yield strength of the cast.

Statistical analysis of results was performed using R. Independent two-sample t-tests were used to analyse the statistical significance of variation in the means of maximum force that the two types of casts (ridged and non-ridged) can withstand in two different directions (flexion and extension). Effect size was calculated using Cohen's d. ANOVA was used in cases of more than 2 groups. Levene's test was used to compare variance in strength between cast designs.

Ethics approval was not required for this study.

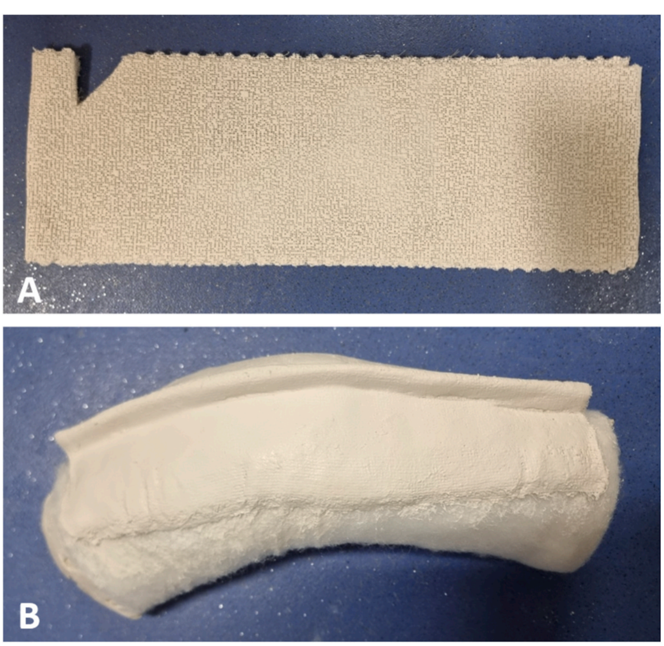

Fig. 1. A) 8-layer plaster with thumb notch prior to wetting with cold water. B) Moulded plaster with ridge prior to wrapping with crepe bandage.

3. Results

The study included 24 total plaster casts – 12 created with a longitudinal ridge and 12 without. Six from each group were tested in simulated wrist extension and the other six tested in flexion. The mean (± standard deviation) width of the ridged backslabs was 90.1 ± 3.4 mm and 92.0 ± 6.8 mm among the non-ridged backslabs, likely in part due to the formation of the ridge using a pinching technique (Table 1). This represented a non-significant difference. Furthermore, mean thickness of the ridged and non-ridged backslabs was not significantly different - 6.5 mm and 6.3 mm respectively. Ridge height among the casts tested in flexion was 7.2 mm and 9.5 mm among those tested in extension, representing a non-significant difference ($p = 0.056$).

The force required to deform the plaster in simulated wrist extension was significantly greater in the ridged backslabs compared to the non-ridged backslabs (91.14 ± 13.50 N vs 56.98 ± 4.11 N, $p < 0.001$, Cohen's d = 3.42) with very large effect (Fig. 2). However, during simulated wrist flexion, ridged casts did not outperform non-ridged casts (51.66 ± 8.77 N vs 45.02 ± 3.85 N, $p = 0.16$, Cohen's d = 0.98). The yield strength of the ridged casts exhibited greater variance than the non-ridged casts, suggesting a level of heterogeneity in the construct at the point at which bending occurred ($p = 0.0025$).

