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A new Proposal on Analysis of the Interfragmentary Displacements in the Fracture Gap

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***Abstract* – Research activities in the field of modern Biomedical engineering show a more intense trend towards the use of sophisticated engineering measurement tools in order to optimize existing medical devices. External fixators are such an example of the above mentioned. Critical design parameters are being optimized by the use of existing engineering research methodology. One of the most important parameter for external fixators that have to be tracked are the interfragmentary displacements between the proximal and distal bone segment. This is usually achieved by the use of a finite element method. Another way is the use of displacement sensors or transducers. To verify these numerical results and to gain additional real life footage of interfragmentary displacements during testing, the use of a high speed camera has been taken into consideration. This paper compares previously acquired numerical data for a specific external fixator design parallel to the same setup whilst being recorded with a high speed camera. Results indicate good superposition with previously obtained data.**

***Keywords* – High speed camera, external fixator, interfragmentary displacements, finite element method**

1. Introduction

External fixators are considered as medical devices forimmobilization of fractures or serious damage to the structure of extremities with the primary function of surgical correct immobilization of bone segments as well as maintaining this function throughout the process of treatment. This function is achieved by an external frame which is connected to the bone by a certain number of pins or wires which are applied to a specific depth or all the way through the bone. These fixators follow the shape of a specific place they are applied to but do not come out of a general design concept that is mentioned above.

This general design concept has not changed since its origin but constant improvements are reflected through the development of new design approaches (which do follow the frame – pin, wire concept) and the use of new materials.

In order to be able to evaluate new design intents and to precisely measure specific parameters, a set of measuring methods have to be available. Current methods for examination of certain design parameters regarding external fixators include numerical FEM analyses and the use of displacement sensors or transducers.

This paper adds to previous investigation [1, 2] were design parameters are estimated by using a high speed camera for precise evaluation of interfragmentary displacements.

The experiment was conducted on the *Sarafix* external fixator system. The *Sarafix* system represents adjustable external fixator system which can be applied in several ways regarding the type of defected bone structure [3]. In order to assure the validity of the obtained data, measurements were conducted identically as in previous investigations. The bone was modelled as a wooden cylindrical rod with a fracture gap of 50 mm. The models were then supported on ball joints which then are fixed into supports of the testing machine as shown in Figure 1. The measurement was conducted under a axial loading force of F_p=600N [1].

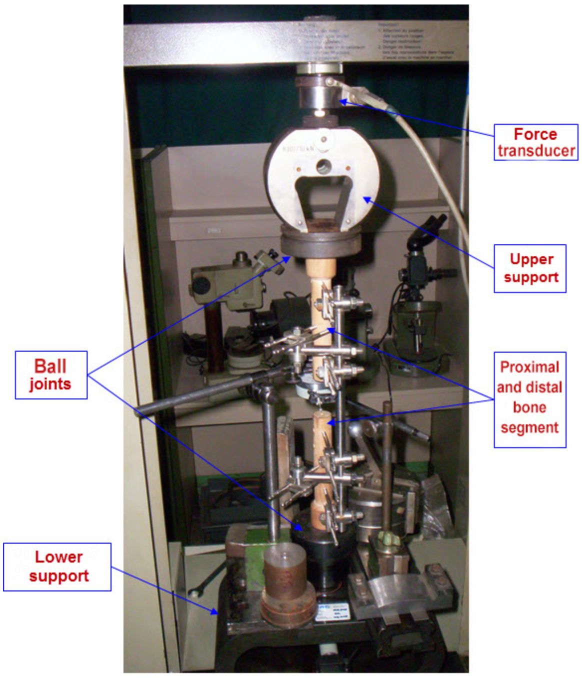

Figure 1. Experimental fixator setup

Operative practice has led to three major types of the *Sarafix* external fixator system. These are the configurations A, B and C, each with two versions “50” and “20” according to the fracture gap that was simulated either 50 mm or 20 mm. Every of these designs has several advantages and disadvantages according to its specific use. According to previous investigations and practical experience, the C configuration has the greatest stiffness in comparison to B and A configuration. The main aim of this paper is to approve the above mentioned result but from the viewpoint of interfragmentary displacements.

