Numerical investigations of stress-deformation responses in fractured paediatric bones with prosthetic bone plates

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Abstract. Nearly 25% of paediatric injuries happen due to fractures of femur bones, either under accidental or inflicted conditions. In the present investigation, static analyses are performed for fractured paediatric femur bones of children joined with bone plates using finite element method (FEM) approach to find stresses and deformations in the bone and plate assembly under axial compressive and torsional loadings. The investigation aims to suggest the suitable biomaterial for fracture fixation bone plates modeled using two recently-developed biomaterials such as titanium and magnesium alloys, after studying the stresses and deformations at the fracture spots of the paediatric femur bones of children aged between 1-3 years. The stress-deformation responses are further analyzed in relation to ages of the children.

1. Introduction

The report suggests that children aged between 1-3 years are relatively at higher risk of fatal paediatric injuries due to their inability to save themselves [1]. In the present investigations it has been thus realized the need of addressing the stress-deformation responses in fractured paediatric bones with prosthetic bone plates for children aged between 1-3 years. In most of the cases the suitable fracture fixation bone plates are used to join fractured paediatric femur bones of children [2, 3]. The aim of study is to investigate the suitable biomaterial for fracture fixation bone plates modeled using two recently-developed biomaterials such as titanium and magnesium alloys [4], after studying the stresses and deformations at the fracture spots of the paediatric femur bones of children aged between 1-3 years under axial compressive and torsional loadings [5-7].
2. Modeling and analysis

2.1. Generation of models using finite element
The computer tomography (CT) scanned data of asymmetric femur bones are used in medical imaging system (MIMICS) in digital formats to assign material properties in cortical bones [2]. The CT scanned data of fractured paediatric femur bones (having 0.5 mm slice thicknesses) of children aged between 1-3 years are imported into the PTC Creo software to assemble these with fracture fixation bone plates and screws. In the present investigation the fracture fixation bone plates are modeled using the material properties of two recently-developed biomaterials such as titanium and magnesium alloys as shown in Table 1 for the static analyses of cortical bones under axial compressive and torsional loadings in ANSYS 15.0 software.

**Table 1.** The mechanical properties of paediatric femur bones and recently-developed fracture fixation bone plates

| Age          | Poisson’s Ratio | Bone Density (kg/m$^3$) | Modulus of Elasticity of Bone (GPa) | Material | Modulus (GPa) | Density (g/cm$^3$) |
|--------------|----------------|--------------------------|-------------------------------------|----------|---------------|-------------------|
| 48 weeks (Male) | 0.342         | 346.6                    | 17.25                               | Mg alloys | 35-45         | 1.79-2            |
|              |                |                          |                                     | Ti alloys | 110-120       | 4.2-4.5           |
| 96 weeks (Female) | 0.342      | 346.6                    | 18.48                               | Mg alloys | 35-45         | 1.79-2            |
|              |                |                          |                                     | Ti alloys | 110-120       | 4.2-4.5           |
| 144 weeks (Female) | 0.342     | 480                      | 19.09                               | Mg alloys | 35-45         | 1.79-2            |
|              |                |                          |                                     | Ti alloys | 110-120       | 4.2-4.5           |

2.2. Meshing and boundary conditions
The assemblies of fractured paediatric femur bones of children aged between 1-3 years joined with bone plates are discretized using the *solid 186* layered solid elements. These 20-noded higher order elements are having three degrees of freedoms for quadratic displacement behaviors. The assemblies are meshed with such 8631 elements, and 15608 nodes for accurate static responses in terms of the stresses and deformations at the fracture spots of the paediatric femur bones of infants and toddlers. The convergence test is carried out for the suitable optimum mesh to reduce the computational efforts.

2.3. Validation of model
The models (assemblies of fractured paediatric femur bones of children aged between 1-3 years joined with bone plates) are validated using the results available in the references [2, 3]. The mechanical properties of paediatric femur bones joined with prosthetic bone plates used in validation of our models are shown in Table 2.

The eccentric load of 750 Pa is applied at the head of the femur bone which is fixed at its opposite end as shown in Figure 1. The maximum directional deflection (Figure 1 (b)) and equivalent stress (Figure 1 (d)) are obtained under the compressive loading as 0.000001942 m and 76346 Pa, respectively. Thus, the results obtained are in good agreement with the corresponding data sets available in Ref. [3] (Figures 1 (a)-(c)). The maximum deflection under torsional loading (50 Nm) is 0.013288 m (Figure 1 (f)) whereas under compressive loading (700 N) is 0.00004302 m (Figure 1 (h))
and thus, the efficacy of present model are validated with the corresponding data sets available in Ref. [2] (Figures 1 (e)-(g)).

**Table 2.** The mechanical properties of paediatric femur bones [3] and fracture fixation bone [2]

| Properties of Bone [3] | Properties of Bone Plate [2] |
|------------------------|-------------------------------|
| Poisson’s Ratio        | Material | Modulus (GPa) | Density (kg/m³) | Poisson’s Ratio |
| Bone Density (g/cm³)   |          | Modulus of Elasticity of bone (GPa) | Titanium | 120 | 4500 | 0.3 |
| 0.3                    | 2000     | 2.13          |               |               |               |     |

![Figure 1](a)

![Figure 2](b)

![Figure 3](c)

![Figure 4](d)
3. Results and discussions

The results are presented for suitable biomaterial for fracture fixation bone plates modeled using two recently-developed biomaterials such as titanium and magnesium alloys, after studying the stresses and deformations at the fracture spots of the paediatric femur bones of children aged between 1-3 years. The stress-deformation responses are further analyzed in relation to ages of the children as shown in Figures 2 (a)-(d). It is found that titanium alloy is the suitable biomaterial for the bone plates.
as under axial compressive and torsional loadings, the effect of equivalent stresses at the fracture spots of the paediatric femur bones is significantly reduced.

4. Conclusions
In the present investigations, the fracture fixation bone plates are modeled using two recently-developed biomaterials such as titanium and magnesium alloys. After studying the stresses and deformations at the fracture spots of the paediatric femur bones of children aged between 1-3 years under axial compressive and torsional loadings, it is found that titanium alloy is the suitable biomaterial for the bone plates (used to join fractured paediatric bones of children). Under axial compressive and torsional loadings, the effect of equivalent stresses at the fracture spots of the paediatric femur bones is reduced significantly after modeling the prosthetic bone plates with titanium alloy instead of magnesium alloy. Thus, the present investigation favours the future applications of recently developed titanium alloy as the suitable biomaterial for modeling the prosthetic bone plates instead of commercially available prosthetic bone plates made up of magnesium alloys.

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