

# Polymethylmethacrylate (PMMA) Augmentation Increases the Strength of Midfoot Beam Constructs for Treatment of Charcot Neuroarthropathy: A Biomechanical Study

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**INTRODUCTION:** Charcot Neuroarthropathy (CN) is a neurotraumatic foot disorder commonly seen in patients with advanced peripheral neuropathy often from long standing diabetes mellitus. In Charcot neuroarthropathy, the bones and joints of the affected area (most commonly the feet and ankles) undergo progressive degeneration and deformity due to repeated trauma and microfractures. Early diagnosis and management are crucial to prevent the progression of Charcot neuroarthropathy. Treatment may involve immobilizing the affected joint with casts or braces to allow healing, reducing pressure on the foot, and managing any underlying conditions contributing to nerve damage. In severe cases such as midfoot collapse, surgical intervention might be necessary to correct deformities and restore functionality. Surgical intervention often utilizes beaming of the metatarsals columns to mend fractures and dislocations in multiple joints. However, even with surgical treatment, only 50% of patient achieve clinical union<sup>1</sup>. Therefore, the CN bone presents an opportunity for surgeons to improve surgical fixation and increase the strengths of their constructs. Polymethylmethacrylate (PMMA) hardware augmentation is well-described orthopedic technique to improve fixation in patients with weak, osteoporotic bone that does not ordinarily permit good bony ingrowth<sup>2</sup>. The objective of the study was to test the biomechanical strength of PMMA augmentation of CN midfoot beam. We hypothesized that bone cement would significantly increase the stability and load to failure of the fusion construct compared to midfoot beams alone.

**METHODS:** Institutional review board approval was not required for this study. Six matched pairs (n=12) of female mid-tibia to toe tip cadaveric specimens from donors 70 years or older were procured from an institute-approved tissue bank and stored at -30°C. The age and gender requested was to simulate the osteopenia seen in CN. To emulate the midfoot collapse and fragmented osteopenic bone, a novel rocker-bottom foot model was developed. The proximal tibia and fibula were removed; all skin, subcutaneous fat, and extensor tendons were sharply resected. The plantar fascia and joint capsules were left intact allowing force transmission across the midfoot during subsequent crush protocols. 12 drill holes were placed in each specimen, including three evenly spaced holes in the medial-lateral plane at the distal talar neck, navicular, proximal and distal medial cuneiform, and proximal first metatarsal. A hydraulic press and a customized jig were used to selectively depress the midfoot arch by crushing the medial column bones while keeping capsular structures intact, and the post-crush result was confirmed by radiography.

After the CN model was created, matched pairs were divided into 2 fusion groups: (1) Midfoot beam fusion, and (2) Midfoot beam fusion augmented with PMMA. The PMMA cohort utilized a column channel with the cement introduced along the trajectory of the beam through a cannula. For biomechanical testing, the hindfoot was fixed with wood screws and embedded in a cuboid 3D-printed pot using a two-part epoxy resin. The foot orientation and position were standardized for the embedding process for each specimen with the navicular joint to metatarsal heads exposed. Once potted, the cuboid pot was fastened to the platform of the testing system with the foot inverted (plantar foot facing toward the actuator) to simulate the ground reaction force on the metatarsal heads during the toe-off phase of the gait cycle, Figure 1. A 25 N compressive preload was applied to the metatarsal heads, followed by 1800 cycles of compressive cyclic loading between 100N and 400N at 0.5 Hz. The compressive load returned to 25N once the cyclic loading was completed. It was followed by a load to failure at a rate of 1 mm/sec. The load and displacement data were continuously recorded at 128 Hz. Outcome measures were calculated using a customized script (Python 3.9): normalized displacement during cyclic, the ultimate load at failure, the displacement at the maximum force, stiffness, and the toughness.

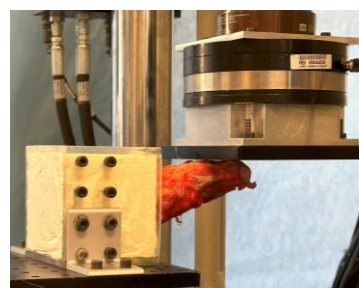
**RESULTS SECTION:** The beam with PMMA cohort exhibited lower cyclic displacement (indicative of greater stability) compared to the beam only cohort across all 1800 loading cycles,  $p < 0.05$ , Figure 2. The beam with PMMA group demonstrated significantly greater maximum force ( $p < 0.05$ ), stiffness ( $p < 0.01$ ), and toughness ( $p < 0.05$ ) in comparison to the beam only group, Figure 3. No significant differences were observed in maximum displacement between the two groups.

**DISCUSSION:** PMMA augmentation adds an effective modification to the current surgical intervention that improves the strength and stability of the Charcot Neuroarthropathy foot.

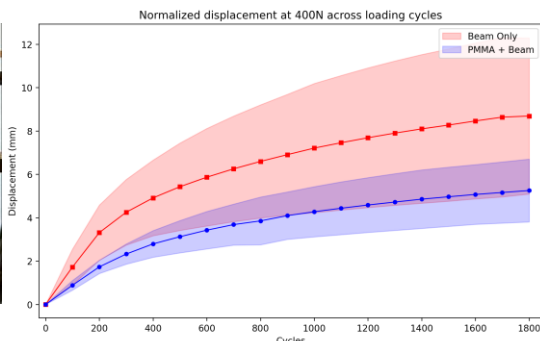
**SIGNIFICANCE/CLINICAL RELEVANCE:** CN can severely impact a person's ability to walk, perform daily activities, and maintain their overall quality of life. Enhancing surgical interventions could result in significant improvements in mobility, and overall well-being for CN patients.

**REFERENCES:** [1] Eschler et al., *J Diabetes Res*, 2015, 246792. [2] Zhu et al., *Theranostics*, 2020, 10(14): 6544–6560.

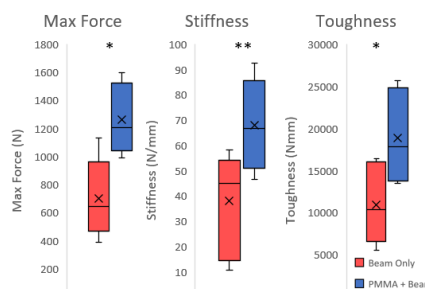
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**Figure 1.** Experiment set up. Compressive load was applied on the plantar aspect of the metatarsals to simulate the toe off phase of the gait cycle.



**Figure 2.** Mean displacement in response to a 400 N load as a function of the number of cycles. The midfoot beam alone displayed greater translation at every 100-cycle interval tested compared to the beam with PMMA,  $p < 0.05$



**Figure 3.** The beam with PMMA cohort shows significant greater max force ( $p < 0.05$ ), stiffness ( $p < 0.01$ ), and toughness ( $p < 0.05$ ) compared to beam only cohort.