4. Discussion

Dorsal wrist backslabs are frequently applied in trauma settings within orthopaedics. Despite this, to our knowledge, our study is the first to investigate the effectiveness of a pragmatically applied dorsal backslab with a ridge. We investigated the yield strength of ridged and non-ridged dorsal wrist backslabs and found that the ridged casts withstood 1.60 times more force in wrist extension but were not significantly stronger in wrist flexion. Yet, there was a large effect size (Cohen's d = 0.98) when investigating flexion, which may represent an underpowered sample size for the test. The increased strength in extension with the ridge demonstrates that its benefit comes from its ability to withstand greater compressive stress rather than failure force. Pre-test theoretical moment of inertia calculations used parallel axis theorem, which is a theorem stating that the moment of inertia about a parallel axis is the centre of mass moment plus the moment of inertia of the entire object imagined as a point mass at the centre of mass.[10] Using the mass moment of inertia of a beam ($I = \frac{bh^3}{12}$) and this theorem, we estimated that the ridge improves bending strength by 1.91 times. Plaster itself is also reported to be stronger in compression than tension, further explaining the significant difference in extension rather than flexion.[11]

The increased yield strength in wrist extension offered by the ridged backslab is particularly useful in settings where preventing dorsal displacement of a fracture – for instance Colles' fractures, which are

Table 1
Average dimensions of dorsal backslabs and their maximal load during testing.

	Non-ridged		Ridged		
	Flexion	Extension	Flexion	Extension	p value
Plaster width, SD (mm)	92.0, 6.8		90.1, 3.4		–
Plaster thickness, SD (mm)	6.12, 0.32	6.57, 0.19	6.47, 0.40	6.43, 0.62	0.600
Ridge height, SD (mm)	–		7.2, 1.3	9.5, 1.4	0.056
Maximal load, SD (N)	45.02, 3.85	56.98, 4.11	51.66, 8.77	91.14, 13.50	Flexion: 0.16 Extension: <0.01

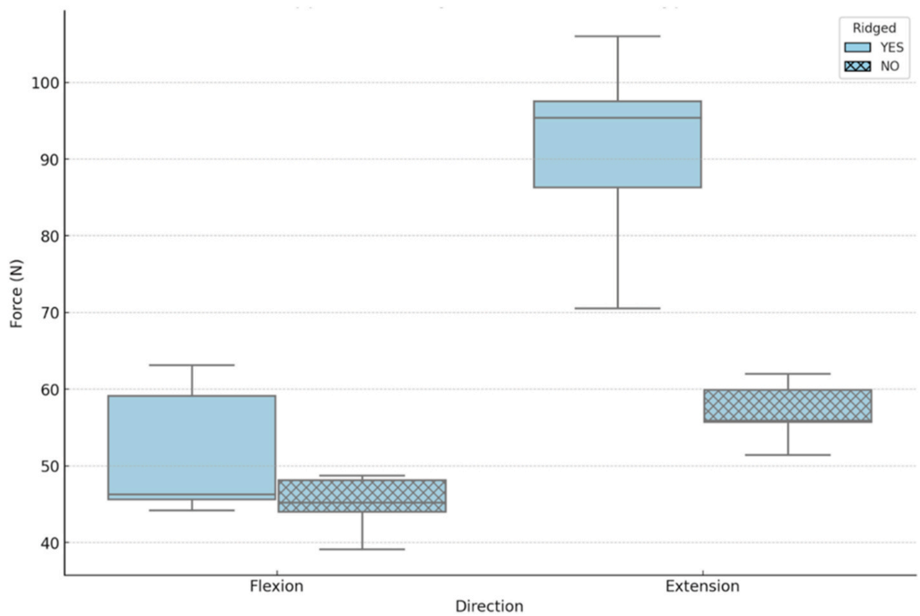

Fig. 2. Average maximal load before plastic deformation in simulated wrist flexion and extension of dorsal backslabs.

ubiquitous – is desirable. Additional benefit from preventing wrist extension can be seen in the setting of tendon repair in the flexor compartment. This may potentially confer reduced fracture displacement and tendon rupture rates in the clinical setting, yet this remains to be explored and may be a worthwhile investigation in future studies.

Similar studies investigate volar slabs and use flat casts,[6,8,9] rather than the one-third to one-half tubular structure that backslabs assume after moulding to the forearm and wrist. This distinction is important, since a curved structure has greater strength in bending compared to a flat structure, impacting the benefit in strength that the ridge offers. While flat casts are simpler to mount onto testing apparatus compared to the more complex curved cast, using flat casts and absence of wool and crepe sacrifices the external validity of prior study results. The casts created in this study featured a thumb notch and were moulded to the model forearm and wrist by hand, just as would be done clinically.

