Experimental Testing of Joshi's External Stabilizing System (JESS) under Axial Compression

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***Abstract*— Joshi's External Stabilizing System (JESS) is a versatile, cost effective, light weight external fixation system that is successfully used as a primary stabilization device or as an accessory to other fracture stabilization devices. Present study aims to experimentally measure the axial stiffness of the three different types of specimens of JESS, each having identical geometrical configuration but different sizes of k-wires. Laboratory specimens of JESS were configured on hollow cylindrical stainless steel tubes simulated as proximal and diaphysis of a human tibia bone. Each specimen was fabricated with identical geometrical features except that the k-wires used for proximal tibial hold were of different cross sectional diameters of 2mm, 2.5mm and 3mm respectively. Four samples of each specimen were configured. The metaphyseal tibial fracture was created by providing a 15mm gap in the JESS frame construct. The specimens were tested under axial compression in an INSTRON Universal Testing Machine. The average axial stiffness of the JESS was found to be varying from 31.99 N/mm for frame with 2mm k-wires, 37.82 N/mm with 2.5mm k-wires and 45.81N/mm with 3mm k-wires. It was observed that the JESS specimen with 3mm k-wire was about 41% stiffer than the JESS specimen with 2mm k-wires under axial compression. The study provides the experimental data of axial stiffness of JESS external fixation device used for management of proximal tibial fractures which will be useful for surgeons to have an accurate estimation of mechanical properties of the JESS compared to other stabilization devices for fracture treatment.**

Keywords*— *JESS; external fixation, metaphyseal tibial fracture; axial stiffness

I. INTRODUCTION

Joshi External Stabilizing System (JESS) is a bone stabilizing device used in the Indian subcontinent for the last 30 years [1]. The JESS was indigenously designed, fabricated and used by Dr B B Joshi in late seventies for the hand surgery; however, due to its versatile nature and ease of applicability it is now being used in the treatment of variety of musculoskeletal disorders [2]. Due to its simple design, reliance on readily available materials, versatility, light weight, easy maneuverability and low cost it has been used as primary stabilization device or as an adjunct in the treatment of many bone and soft tissues complications like post burn contractures of the hand and wrist [3], interphalangeal joint contractures in leprosy [4], intra-articular distal radial fractures [5], management of idiopathic clubfoot [6], hand trauma and its sequels [7], calcaneal fractures [8] and CTEV [9, 10]. Recent applications have been reported about JESS being used in treatment of specific injuries of tibial plateau and fractures of tibial plafond [2].

Many experimental procedures have been employed to study the behaviour of external fixation devices. Yilmaz *et al.* [11] conducted an experimental study to determine the stiffness characteristics of standard and hybrid Ilizarov circular fixators. Bronson *et al.* [12] conducted a multi-variable study of stability of external circular fixation to evaluate how the manipulation of parameters of fixation and components of circular frame could improve and maintain optimal stability of bone fragments. The study concluded that contribution of each component to overall stability is dependent upon the mode of loading. Stein *et al.* [13] performed a biomechanical study on hybrid ring tubular external fixator to measure and compare the mechanical properties in transverse of the four-ring and three ring/one tube hybrid fixator.

Schrøder *et al.* [14] performed experimental investigations of four different configurations of the Hoffmann external fixation system using 4 mm steel pins to assess the mechanical properties. The study conducted the laboratory evaluation of mechanical properties of various unilateral frame configurations and compared it with the Hoffmann-Vidal frame. Gardner *et al.* [15] evaluated the mechanical performance of the Pinless and Centrafix fixators for rapid application to tibial fractures. Experimental studies were conducted to measure the stiffness, maximum service loads and fatigue strengths of the fixators. Kumar *et al.* [16] investigated and compared the axial compressive stiffness of JESS by experimental and by finite element method.

JESS frame is in extensive use by medical fraternity in India for more than thirty years. However, there are very few studies in the literature describing its mechanical properties. As a result, estimation of its mechanical performance solely lies with the experience of the orthopaedic surgeon. Therefore, aim of the present study was to conduct an in-vitro mechanical test to measure and to compare the axial stiffness of three specimens of JESS frame with identical configuration but having different sizes of k-wires. The present study will try to elucidate the mechanical properties of the JESS frame which is used in the treatment of tibial fractures.