2. General design concept and theoretical background

The *Sarafix* External fixator system is a pin based external fixator meaning that the main function of healing the damaged bone structure is carried out by pins. This design approach implies a simple construction consisting of a main, primary carrier (trunk) which is supporting the secondary carrier. This secondary carrier holds the connecter in place which at the end supports the half-pin that is applied into the bone (Figure 2).

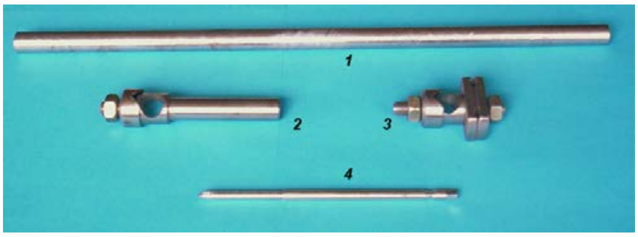

Figure 2.Sarafix External fixator components; 1 – Primary carrier; 2 – Secondary carrier; 3 – Connector; 4 – Half-pin

According to the arrangement of the above mentioned main components, several configurations of this fixator system are distinguished. Configuration A has the less complicated design with the smallest amount of components. This configuration is mainly used on upper extremities and is not suitable for greater loads and was not considered in this paper.

Configuration B is a unilateral external fixator system with the designation 4+4, meaning it consists out of four half-pins that are applied in the proximal and distal section of the bone (Figure 3). It is mainly applied on the lower leg and upper extremities.

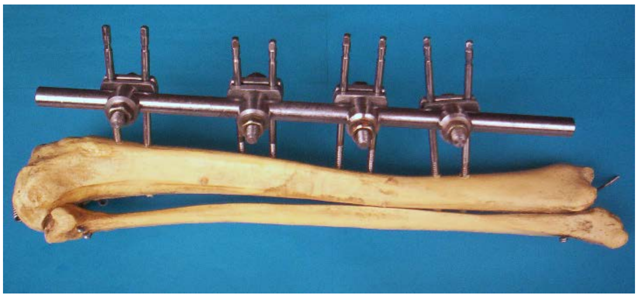

Figure 3.SarafixB configuration

Configuration C is a unilateral biplanar external fixator which consists of four half-pins applied to the distal and proximal bone segment. Unlike configuration B it has one half-pin in the distal and proximal bone segment that are applied in a plane that is rotated by 45 degrees compared to Anterior-Posterior plane - basic plane (Figure 4). In this way, a delta triangle construction is formed achieving greater final stiffness.

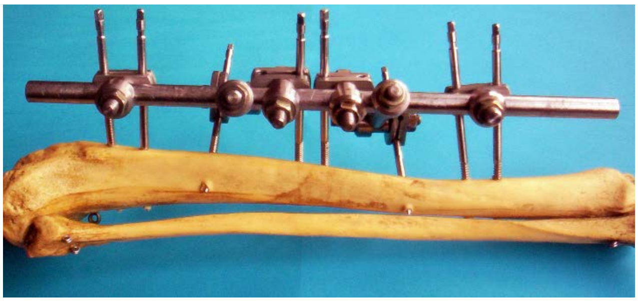

Figure 4.Sarafix C configuration

In order to be able to compare obtained data, the bones were modelled as in previous investigations to which this paper refers [7].

This approximation consists of modelling the bone as a cylindrical rod from wood which is separated into two parts by a distance of 50 mm representing the fracture gap that occurs during real life.

