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New Methods in Bio-mechanical Experimental Investigations

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Abstract: The authors present their experimental results on the fractured long human bones fixing systems' evaluation, respectively in the dental filling materials' comparative evaluation. In the first topic was used the Video Image Correlation, respectively in dental filling materials' problem: the Electronic Speckle Pattern Interferometry/Shearography. The obtained results offer useful information to surgical doctors, respectively to dental ones.

Keywords: VIC; ESPI/Shearography; long human bones; dental filling materials

1. Introduction

In the present contribution the authors offer their investigation results in two main domains:

a. in *fractured long human bones fixing optimisation* using Video Image Correlation, respectively
b. in *establishing of the mechanical characteristics for some modern dental filling materials* by mean of ESPI/Shearography method.

With respect to *the first topic*, one can summarize *the following important preliminary aspects*. The deeply analysis of the biomechanical conditions of the fixation protocol for the fractured long human bones (between others: the diaphyses ones) was started in 1958 by the so-called ***AO school*** (*Arbeitsgemein-schaft für Osteosynthese-fragen*) and continuously improved [1]. Their classification contains in fact a high-accuracy deeply identification method (in 4-levels) and Figure 1 offers its first level. In their investigations, the authors analyzed only **32A2**, **32C3**, respectively **42A2** cases [2; 3]. For the fractured bones, especially for the femoral bones' stress-state, many scientific reports were elaborated. Between others, some

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remarkable contributions represent the papers [4-9], where were applied especially the Photoelastic Coating Technique.

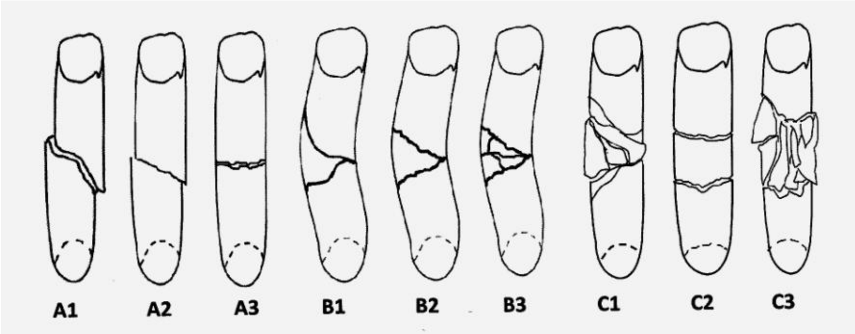

Fig. 1. The first level AO classification [1-3].

It is well-known fact that the fixing of the long fractured bones, especially in the middle part of them (the diaphyses), requires respecting some biomechanical conditions. It was established the piezo-electrical behaviour of the human bones (under mechanical loading it produces some small electrical signals/impulses, which encourage/promote the developing/ formation of the primarily callus and consequently reduces the healing process period). Based on this fact, Prof. Perren elaborated his theory [10-12], where establishes/states that small relative micro-movements of the fractured bones parts will present favourable condition for the healing period diminishing. Taking into the consideration the fact that there are several fixing system/procedures; part of them allow, and the others exactly prohibit these micro-movements. So, *became very useful to investigate these fixing methods' behaviours from the point of view of the micro-movements and compared the obtained results with the clinical praxis' ones*.

With respect to *the second topic*, one can summarize *the following important preliminary aspects*. In order to select the better (or: the best) filling material one should take into consideration not only its biocompatibility but also its mechanical characteristics. In literature there are several useful investigations, especially regarding on the mandible-tooth prostheses stress-states correlations, e.g. the reference [13].

In the filling materials choosing, should be taken into account not only the complex phenomenon of the curing process, when it is produced certain polymerisation shrinkage of the filling materials but also the phenomenon of the mastication itself. Most of the dental practitioners believe that polymerization shrinkage is the causing mechanism for the poor marginal adaptation between the two surfaces (tooth-filling material), ultimately leading to micro leakage and appearance of secondary caries lesions. Although this misconception is in clear contradiction with the facts experienced in dental practice it is widely spread. The goals of the described investigation consist in proving that the poor marginal adaptation is caused mainly by the different mechanical characteristics (e.g.: Young modulus, Poisson ratio) of the tooth and filling materials, respectively offering an objective selecting procedure/method for the most widely spread dental filling materials in Romania from this point of view. It is a well-known fact that during the mastication, the filling material will be subjected to compression and consequently lateral shrinkage will appear. This shrinkage produces practically a horizontal load on the lateral walls of the tooth's cavity therefore the wall is subjected to a cyclical bending. If the filling material has a higher value of the Poisson ratio, then a smaller amount of a given mastication force becomes a horizontal load which is, in fact, a periodic load exerted on the tooth's walls. Consequently the tooth filled has a better reliability.