II. MATERIALS & METHODS

A. *Joshi's External Stabilizing System (JESS)*

A typical JESS frame for management of proximal tibial factures consists of two main parts; a helmet frame which acts as a proximal tibial hold and a diaphysial hold. These two parts are connected with the help of two Z connecting rods and two sets of anterior and posterior connecting rods to complete the frame. The construction of the frame is achieved by inserting one k-wire from posterolateral to anteromedial in the proximal region of tibia and the second wire from posteromedial to anterolateral region. A third k-wire is then inserted between the first two k-wires. A 4 mm diameter rod is curved into a three quarter circular ring and connected with the k-wires using universal link joints. This assembly is reinforced by another identical 4 mm diameter rod curved into a similar circular ring of smaller diameter and connected to the k-wire with the help of another set of universal link joints. This assembly completes the helmet of JESS frame construct. The diaphysial hold is constructed by inserting three parallel 2.5 mm diameter pins in medio-lateral plane which in turn are connected to two Z connecting rods on either ends of the diaphysis. The diaphysial hold is connected to the helmet or the proximal hold in the metaphysical region with help of two anterior and two posterior connecting rods [2]. A typical JESS frame for treatment of proximal tibial fracture mounted on a cadaver tibia bone is shown in figure 1.

B. *Specimen preparation*

In the present study, we prepared three types of specimens. The dimensions of the JESS frame were measured from a 62 year old male patient undergoing treatment for a metaphyseal fracture using JESS. All the specimens were prepared as per the measured data. In both types of specimen, all the geometrical parameters were kept identical except that in first type of specimen k-wires of diameter 2.0 mm were used while for the second and third specimen we used k-wires of size 2.5 mm and 3 mm respectively. Table 1 lists the standard sizes of

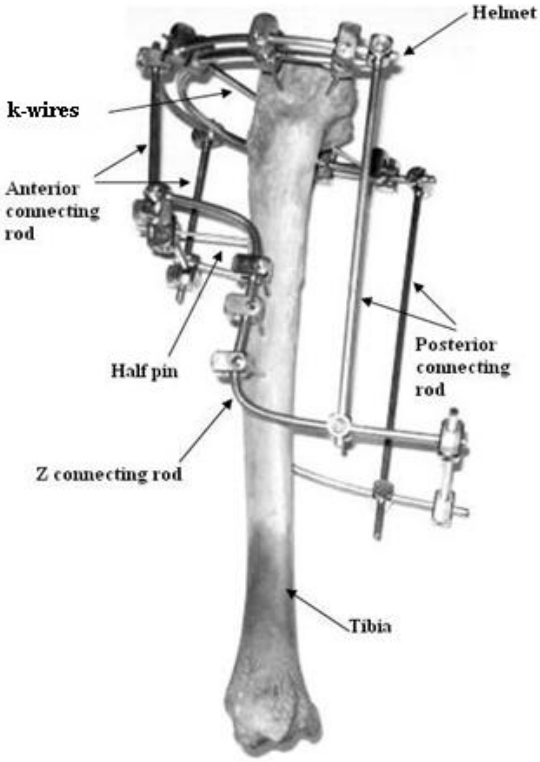

Fig. 1: JESS configured on a cadaver tibia

the different components used in making the laboratory specimens of the JESS frame.

Table 1: Specifications of laboratory specimen of JESS

	Part name	Quantity	Specifications
1	Inner ring	01	Mean diameter = 135 mm Rod diameter = 4 mm
2	Outer ring	01	Mean Diameter = 155 mm Rod diameter = 4 mm
3	Connecting Rod (two anterior and two posterior)	04	Rod diameter = 4 mm Anterior Rod length = 130 mm Posterior Rod length = 70 mm
4	Z connecting rod	02	Rod diameter = 4 mm
5	k-wires	03	Specimen 1:Diameter 2 mm Specimen 2: Diameter 2.5 mm Specimen 3: Diameter 3 mm
6	Half pin	01	Diameter 2 mm
7	Pins	03	Diameter 2.5 mm Length 90 mm