3. Experimental setup

The experimental setup consists of primary and secondary components. Primary components are intended to be those one which represent an inevitable part of the setup without which the experiment wouldn’t be possible. Secondary components are considered to be assisting components which are not infallible for the conduction of the experiment, but do improve quality of collected data.Primary components are considered to be the camera with the computer for data evaluation, testing machine and external fixator device in two various design configurations (B and C).

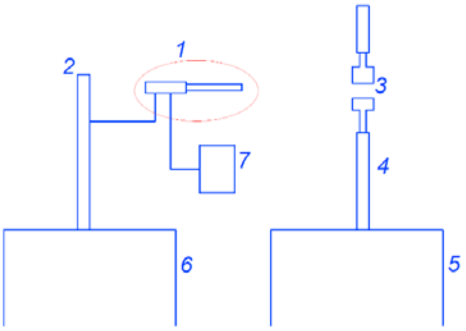

Figure 5.Experimental setup scheme 1 – Camera; 2 – Specialised camera stand; 3 – External Fixator; 4 – Testing machine; 5,6 – supporting table; 7 – Computer (additional light source is not shown)

Secondary components where a supporting table for the camera and testing machine, special camera stand for precise adjusting of the camera position as well as a light source for better picture quality. A scheme of the experimental setup is shown in Figure 5.

Additional laboratory resources that could influence the measurement where removed before the testing so neutral measuring conditions could be ensured. This applies mostly to the vibrations which came from the near located mass public transportation systems. A preview of the experimental setup in laboratory conditions is shown in Figure 6.

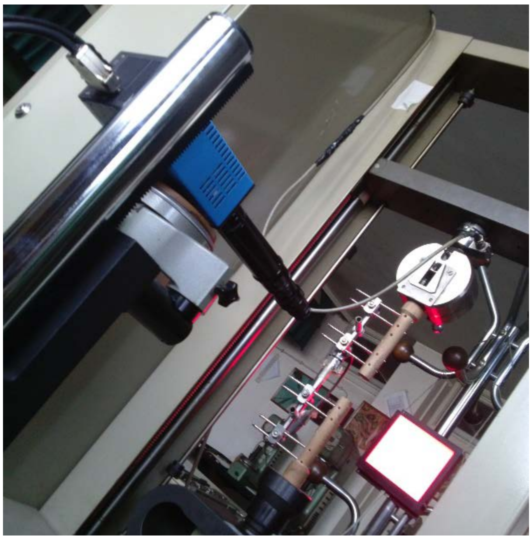

Figure 6.Experimental setup in laboratory conditions. The Picture shows the camera, testing machine, light source and the external fixator

The testing machine, together with the prepared external fixator, was prepared to simulate axial load. The camera was set in such a position so it could cover the end of the upper (proximal) and lower (distal) bone segment. The load process was set incrementally, meaning it started with 50 N, 100 N, 200 N, 300 N, 400 N, 500 N and 600 N. The testing machine was stopped by every load increment so the camera could finalise the record of an incremental load. According to this methodology, a total amount of eight records was made. From every record, a frame sample was taken off the first and last shot. In this way a continuous chain of records could be established according to which the data was evaluated later on.

4. Data evaluation

After processing the final recordings in a photo editing software to get better quality, recordings were evaluated according to the following methodology.

The maximum resolution was set to be active. After this, some testing records were made to establish a scale factor for later evaluation. After approving this scale factor and additionally editing photos to get more quality every first and last record was taken from a certain set of eight measurements. Two points (on proximal-PR and on distal-DR segment) were observed.Every picture had to be sharpened in such an amount so that certain characteristic points could be precisely picked up during record evaluation. Examples of conducted record analyses are given in Figure 7.

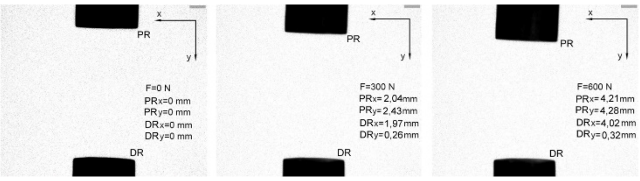

Figure 7.Evaluation of proximal and distal segment displacements during axial force load

After visual inspection of every picture, visual information about the proximal and distal bone segment in form of pixels where transferred into Excel for further analysis.

