Transactions on Additive Manufacturing Meets Medicine
Trans. AMMM, Vol 1, No 1, 2019, Article ID S03P01



# Modeling of a functional brace using the finite element method

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*Abstract: Ilizarov systems are required to treat critical bone defects. However, they are not customized to the patient presenting significant risk of infection and inducing pain and discomfort. This paper presents a novel customizable functional brace overcoming the main limitations of the Ilizarov system. This brace is being designed, together with clinicians, to be produced using additive manufacturing (AM). This paper presents preliminary design concepts assessed using Finite Element Analysis (FEA), considering different impact loading conditions and different materials.*

## I. Introduction

Bone defects associated with non-unions and large bone loss often resulted in extended healing periods, higher complication rates and long term morbidity. Moreover, the inoculation of microbial pathogens at the time of initial trauma, during the initial fixation surgery or during the healing process may lead to a delay of fracture union, loosening of fixation and chronic osteomyelitis [1,2]. The treatment of these defects is complex and expensive, placing a burden on the health system. The cost resulting from the patient's inability to work and mental conditions because of the post-traumatic psychological distress are also significant.

As part of the EPSRC/GCRF project "Bone Bricks: Cost effective modular osseointegrated prosthetics for large bone loss surgical procedures", we are developing and implementing a novel cost-effective osseointegrated modular prosthetic solution to treat large bone loss injuries to enable limb salvage. Due to the large bone defects being considered (~20 cm), an external fixator is required. The Ilizarov system is the common solution but presents several disadvantages such as the risk of infection, the size and the weight of the device which causes discomfort and pain. This might happen due to the use of pins/wires and the manual lengthening process. Therefore, a novel functional brace is being developed as the external fixator to overcome these limitations. This paper presents the initial design concepts. Different materials are considered and preliminary numerical simulations used to assess the impact behavior.

## II. Design of a novel external fixator

The novel functional brace is being designed to solve the main limitations of the Ilizarov system. The brace is being designed to allow customization and to minimize weight and costs. A cellular and lightweight design is considered, and the brace will be produced using AM. The final brace design will consist of multiple materials presenting biocompatibility, appropriate moisture absorption, low friction, and good mechanical properties. To guarantee appropriate mechanical performance three different thermoplastic materials (Polylactic acid, PLA; Acrylonitrile butadiene styrene, ABS; and polyamide (nylon), PA), commonly used for AM applications, were considered and reported in this paper. The main material properties are presented in Table 1. The brace is being designed considering a reduced number of components such as wires and rods. It must provide protection, stability and also an easy access to the wound area for cleaning and treatment. The main geometric characteristics of the brace were based on anthropometric data obtained from a patient's leg by using a 3D laser scanning system (iSense, 3D systems, Inc, China). The brace thickness was considered to be 3 mm.

*Table 1: Material properties of PLA, ABS and PA [3].*

| Property | Material | | |
|---|---|---|---|
| | PLA | ABS | PA |
| Young's Modulus (GPa) | 2.35 | 1.62 | 0.58 |
| Poisson Ratio | 0.39 | 0.399 | 0.35 |
| Yield Strength (MPa) | 49.5 | 39 | 27.8 |
| Density (g/cm3) | 1.24 | 1.10 | 1.14 |

## III. Modeling and simulation

The brace was designed using the Autodesk Fusion 360 software. Two different geometries were considered: a solid brace (Figure 1a) and a brace with uniformly distributed holes (Figure 1b). The dimensions of the brace can be adjusted to the anatomic characteristics of each patient. The brace with uniformly distributed holes is considered for different reasons such as air circulation, hygiene, visualizations control, as well as to reduce costs and the amount of material. Both designs present an opening gap to ease donning and doffing. The two models were exported as .iges files to the Ansys Workbench software for FEA. A static analysis was performed considering a mesh of tetrahedral elements, different structural materials (PLA, ABS, PA) and impact cases assuming different arbitrary impact loads (10, 20 and 30 N) on a specific area. For the simulations, the two ends of the brace are considered fixed.