2. Methods

In order to fulfil - in the case of *the fractured long human bones* - the high-accuracy investigation's requirements, the authors choose the **V**ideo **I**mage **C**orrelation method. Its 3D version (***VIC-3D***), from ISI-Sys GmbH, Kassel, Germany [14, 15] corresponds in the best manner to the proposed investigations' requirements. In this sense, between others, one can mention that: it is a full-field contact-less method; eliminates the rigid body movements from the achieved values; has a good accuracy (up to approx. $1\,\mu m$) in 3D displacements fields; offers not only the displacements field, but also the strains' ones; presents a large interval/range of the measured values of displacements (starting from some *micron*s up to several *cm*); allows the data extracting in different manners (e.g.: in Excel (cvs-files), respectively using metric node mapping, similarly with the FEM-analysis one); has a good stability, allowing high-accuracy measurements in operating conditions. In principle, the system consists of two high-resolution video cameras, mounted on a tripod by means of a high-precision connecting rod. The surface of the tested object is sprayed in advance with a water-soluble paint, in order to obtain a non-uniform dotted surface; the sizes of dotes depend on the surface sizes. After the calibration, the cameras will perform the image acquisition in an $[n \bullet m]$ matrix of pixels, firstly for the unloaded tested specimen (where on has to define *the area of interest*) and after then: for the loaded one. On the unloaded state's images the soft-ware allows the pre-selecting of a *Subset*'s (primarily cell) sizes (e.g.: $5 \bullet 5 = 25\, pixels$), respectively the step-magnitude (step size) for moving/ translating of the Subset in horizontal and vertical direction. For this Subset the program will establish/determine an unique grey-code, correlated to its median pixel's high-accuracy 3D positioning. By analyzing of the whole image (having each an $[n \bullet m]$ matrix of pixels), this will be substituted by these median pixels of the Subsets. The captured images for the loading states will be similarly analysed and compared with the initial state's images; in this way, for every representative median pixel will be obtained the displacement vector. Using these values the soft-ware offers for each representative median pixel: the strains and main strains, too.

In the case of *the dental filling materials*, the authors choose the ESPI (**E**lectronic **S**peckle **P**attern **I**nterferometry)/Shearography System, from the ISI-Sys GmbH, Kassel, Germany) [16]. In principle, the system consists of two sets of laser diodes ***3*** and ***4*** , disposed symmetrically in the left and right sites of the properly so called ESPI/Shearography subassembly (the Michelson interferometer ***5*** and the CCD camera ***6***) on the carbon-fibre rods ***7*** and ***8***. This subassembly is fixed, by means of a high-stiffened Aluminium rod on a very stable and high-accuracy adjust-

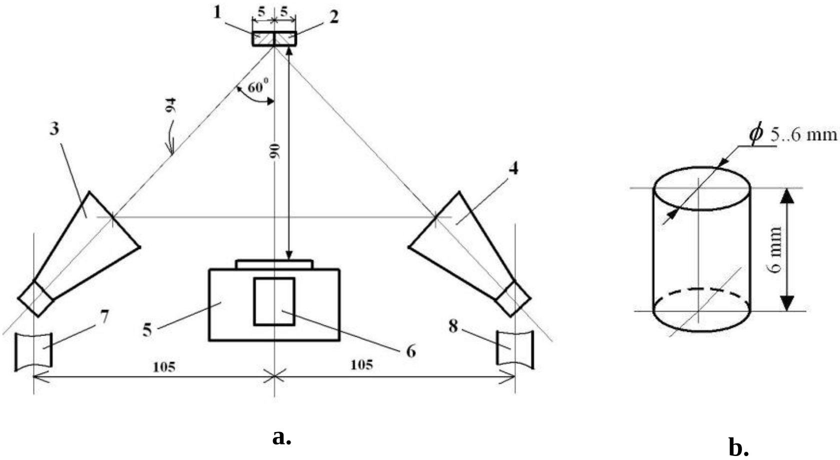

Fig. 2. Experimental set-up (a) and dimensions (in *mm*) for the tested specimen (b) [16, 17].

table tripod (Fig.2). The system allows a high-accuracy evaluation of the displacements field with some *nanometres* resolution. In this sense, the so-called *reference plate method* is applied. The tested object has to present a diffusely scattering surface in order to work each surface point as a secondary light source.