With an established scale factor and different pixel information for every picture, a wide range of data could be acquired. With the help of the gained data a set of diagrams could be plotted that represent the displacement of the most proximal and distal point at the fracture gap.

The obtained diagram from Figure 8.shows a slight distortion of the primary carrier, even though the carrier is not visible at the records. This conclusion can be made according to the bone segments position at the beginning and end of the load process. This diagram serves more as a visual indicator for quick analyses but the main focus of this paper is to compare previous investigation results with those tracked with a camera.

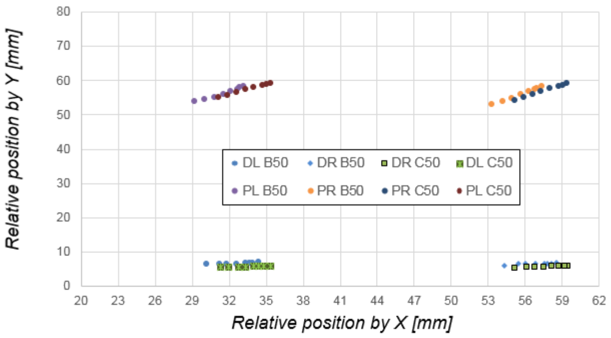

Figure 8.Relative position of the analysed points on proximal and distal bone segments during the loading cycle – interfragmentary distance 50 mm

However, in addition to numerous research, it remains unclear which forms of movement are helpful and harmful to the healing of fractures, therefore the information about the values of relative movement of the bone parts is of limited value. But on the basis of literature [4] the following two hypotheses could be suggested:

- Cyclic axial micro motion is beneficial for healing of fractures.
- Shearing motions of bone segments at the fracture site are detrimental to its healing.

Absolute displacements of analyzing points at the proximal and distal fracture endplate in the x, y and z direction were determined. Analyzing points were selected in such a manner for the resulting vector of relative displacements (R) has maximal value (Fig. 9).Relative craniocaudal and lateromedial displacements (x and y direction) and axial displacements (z direction) for analyzed points were calculated as:

$$r_{D(x)} = D_{p(x)} - D_{d(x)}; r_{D(y)} = D_{p(y)} - D_{d(y)};$$
$$r_{D(z)} = D_{p(z)} - D_{d(z)} \qquad (1)$$

where:

$r_{(D)x}$, $r_{(D)y}$ and $r_{(D)z}$ - are the relative displacements at the fracture gap in the x, y and z directions (mm),

$D_{p(x)}$, $D_{p(y)}$ and $D_{p(z)}$-are the absolute displacements proximal at the fracture gap in the x, y and z direction (mm),

$D_{d(x)}$,$D_{d(y)}$ and $D_{d(z)}$ - are the absolute displacements distal at the fracture gap in the x, y and z direction (mm).

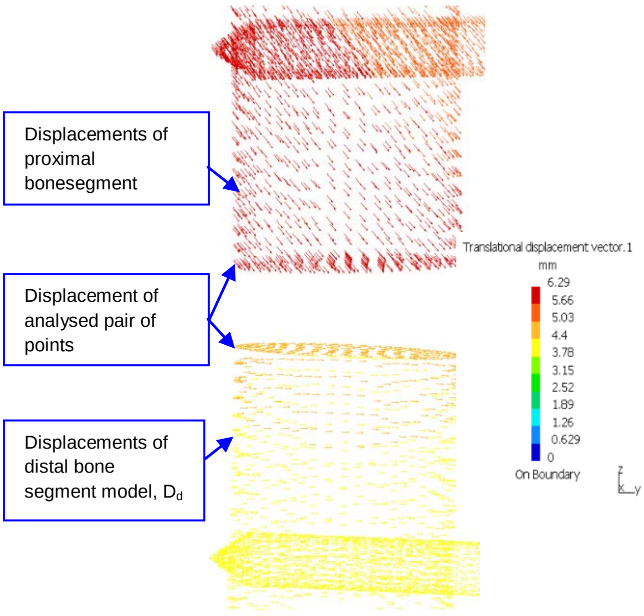

Figure 9.Translation displacement vectors of points at the fracture gap (Finite Element Method)