DOI: 10.18416/AMMM.2019.1909S03P01

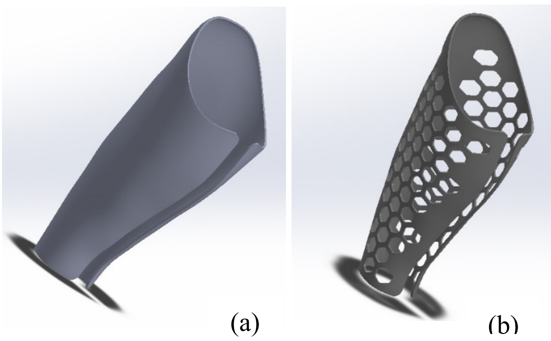


*Figure 1: (a) Solid brace, (b) brace with holes*

## IV. Results and discussion

The maximum deformation values for the two designs and different materials are presented in Table 2. The values significantly increase by increasing the load. For the same materials and loading conditions, the deformation is higher in the case of the brace with holes. Moreover, for the same brace design and loading conditions, PA braces present high deformation values. For this application, the deformation values presented by the solid brace are acceptable. However, the brace with holes must be redesigned (the pore size must be changed) due to the large deformation obtained for the high impact load case.

*Table 2: Maximum deformation values for both braces.*

| Load (N) | Max. Deformation (mm) | | | | | |
|---|---|---|---|---|---|---|
| | Solid Brace | | | Brace with holes | | |
| | ABS | PLA | PA | ABS | PLA | PA |
| **10** | 0.076 | 0.052 | 0.218 | 0.369 | 0.254 | 1.032 |
| **20** | 0.153 | 0.105 | 0.436 | 0.739 | 0.509 | 2.063 |
| **30** | 0.229 | 0.158 | 0.654 | 1.109 | 0.764 | 3.095 |

Figure 2 shows the load vs displacement curves. The area under these curves represent the work required to deform the material and corresponds to material toughness. As observed PLA presents higher stiffness than ABS and PA but PA is the toughest material. In terms of processing, the PLA is the easiest material to print due to the lower melting temperature.

Table 3 shows the weight values for the two considered designs and different materials, the corresponding critical forces, which are the forces at which the part will fail, and the specific critical force per unit of mass. The specific critical force considers the stiffness of the material as well as the weight, whereas the critical force does not consider the weight as it is an absolute value. A reduction of weight of around 32% was obtained for the brace with holes. Moreover, it is also possible to observe that the reduction in specific strength for ABS, PLA and PA braces with holes is 63.4%, 64.2% and 64.7% respectively.

(a)

(b)

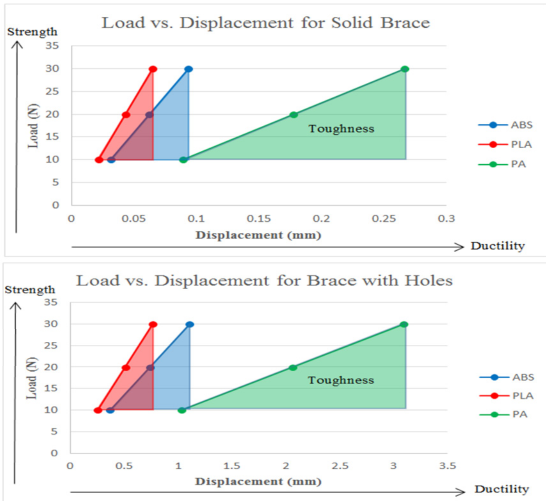


*Figure 2: Load-displacement curves for (a) solid brace and (b) brace with holes.*

*Table 3: Properties for the different brace designs.*

| Structure | Sold Brace | | | Brace with holes | | |
|---|---|---|---|---|---|---|
| **Material** | **ABS** | **PLA** | **PA** | **ABS** | **PLA** | **PA** |
| **Weight (g)** | 409.6 | 461.7 | 424.5 | 280.6 | 316.3 | 290.8 |
| **$F_{critical}$ (N)** | 293.1 | 374.7 | 217.3 | 74.59 | 94.72 | 53.3 |
| **$F^{*}_{critical}$ (N/g)** | 0.71 | 0.81 | 0.51 | 0.26 | 0.29 | 0.18 |

## V. Conclusions

A functional brace to replace the use of the Ilizarov system is presented. The main design requirements being considered are presented and a preliminary numerical simulation study conducted considering different materials and two designs (a solid brace and brace with holes). Braces made with PLA present high stiffness and rigidity. Although braces made with PA show high ductility. Results also show that braces are able to absorb higher amounts of energy during the impact. In the future, the design of the brace with holes will be performed using topology optimization aiming to achieve the optimal balance between weight reduction and mechanical performance.

### Acknowledgments

The first author acknowledges the support received by The King Saud University to conduct his Ph.D. studies. This project has been partially supported by EPSRC through the grant EP/R01513/1.

### Author's statement

Conflict of interest: No potential conflict of interest was reported by authors. Informed consent: Informed consent has been obtained from all individuals included in this study.

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