3. Results

In the Table 1 are presented the sort of *the experimented bones* and their fixation methods. The fractured bones, subjected to compression up to 400 N in an universal tensile-compression testing machine, were monitored during several cycles of loading and unloading. On the captured images is predefined the area of interest, where the soft-ware will perform the adequate displacements' calculus. On this area of interest were marked the significant points at the both sizes of the fracture (Fig.3). For each significant pair of pre-selected points were determined by soft-ware the corresponding coordinates; e.g.: to the pair *a-b* are determined: their initial distance ℓ^0_{a-b}; the elongation/shortening $\Delta\ell_{a-b}$; their projections on axes x and y [(x_0, y_0); (u, v)]; respectively the corresponding strains ε_x , ε_y. For illustration, in Table 2 are presented some of the obtained results. The upper index $j = 1,2,3$ of the strains ε^j_x , ε^j_y correspond to the investigation distance ℓ^j_0: $\ell^1_0 = 4.5\ mm$; $\ell^2_0 = 7.0\ mm$, respectively $\ell^1_0 = 10.0\ mm$ from Figure 3, case ***III***. On can conclude, based on these data, that in case of *dynamic compression plate fixation without over-bending*, on the principle of fracture compression, and loading at 400N involves more tensile strain, than on the opposite side, where occurs stress relieve when compression is applying by plate fixation with values of strain compared with those observed *in the model with over-bending*. Basically, over-bending of the plate reduces to 40% the longitudinal strain. In terms of type of micro-movement occurred on the axis *y*, is found that with over-bending of the plate displacement occurs as a sliding between the surfaces and in the absence of over-bending appears as a rotational movement,

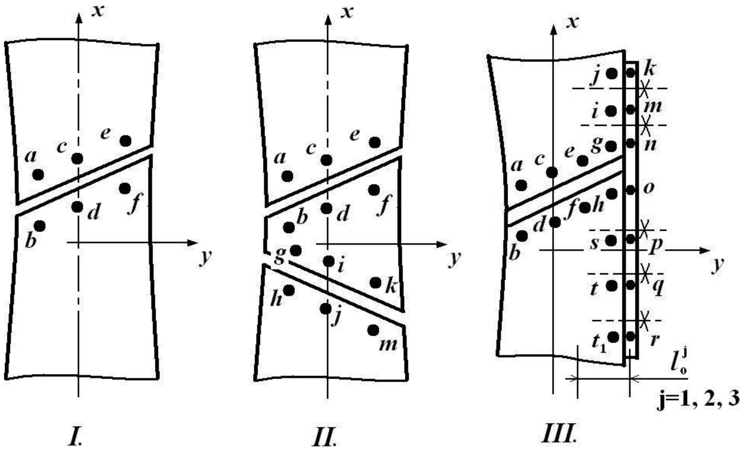

Fig. 3. The selection modality of the significant/interesting points on the tested bones: ***I.*** a simply unstable fracture; ***II.*** A multiple fractured bone; ***III.*** The case of the plate-fixators [2, 3].

Table 1. The analyzed osteotomies and the corresponding fixation protocol

Bone type	Osteotomy	AO type	Fixation device
Femur/tibia	Simple oblique	32A2/42A2	Dynamic compression plate (+/- bending)
	Wedge osteotomy		Neutralization plate
	Complex irregular osteotomy	32C3	Bridge plate

Table 2. The obtained results for two kind of fixators

Type of the fixator plate	The obtained strain ε_x in point ***j***			The obtained strain ε_y in point ***j***		
	ε_x^1	ε_x^2	ε_x^3	ε_y^1	ε_y^2	ε_y^3
Dynamic compression plate	0.0003	0.0020	0.0223	0.0600	0.1320	-0.3290
Bridge plate	-0.0010	0.0149	0.0237	0.0283	-0.0199	-0.0213

centered on the longitudinal axis of the plate and in this case exceeded the limit value of 0.02% of gap strain under stabile fixation. On the other hand, the biomechanics of *bridge plate fixation* impose high unstable osteotomies. It was simulated a **42-C3** fracture, and that, after the restoration of length, alignment and rotation of the two major fracture ends, were fixed with a bridge plate. Although the relative movements are more than 1 *mm* opposite to the plate, the specific movements by report to the distance between the main fragments are maintained between 2-3% which creates a true biological environment favourable to indirect healing. Note strain values below 2% immediately by the plate, a reason for the absence of periosteal callus in the vicinity of the plate - the other reason is related by disruption of local biological environment. Similarly were analyzed all of the mentioned case and compared with the clinical results of healing.