Wrapping the ridged casts with crepe bandage affected the ridge height since this was done prior to cast setting. This contributed to the variance in ridge height seen on the box plot, however the difference in ridge height between those tested in flexion and those tested in extension was not significant. It may also explain the significant difference ($p = 0.0025$) in variance of yield strength between the ridged and non-ridged casts. We hypothesise that small variations in ridge height along the cast subsequently induce failure in the same region upon application of bending force. The impact of ridge height suggests that technician experience will alter the benefit conferred by the ridge.

Several limitations exist in our study. This study was not a clinical study involving participants. There was a moderate coefficient of variance of 19.6 % in the ridge height between casts, contributing to the large standard deviation in the yield strength of the ridged casts in flexion and extension. We believe this is an accurate reflection of the variable performance of the ridge in the clinical context and would be more exaggerated still when considering different operators moulding the same cast, however this introduces a potential limitation in the practical application of our results. In an effort to standardise ridge height in future studies, a mould or guide may be used to produce casts for testing. In the clinical context, the length from the fingertip to the base of the operator's fingernail or similar alternative may be a convenient measure to ensure ridge height consistency. The power calculation was predicated on a larger difference in failure force between the cast designs, however our results revealed a smaller difference than anticipated, particularly for wrist flexion. Despite the large effect size in wrist flexion (Cohen's $d = 0.98$), there was no statistically significant difference due to the small sample size. Hence, biomechanical studies in the future require a larger sample size to validate our findings.

Future work could involve fatigue testing – repeated loading of a constant force. This form of testing more closely mimics forces exerted on the cast as a patient goes about their daily activities[2] and would therefore yield more clinically relevant results. Additionally, while wrist extension is the primary movement limited by the dorsal backslab, rotation and bending in the coronal plane are also pragmatic movements to test with the ridged cast. As mentioned earlier, use of a mould or guide to more readily standardise cast ridge height is of critical benefit for future investigations, as well as patient cohort involvement to investigate if the improved biomechanics introduced by the ridge confers a clinical benefit in reduced fracture displacement rates. Varying the number of layers in the cast is a future avenue for pragmatically-designed cast biomechanics research with the aim of identifying the lowest number of plaster layers in a ridged cast that would provide a satisfactory immobilising function. Ideally, a light-weight, cost-effective design is achieved. In summary, future efforts may build on this present study and existing literature through a number of means: standardising ridged/non-ridged cast production with a mould; exploring the minimum required number of ridged cast layers required for acceptable yield strength; incorporating rotational failure force and fatigue testing; and application to a patient cohort to examine clinical benefit, for instance in fracture displacement or tendon rupture rates.

5. Conclusions

In summary, the addition of a dorsal longitudinal ridge to a dorsal wrist backslab is a rapid method of increasing the yield strength of the cast without adding cumbersome mass to the construct. However, the strength increase conferred by the ridge is varied due to difficulty in maintaining a consistent ridge height when wrapping crepe bandage after plaster moulding. The dimensions of the backslab are not affected to a great degree by the formation of the ridge. Incorporating a ridge into dorsal wrist backslabs may be a simple way to improve the integrity of the device in a variety of clinical settings.

CRediT authorship contribution statement

Aiden Jabur: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. **John Maunder:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing – review & editing, Supervision, Project administration. **Alexander Mitrichev:** Conceptualization, Methodology, Validation, Investigation, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Scott Sommerville:** Writing – review & editing, Supervision.

Guardian/patient's consent

The study did not involve the use of animal or human subjects.

Ethical statement

This work did not involve the use of human or animal subjects. The study was conducted in accordance with the Declaration of Helsinki and ICJME Uniform Requirements for manuscripts submitted to Biomedical journals.

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Declaration of competing interest

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