The JESS specimen in laboratory was also prepared in two parts, helmet or proximal hold and diaphyseal hold. The diaphysis or the bone shaft of tibia was simulated by using a cylindrical stainless steel rod 250 mm long (outer diameter 22 mm with two mm wall thickness) and to simulate the proximal region of tibia a 35 mm long hollow cylindrical rod (outer diameter of 68 mm and inner diameter of 60 mm) was used. The higher diameter cylinder was used for proximal region to ensure that the effective length of k-wires should remain intact. The construction of the helmet frame was done by inserting one k-wire in the hollow cylinder that was used as the proximal region of tibia. The second k-wire was inserted at about 45° to the first wire. A third k-wire was then inserted between the first two k-wires. All the k-wires were connected with two three-quarter circular rings of 4 mm diameter, one inner ring (135 mm diameter) and one outer ring (155 mm diameter), with the help of universal link joints to construct the helmet of the frame. The inner circular ring was used to provide additional strength to the frame. The diaphysial hold was constructed by inserting three parallel 2.5 mm diameter pins in the hollow cylindrical rod that is used to simulate the diaphysis of tibia. These pins were connected with two Z connecting rods on the either sides of the rod simulating the diaphysis of a tibial bone which in turn were connected to the outer circular ring of helmet frame with help of two anterior and two posterior connecting rods each of 4 mm diameter. In addition, one half pin of diameter 2 mm was inserted from anterior to provide further fragment stability.

A 15 mm gap was maintained between the rod ends to represent the metaphyseal tibial fracture. The gap was maintained at 15 mm as we wanted to measure the stiffness of fixator construct rather than that of the steel tubes. The k-wires in JESS are not given any pretension. The laboratory specimen of full tibial JESS frame is shown in figure 2. For each type of specimen, four laboratory specimens of JESS frame construct were configured.

Since the aim of the study was to characterize the mechanical properties of the device therefore other components of the bone-fixator assembly such as bone and interfragmentary gap were idealized and approximated so that experimental tests can be conducted.

C. Testing in axial compression

Testing of JESS specimens under axial compression was carried out as per the guidelines suggested by Solomin [17]. The JESS specimens were propped up vertically between the compression plates of a 10 ton capacity universal testing machine (INSTRON 3382 at Central Institute for Plastic Engineering & Technology, Lucknow) for axial compression loading (Fig.3). The construct was subjected to a gradually increasing axial compressive load at rate of 1 mm/min. As soon as the axial deformation at bone fragment site reached to a value of about 1.0 mm the universal testing machine was stopped as the loading of the frame beyond fragment displacement of 1 mm is not recommended [17]. Load on the JESS specimen was released and the specimen was again loaded to same axial deformation.

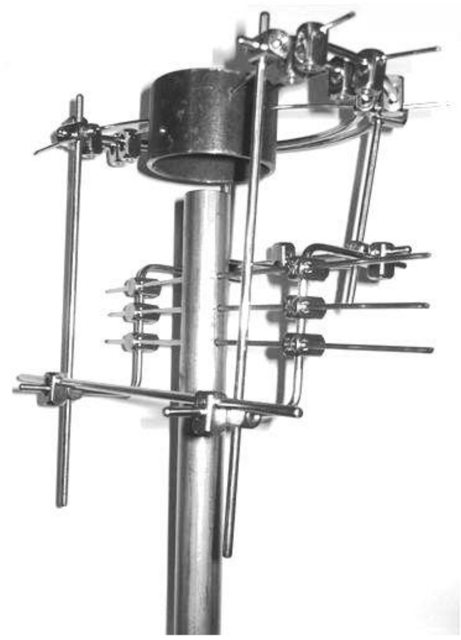

Fig. 2: Laboratory specimen of JESS configured on stainless steel tubes

This way, each specimen was tested five times under axial compression load. Axial stiffness of the fixator can be characterized by the rigidity coefficients of distraction and compression K_A:

$$K_A = F_A / u \quad (1)$$

where u is the fragment displacement in the axial direction due to axial compressive force F_A. The unit for measuring the axial stiffness is Newtons per millimetre (N/mm).

Fig. 3: JESS specimen under axial compression on universal testing machine

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III. RESULT

All the specimens were tested under axial compressive loads on a universal testing machine. The axial stiffness was calculated from the slope of load-deformation curve obtained by laboratory testing. The axial stiffness of the JESS frame with 2 mm k-wire was found to be 31.99 ± 1.63 N/mm, 37.82 ± 1.98 N/mm with 2.5 mm k-wire and for specimen with 3 mm k-wire it was 45.81 ± 2.26 N/mm. The measured axial stiffness of each specimen is listed in table 2.