In the case of the dental filling materials, in order to determine their Young moduli, small cylindrical samples were manufactured (Fig. 2,b) and subjected to uni-axial compression. The small reference plate ***1*** (with a width of 5 *mms*) is appropriately (place / set beside) put beside the specimen tested (***2***). The Michelson Interferometer ***5*** and the four-Mega pixel CCD cameras ***6*** are disposed in normal direction to the object. A comparison of the image that belongs to the small and unloaded plate to that of the specimen makes possible a good and accurate in-plane strain analysis. Were tested two types of filling materials: *composites* (TE-Econom, Carisma, Extra Fil) and *glass-ionomers* (Fuji Gp IX, Ketach Molar, Ionofil +), manufactured in an adequate number of specimens in order to ensure a reliable statistical evaluation. In order to illustrate the most important steps of the displacement's field evaluation, Figures 4 and 5 show, for a cylinder-shape specimen, two of the most important steps in this sense: the filtering and the final evaluation along a central vertical line (having a known length ℓ_0), which represents the x-axis of the specimen. Using the values of the displacements on a selected line (e.g. a central/median line of the specimen, but not only there!) one can determine the elongation $\Delta\ell$ and then the corresponding axial strain ε_x. With the knowledge of the load applied and the cross sectional area of the specimen one can determine the axial stress σ_x. Consequently one can draw the stress-strain curve $\sigma_x - \varepsilon_x$ from where the sought Young modulus can be determined without difficulties. Figure 6 illustrates the accuracy of the strain-evaluation procedure. The selected initial length $\ell_0 = 8mm$ was divided in a very high number of pixels and starting from the 100th pixel (!), corresponding to approximately $0.4mm$, it became possible an adequate calculus, obtaining finally a strain. $\varepsilon_x = 1240.1\ \mu m/m$. It should be mentioned that this value belongs to a fixed value of the applied compressive load (force). This procedure was repeated for each load so that one could draw the final stress-strain curve $\sigma_x - \varepsilon_x$ and could determine the Young modulus as well. Figure 6 shows the Young moduli for the distinct filling materials which were tested.

4. Conclusions

The obtained results offer several important and useful biomechanical conclusions, applicable by the medical members of the authors' team. In the authors' opinion, both methods (VIC-3D and ESPI/Shearography) will represent in the next period some very useful methods in Biomechanics. In the next period the authors intend to continue these investigations on other useful clinical cases.

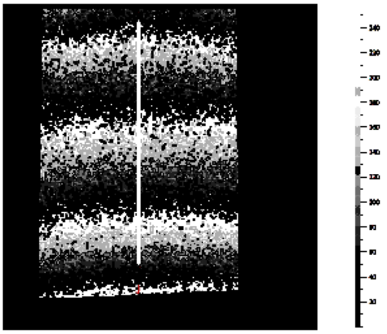

Fig. 4. Cylindrical specimen #1, Filtered data

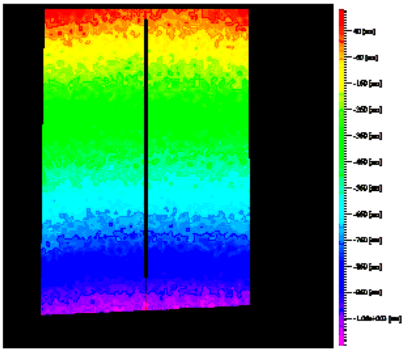

Fig. 5. Cylindrical specimen #1, Evaluated data

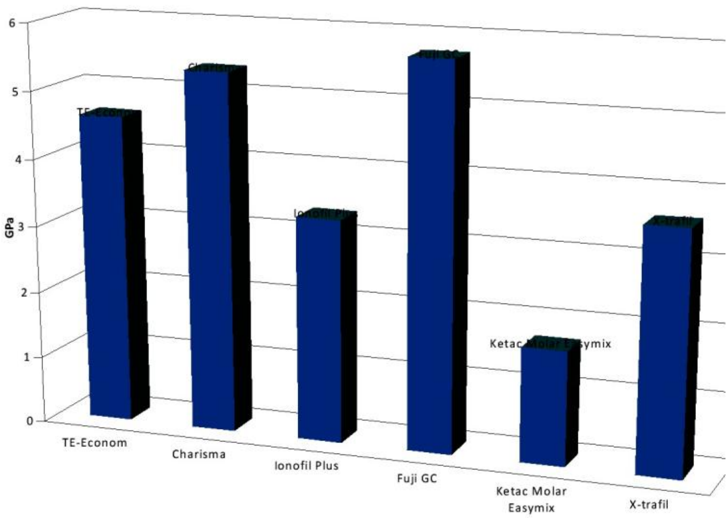

Fig. 6. Young moduli for the distinct filling materials

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References

[1] Müller, M.E., Allgöwer, M., Bandi, W., Schneider, R. and Willenegger, H., *Manual of internal fixation*, Springer Verlag, New York, 1970.

