Strength of the Joshi External Stabilising System

Rajeev Kumar,1 Anupam Gupta,1 VP Sharma,2 Sanjay Mishra3

1 Department of Mechanical Engineering, Institute of Engineering and Technology, Lucknow, UP, India
2 Department of Physical Medicine and Rehabilitation, CSM Medical University, Lucknow, UP, India
3 School of Engineering Systems and IHBI, Queensland University of Technology, Brisbane, Australia

ABSTRACT

Purpose. To conduct an in vitro strength test for the Joshi External Stabilising System (JESS) for stabilisation of tibial fractures using a cadaveric tibia and steel rods.

Methods. The configuration of the JESS specimens was based on a 62-year-old man with a metaphyseal tibial fracture. Two types of JESS specimens were prepared, using either the tibia of an average male adult cadaver (n=1) or stainless steel cylindrical rods (n=3). The strength of the JESS rather than that of the rods was measured using a universal testing machine. The axial compressive load was gradually increased at 1 mm/min to 35 N. Axial deformation of the fracture fragment was recorded. Each experiment was repeated 3 times in identical manner. A finite element analysis of the JESS was developed. The axial compressive loads and corresponding interfragmentary displacement in the experimental specimens and in the finite element analysis were compared.

Results. The mean strength of the JESS was 32.5 N/mm in experiments and 35.3 N/mm in finite element analysis; the difference was 8.4%. The interfragmentary displacement was directly proportional to the axial compressive load.

Conclusion. The strength of the JESS is one fourth of that of the Ilizarov fixator, and therefore not suitable for full load bearing activities.

Key words: compressive strength; external fixators; finite element analysis; materials testing; shear strength; tibial fractures

INTRODUCTION

The Joshi External Stabilising System (JESS) has been used for bone stabilisation in the Indian subcontinent for 30 years.1 It was first used in hand surgery and then in various other musculoskeletal disorders. Owing to its simple design, light weight, easy manoeuvrability, and low cost, it has been used for treatment of post-burn contractures of the hand and wrist,2 interphalangeal joint contractures in leprosy,3
intra-articular distal radial fractures, idiopathic clubfoot, hand trauma and its sequels, calcaneal fractures, and congenital talipes equinovarus. We conducted an in vitro strength test for the JESS for stabilisation of tibial fractures using a cadaveric tibia and steel rods. Data of the tests were input to a finite element analysis. Experimental testing was a destructive process, whereas a finite element analysis enabled comparison of different configurations without destruction of the device.

MATERIALS AND METHODS

For stabilisation of a tibial fracture, the JESS consisted of one inner (135 mm diameter) and one outer (155 mm diameter) three-quarter circular rings connected with 2 front (130 mm long) and 2 rear (70 mm long) support rods. These were connected to 2 Z-shaped links, using universal joints (Fig. 1). The diameter of all rings, rods, and links was 4 mm. The circular rings were mounted on the proximal tibia using 3 Kirschner wires (2 mm diameter) inserted at about 22.5° to each other. No pretension was applied to the Kirschner wires. The Z-shaped links were connected to the diaphysis in the mediolateral plane using 3 pins (2.5 mm diameter) below the fracture fragment. An additional half pin (2 mm diameter) was inserted from posterior in the anteroposterior plane to provide further stability. Other components of the bone-fixator assembly such as bone and interfragmentary gap were idealised and approximated.

The configuration of the JESS specimens was based on a 62-year-old man with a metaphyseal tibial fracture. Two types of JESS specimens were prepared, using either the tibia of an average male adult cadaver (n=1) or stainless steel cylindrical rods (n=3). In the bone-JESS specimen, a 15-mm-wide section at 35 mm from the top of the tibia was removed to simulate the fracture. In the steel-JESS specimens, a 250-mm long rod (outer diameter, 22 mm; wall thickness, 2 mm) was used as the tibial shaft, and a 35-mm long rod (outer diameter, 60 mm; inner diameter, 52 mm) was used as the proximal region of tibia. To simulate the metaphyseal tibial fracture, a 15-mm gap was left between the rod ends.

The strength of the JESS rather than that of the rods was measured using a universal testing machine (Fig. 2). The testing was carried out according to the guidelines for Ilizarov frames; loading of the frame beyond fragment displacement of 1 mm is not recommended. The axial compressive load was gradually increased at 1 mm/min to 35 N, which is the predicted force to cause a fragment displacement of 1 mm. Axial deformation of fracture fragment was recorded. Each experiment was repeated 3 times in an identical manner.

The finite element analysis was idealised with linear, elastic and isotropic properties, using ANSYS software (ANSYS, Canonsbury [PA], USA). The bones and the JESS were discretised using 3
dimensional beam elements. The analysis included 146 nodes and 205 elements. All the link joints and pin-bone interfaces were modelled as rigid joints. An interfragmentary gap of 15 mm was produced as the fracture to measure the strength of the JESS. The elastic modulus of 200 GPa and Poisson’s ratio of 0.28 of structural steel were applied. For the boundary condition, the distal end of the idealised bone was fixed by setting all degrees of freedom to zero. An axial compressive load of 0 to 35 N (in the steps of 5 N) was applied to the proximal end. The linear elastic, static analysis, and deformations of the JESS were calculated (Fig. 3). The axial compressive loads and corresponding interfragmentary displacement in the experimental specimens and in the finite element analysis were compared (Fig. 4).

RESULTS

The mean strength of the JESS was 32.5 N/mm in experiments and 35.3 N/mm in finite element analysis (Table); the difference was 8.4%. The load-deformation curve was linear, as the interfragmentary displacement was directly proportional to the axial compressive load (Fig. 4).

DISCUSSION

The strength of JESS is approximately one fourth of that of a standard Ilizarov circular external fixator (32.51 vs. 123.39 N/mm). Therefore, the JESS is not suitable for full load bearing activities. After consolidation of callus tissues in the fracture, the loading is shared by the bone and the JESS, such that some weight bearing activities may be recommended. Further studies are required to demonstrate the mechanical properties of a JESS (such as bending and torsional strengths and interfragmentary displacement) during the various stages of fracture healing.

The 8.4% difference was due to inaccuracy in measuring the JESS geometry, material properties, and the direction of loading in the finite element analysis. The higher strength of the JESS in the finite element analysis was expected, as all universal joints were modelled as rigid joints. Under these constraints and range of error, the finite element analysis appeared to be valid for investigating the mechanical properties of other configurations of the JESS so as to improve performance.

The limitations of the study were that only 4 experiments were performed. The JESS is not patented and different manufacturers provide slightly different modules. Different configurations are used at the discretion of the surgeon. Therefore, our results may not be generalised for all types of the JESS configurations.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Mean±SD strength (N/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JESS-cadaver tibia</td>
<td>32.8±1.0</td>
</tr>
<tr>
<td>JESS-steel sample I</td>
<td>33.8±1.6</td>
</tr>
<tr>
<td>JESS-steel sample II</td>
<td>30.7±0.4</td>
</tr>
<tr>
<td>JESS-steel sample III</td>
<td>33.8±0.5</td>
</tr>
<tr>
<td><strong>Overall mean</strong></td>
<td><strong>32.5±1.2</strong></td>
</tr>
<tr>
<td>Finite element analysis</td>
<td>35.3</td>
</tr>
</tbody>
</table>

Figure 3 Finite element analysis of the Joshi External Stabilising System showing a deformed frame under 35 N axial compression load.

Figure 4 Load-deformation curves of the Joshi External Stabilising System in experiment and in finite element analysis.
REFERENCES