IV. DISSCUSSION

Mechanical properties of an external fixator not only influence the biological environment at the fracture site but it also has a bearing at the outcome of the fixation process [18]. A very rigid fixator may cause delayed healing or non-union, while an over flexible fixator may lead to mal-union, increase chances of pin-bone tract infection and even non-union [11]. Therefore, it is extremely important to have adequate information about the mechanical properties of the fixation device for a surgeon to use it in clinical applications.

Table 2: Average axial stiffness of JESS specimens

S No.	Specimen	Axial Stiffness (N/mm)		
		k-wire = 2mm	k-wire = 2.5mm	k-wire = 3mm
1	specimen I	29.95 ± 1.07	36.95 ± 1.20	48.34 ± 7.16
2	specimen II	31.58 ± 1.63	37.56 ± 1.67	45.69 ± 2.90
3	specimen III	33.79 ± 3.28	36.13 ± 1.25	42.88 ± 3.23
4	specimen IV	32.64 ± 1.49	40.66 ± 1.46	46.32 ± 2.36
Mean stiffness		31.99 ± 1.63	37.82 ± 1.98	45.81 ± 2.26

The axial stiffness of the JESS frame was calculated in a Universal Testing Machine. Any axial deformation more than 1 mm at the fracture site is not good [17] therefore, the axial stiffness of the JESS frame was evaluated for an average fragment deformation of 1 mm. The average axial stiffness of three specimens are shown in figure 4. It was observed that the axial stiffness of the JESS frame increases with increase in the diameter of k-wires and the overall increase in axial stiffness by changing the size of k-wires from 2 mm to 3 mm was about 41%.

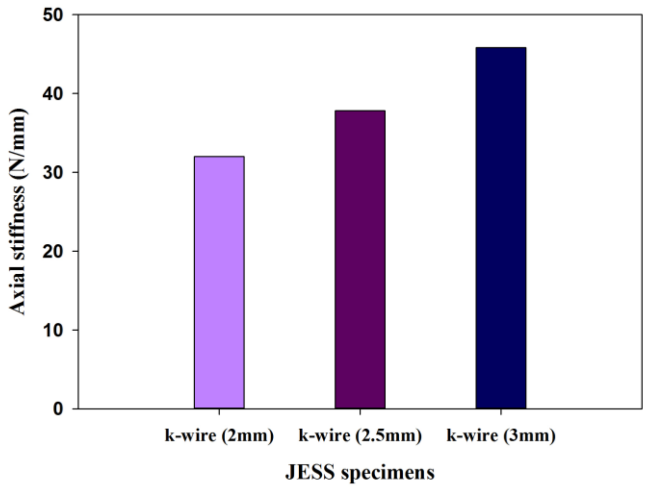

Fig. 4: Average axial stiffness of JESS specimens

The axial stiffness of JESS frame with 3 mm k-wire was compared with the axial stiffness of a standard Illizarov external fixator reported by Yilmaz *et al.* [11]. It was observed that the axial stiffness of JESS with 3 mm k-wire size was only about 37% of that of standard Illizarov external fixator. This suggests that due to its lower stiffness the current design of JESS may not be suitable for full load bearing activities of the patients; however, it may be used for partial load bearing conditions. Further, it may also be suitable as an adjunct in the treatment of many bone and soft tissues complications. During the later stages of fracture healing, due to consolidation of callus tissues in the gap the loading will be shared by the bone as well as the JESS, therefore some weight bearing activities may be recommended. Further studies are required to demonstrate the mechanical performance of a JESS such as stiffness and interfragmentary movements during various stages of fracture healing.

The results of the study are based on three sets of four JESS constructs having same geometry but different sizes of k-wires used in stabilization of metaphysical tibial fractures. In clinical applications, JESS is configured manually by the surgeon. Also, different configurations are used in clinics depending upon surgeon's own judgment and practice. Therefore, the above results may not be generalized for all types of the JESS configurations. Nevertheless, the present study quantifies the mechanical characteristics and stiffness of the JESS.

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