[2] Necula, R.D., PhD thesis, *"Carol Davila" University of Bucharest*, Romania, 2011.

[3] Necula, R.D., Panait, Gh., Száva, I. and Şamotă, I., "Evaluation of micro-movement in the biomechanical context of bone shaft fracture healing in elastic versus rigid fixations", in *Annals of Academy of Romanian Scientists, Series: Medical Sciences,* vol.2, nr. 2, 2011, pp. 64-78, ISSN 2067-7766.

[4] Borbás, L., Thamm, Fr., Hagymási, M. and Krakovits, G., „Investigation of different design of femur head prothesis with respect to the force transition to the femur shaft", in *Proceedings of XXV AIAS International Conference on Material Engineering*, Galliopoli-Lecce, 4-7 Sept., 1996, pag. 245-248.

[5] Borbás, L., Hagymási, M., Krakovits, G. and Thamm, Fr., „Development of the stress-state of a femur prothesis, detected by photoelastic coating technique" (in Hungarian), *Anyagvizsgálók Lapja*, 1996, nr.3, pp.28-34.

[6] Borbás, L., Thamm, Fr., Hagymási, M. and Krakovits, G., „Photoelastic coating technique to investigate the surface stresses of a femur prothesis" (in Hungarian), *Labinfő,* 1999, nr.1., pp.27-35.

[7] Borbás, L., „Investigation of femur prothesis with respect to the femur shaft", *Research News of BUTE*, Budapest, Hungary, 2oo3 nr.1., pp.1o-15.

[8] Borbás, L., Thamm, Fr. and Oláh, L.I., "Application of full-field pattern of photoelastic coating technique for the investigation of femur-head prostheses". In *Proceedings of Magyar Biomechanikai Konferencia*, Budapest, 2004. 12-14 Jun., pp. 35-42, ISBN 963 420 799 5.

[9] Borbás, L., Thamm, Fr. and Oláh, L.I., "Comparison of stain gauge technique and photoelastic coating method in the investigation procedure of femur prosthesis". *Journal of Computational and Applied Mechanics*, Vol. 7., No. 1. (2006), pp. 3-12.

[10] Perren, S.M., at al. „Cortical bone healing. The reaction of cortical bone to compression", *Acta Orthop. Scand*., 1969 (Suppl.) 125, pp.19-30.

[11] Perren, S.M. "Evolution of the internal fixation of long bone fractures. The scientific basis of biological internal fixation: choosing a balance between stability and biology", *J. Bone Joint Surg. Br.*, 2002, vol. 84 (8), pp. 1093-1110.

[12] Perren, S.M., "Physical and biological aspects of fracture healing with special reference to internal fixation", *Clin. Orthop. Rel. Res*., 1979, vol. 138, pp. 175-196.

[13] Gáspár, J., Borbás, L. and Thamm, Fr., "Experimental tests on mandible and tooth prosthesis". In *Proceedings of the XXII. DAS*, Parma, Italy, 2005. 28 Sept- 1 Oct., pp. 130...131. *Available from*: http://das.tuwien.ac.at)

[14] *** - VIC-3D 2010, *Reference Manual*, Correlated Solutions, ISI-Sys GmbH, USA, Germany, 2010.

[15] Sutton, A. M., Orteu, J. J. and Schreier, W., H., *Image Correlation for Shape, Motion and Deformation Measurements*, Springer Verlag, 2010.

[16] *** *User Manual and Service Instructions SE3 Shearography/ESPI-System*, ISI-Sys GmbH, Kassel, Germany, 2009.

[17] Száva, D., Gálfi, B., Száva, I. and Orbán, P., "Research and Academic Exploration about Optimal Attitudes of Dental Filling Materials", in *Proceedings of the 10th YSESM Symposium (Youth Symposium on Experimental Solid Mechanics)*, Chemnitz University of Technology, Germany, 25th-28th May, 2011, pp. 107-108, ISBN: 978-3-941003-34-7.