Based on the values of relative displacements $r_{(D)}$, maximal value of the resulting vector of relative displacements at the fracture gap is determine as:

$$R = \sqrt{(r_{D(x)})^2 + (r_{D(y)})^2 + (r_{D(z)})^2} \qquad (2)$$

This aim is given with table 1.where a comparison of the same results from a previous research work is given. Difference between these measurements is integrated into this table. The experimental maximum relative displacement at the gap R was evaluated only using x and y components of displacement [5,6,8].

5. Conclusion

Obtained results lead to several practical conclusions for future external fixator design development. All these findings are derived from table 1., where a summary preview of numerical and experimental results is given.

Table 1.Final comparison between previous numerical and experimental values made with a high speed camera

Method/Fixator Configuration		Proximal displacements (mm)			Distal displacements (mm)			Maximum relative displacement at the gap (mm)
		$D_{p(x)}$	$D_{p(y)}$	$D_{p(z)}$	$D_{d(x)}$	$D_{d(y)}$	$D_{d(z)}$	R
Numerical	B50	4,05	4,18	-0,42	4,2	-0,25	-0,44	4,43
	C50	4,14	4,36	0,53	4,29	-0,22	0,53	4,58
Experimental	B50	4,00	4,33	-	4,2	-0,32	-	4,65
	C50	4,21	4,28	-	4,02	-0,32	-	4,6
Difference (%)	B50	1,01	3,76	-	0,14	0,14	-	4,73
	C50	1,92	1,7	-	6,24	4,85	-	0,43

These findings can be split into two basic types. Findings that refer to the camera and findings that are related to the fixator itself and its aim.

In terms of camera findings, the main conclusion should be that the camera does not necessarily have to be a high speed camera because of the nature where the fixator is applied. The load process occurs at a speed that is firstly not fast so it does not require a high speed camera to be recorded. Secondly, the speed of bone segment distortion isn't a general design parameter that was tracked in previous research work on this specific topic. With this been said, a use of high speed camera in this case was justified because of available specialised software that enabled a direct connection to a computer station where specific recording parameters could be adjusted quickly and precisely. According to this, several recordings could be made which has specific experimental value meaning records can be made in a short period of time.

One other camera parameter that was noticed by authors to be from importance is the camera zoom. It is closely related the view field of the camera which, in order to make the records useful for further evaluation, has to cover the whole part that is observed. In this case the proximal and distal bone segment. This camera parameter is directly related to the camera resolution which should be as great as possible. Having a huge camera resolution allows someone to pick up special points precisely at any given camera zoom. This is further connected to the camera adjustment for better picture clarity. The aim is to achieve such a picture contrast so the observed object can be clearly distinguished from the surrounding objects which is a prerequisite for a successful picture evaluation later on. Directly related to this is also the special camera stand for precise adjusting of the camera position. One important reason why this particular camera was used was because of this specialised camera support for precise adjusting of the camera position was available. All the above mentioned equipment had to be in correspondence with a light source that is placed directly behind the object that is observed helping to establish a good contrast of the final record.

