3D-Printed One-Third Tubular Plates in an Ankle Fracture Model: A Biomechanical Study

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INTRODUCTION:

In scenarios with disrupted or absent supply chains of orthopaedic equipment (i.e., developing countries, forward operating units, and long-term space flight), it is imperative to develop methods to deliver quality care despite lack of access. 3D printing offers a potential solution, but its use has not been fully explored. In this study, we examined the biomechanical properties of 3D printed one-third tubular plates made from carbon fiber-reinforced polylactic acid (CFR-PLA) and polycarbonate (PC) in a fibula fracture model and compared the results to those of standard stainless steel one-third tubular plates. Fracture fixation constructs underwent lateral bending and torque testing similar to the biomechanical profile of the distal fibula cited in previous literature.

METHODS:

Fibula fracture models were created by cutting composite Sawbones samples with a custom jig to simulate a Danis-Weber Type B fracture pattern (Figure 1a). Specimens were fixed with lag screws (by technique) and 8-hole one-third tubular plates laterally. Stainless steel plates (Synthes, Paoli, PA) were used as the controls. Experimental plates were 3D-printed in CRF-PLA and in PC (Figure 1c). The plates were secured with three bicortical 3.5mm stainless steel screws proximally and with three unicortical 3.5mm stainless steel screws distally (Figure 1b). The control and experimental specimens as well as two intact composite Sawbones were mechanically tested for valgus bending strength (Figure 2a), torsional strength, and torsional failure strength (Figure 2b & 2c). Means and standard deviations from these tests were calculated for each fixation construct. IBM SPSS statistics software (Version 24.0; IBM Corporation, Armonk, NY) was used to run a one-way analysis of variance (ANOVA) with a least significant difference (LSD) multiple comparisons post hoc analysis to determine observable differences between groups. The level of significance was set a $p < 0.05$.

RESULTS:

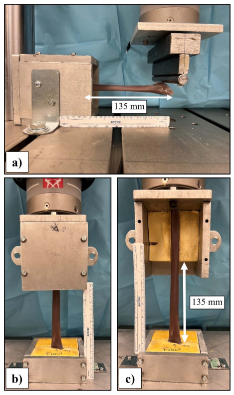
The bending test demonstrated that under increased compressive forces, there were no significant differences in flexural rigidity between any of the samples and that the stainless steel controls had significantly greater stiffness than the PC constructs but not the CFR-PLA constructs. When compressive loads were released, stainless steel controls demonstrated significantly greater stiffness and rigidity compared to both CFR-PLA and PC constructs. Mean peak load measured at 3mm of vertical displacement was significantly greater for stainless steel constructs than all other samples (Figure 3).

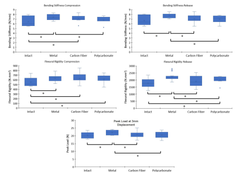
Torsion testing displayed superior stiffness and rigidity in CFR-PLA plate constructs, followed by the stainless steel controls, and then by the PC plate constructs. Mean peak torque at 10 degrees of external rotation among the fixation constructs was highest for the carbon fiber group (Figure 4). Torsional failure testing, however, demonstrated superiority of the stainless steel controls, with a mean failure torque load of 7.9 ± 1.0 Nm (7.0 – 9.0 Nm) at 43.4 ± 6.6 deg (range: 35.8 – 51.4 deg) compared to 6.3 ± 1.1 Nm (range: 5.1 – 8.4 Nm) at 25.4 ± 4.9 deg (range: 21.1 – 32.2 deg) for CFR-PLA constructs and 5.9 ± 1.4 Nm (range: 4.5 – 7.9 Nm) at 35.9 ± 10.3 deg (range: 26.7 – 51.8 deg) for PC constructs (Figure 5).

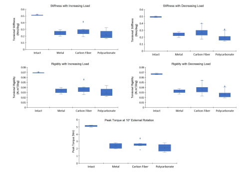
DISCUSSION AND CONCLUSION:

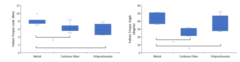
Fracture fixation with the stainless steel plate control outperformed fracture fixation with desktop 3D printed plates in this mechanical study. This study demonstrates that desktop 3D printers are capable of successfully creating trauma implant designs with near mechanical function, at a decreased cost, compared to a current clinical device. The mechanical ranges for several testing values overlapped with the control, indicating that 3D printed plates may be a viable option for fracture care and achieve the mechanical stability needed for fracture healing. Further studies would be needed to test the clinical applicability of this production process and mechanical findings to facilitate biologic bone healing. The cost of material for each of these printed plates was less than $1 (USA) and, if a plate was printed individually, it required approximately 20 minutes to complete. This study supports findings that 3D printing technology could improve access to orthopaedic care and influence supply chain processes for medical facilities functioning in situations of medical supply scarcity such as remote operating environments.


a)
3.5 mm screws,
18 mm length
3.5 mm screws,
12 mm length
3.5 mm lag screw,
22 mm / 24 mm length
35 mm
b)
Intact
Stainless Steel
CFR-PLA
PC
c)


135 mm
a)
b)
135 mm
c)


Bending Stiffness Compression
Bending Stiffness (N/mm)
Bending Stiffness Release
Flexural Rigidity Compression
Flexural Rigidity Release
Peak Load at 3mm
Displacement
Peak Load (N)
Intact
Metal
Carbon Fiber
Polycarbonate


Stiffness with Increasing Load
Stiffness with Decreasing Load
Torsional Stiffness
(Nm/deg)
Rigidity with Increasing Load
Rigidity with Decreasing Load
Torsional Rigidity
Peak Torque at 10° External Rotation
Intact
Metal
Carbon Fiber
Polycarbonate


Failure Torque Load (Nm)
Failure Torque Angle
(degree)
Metal
Carbone Fiber
Polycarbonate