Findings that are related to the fixator itself approve previous investigation results almost completely**.** According to table 1, the biggest error that can really occur is by a percentage of 6,24 %. Error values such 31,44 % and 49,85 % aren't realistic because of the cameras resolution capabilities. Tracked points that had this error amount where at the less important distal bone segment. During the load process, this part had a very unpredictable tendency to move in several directions, making it very difficult to precisely locate the targeted point of the record. This is also a point of the investigation where the camera resolution shows up as very important. This specific bone segment part was very difficult to track due amiss previous positioning of the fixator in the testing machine. In combination with a small resolution of the used camera, this resulted with a situation where two adjacent points of the record do represent the same object but if they would be separately picked and transmitted through the calculation procedure they would give distinct results. Since the camera view enabled the record of a two dimensional picture, some fields in table 1 are left blank because the numerical analyse integrated a three dimensional model. In relation to this, authors considered the use of a second camera which could cover the third component in space in future investigation. During the assessment for this project, in cooperation and consultation with specialised camera and software providers, authors finally conclude that this concept is currently not achievable due to limitations in computer capabilities that are available on the market.

After combining the above mentioned collected experience of camera use for displacement evaluation on external fixators, author's general conclusion is made up of two standpoints. First, the use of high speed cameras for displacement assessment on external fixators is a valuable tool under the above mentioned circumstances. A comprehensive set of subgroup tools has to be installed during the experiment so that a result superposition with previous results is guaranteed. Second, according to the above mentioned, cameras can serve more as a verification tool for previous results rather than a tool for quickvalidation of the design concept during the product development stage. Future refinement of this method is primarily dependent on computational resources and their capabilities.

References

[1]. Mešić E. (2013). *Doprinos razvoju integrisanog CAD/KBE sistema za konstruisanje i redizajniranje medicinskih aparata za spoljašnju fiksaciju kosti,* doktorska disertacija, Univerzitet u Sarajevu, Mašinski fakultet Sarajevo, BiH

[2]. Mešić E. (2008). *Istraživanje mehaničke stabilnosti sistema za spoljašnju fiksaciju Sarafix.* magistarski rad, Univerzitet u Sarajevu, Mašinski fakultet Sarajevo, BiH,

[3]. Dozic, S. Biomechanical characteristics of unilateral, biplanar fixator "Sarafix" in the treatment of extensive gunshot-explosive accidental fractures of long bones of the extremities, Ph.D. Dissertation, Faculty of

Medicine Sarajevo, University of Sarajevo, Sarajevo, Bosnia and Herzegovina, 2011.

[4]. Mow V.C., Huiskes R., Basic Orthopaedic Biomechanics and Mechano-Biology, 3rd Edition, Lippincott Williams & Wilkins, Philadelphia, 2005.

[5]. Mešic, E., A. Muminovic and N. Repcic, “Mechanical Stability Analysis of the External Fixation System Sarafix”. Proceedings of the 12th International Design Conference – DESIGN 2012, Section: Design methods, Session D435: Life science and design for healthcare. Organizers: University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, The Design Society. Editors: Marjanovic D., Storga M., Pavkovic N., Bojcetic N., May 21-24, Cavtat-Dubrovnik, Croatia, 2012, pp.1029-1038, ISSN1848-4700.

[6]. Mesic, E., Muminovic, A., Repcic, N. and Colic, M.: Stress Analysis of the Sarafix External Fixator Design, Journal of Mechanics Engineering and Automation – JMEA, Vol. 1, No. 6, 2011, David Publishing Company, USA, p.p. 473-480

[7]. Mesic, E., A. Muminovic and N. Repcic: Geometrical modelling and structural analysis of the Sarafix fixator configurations. Annals of DAAAM for 2012 & Proceedings of the 23rd International DAAAM Symposium „Intelligent Manufacturing & Automation: Focus on Sustainability”, Zadar, Croatia, October 24th-27th, 2012.

[8]. Mesic, E., Muminovic, A., Repcic, N. and Colic, M.: Stiffness Analysis of the Sarafix External Fracture Fixation System, Technics Technologies Education Management - TTEM, Vol. 5, No. 1, 2010, pp. 60-66.