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A BIOMECHANICAL ANALYSIS OF THE WRIST UNDER TWO PHYSIOLOGICAL LOADING CONDITIONS OF GRIPPING ACTION

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SUMMARY
The main goal of this work was to achieve a three-dimensional human wrist model in order to be able to simulate and analyze how different physiological loading conditions affect the forearm and carpal bones.

INTRODUCTION
The wrist joint promotes the mechanical link between the hand and the forearm. Due to its anatomical complexity, it is one of the most critical joints on a biomechanical point of view. The wrist's skeleton structure is the combination of eight carpal bones, positioned between the two forearm bones and the five metacarpal bones of the hand. The eight carpal bones are assembled in a two row structure. In the proximal row we have the (from radial to ulnar) scaphoid, lunate, triquetrum and pisiforme. The pisiform is a sesamoid bone and plays no part in the overall load transfer [1]. The distal row comprises of the (from radial to ulnar) trapezium, trapezoid, capitate and hamate. The radiocarpal, the midcarpal and the carpometacarpal joints compose the wrist's joint**.** Its main function is to position and orient the hand in space, but also to transmit strength between the forearm and the hand. The load transmission often leads to injuries in the carpal bones and their supporting joints and ligaments.
The goal of this study was to achieved, through images of a computerized tomography (CT), a human wrist three-dimensional finite element model, capable of simulating the biomechanical behavior, using computational tools. Therefore, a model incorporating the bones, cartilages and ligaments tissues of the wrist's structure was developed. The analysis load used was representative of two physiological loading conditions of gripping action. The finite element method (FEM) was used to perform the biomechanical analysis on the forearm and carpal and bones.

METHODS
The three-dimensional finite element model of the human wrist incorporating the bones, cartilages and ligaments tissues of the wrist's structure was developed.
Regarding the bones' structure, a three-dimensional (3D) model was constructed from the images of a CT of a healthy volunteer. The CT images provide the true geometry of the bone's structure and the different bone densities, allowing to define the mechanical properties of the bones. "Simpleware Scan IP" and "Simpleware Scan FE" (Simpleware Ldt, Exeter, United Kingdom) programs were used to obtain the 3D model, to perform its discretization and assign the material properties.
In order to achieve a more realistic wrist model, a set of links were modeled to simulate the cartilage and ligament structure, regarding its insertion in the bones and their stiffness [2,3].
The analysis load used was representative of a maximum and minimum gripping action, and the forces were applied on the metacarpals [4,5]. The magnitude of the forces applied to each metacarpal is presented in Table 1.

Table 1: Magnitude of the forces applied on the metacarpals.

Metacarpals	Maximum Gripping Action (N)	Minimum Gripping Action (N)
1	255.6	21.5
2	120.3	34.3
3	106.4	42.2
4	88.0	25.9
5	77.3	18.1

The load cases applied were used to access the principal strains in the forearm and carpal and bones. "MSC Marc Mentat" (MSC. Software Corporation, Santa Ana, California) program was used to run all our simulations.

RESULTS AND DISCUSSION
The principal strains (maximum and minimum) results for the forearm and carpal bones, in the frontal and sagittal aspects, were calculated.
The minimum principal strain plots for both physiological loading conditions, minimum and maximum gripping action, in frontal aspect, can be seen in Figure 1 and Figure 2, respectively. And the maximum principal strain plots for both physiological loading conditions, can be seen in Figure 3 for the minimum gripping action and in Figure 4 for the **Erro! A origem da referência não foi encontrada.**maximum gripping action.
Regarding the minimal and maximal principal strains values, in frontal aspect, the difference observed between the minimum and maximum gripping load cases, was approximately 5000µstrain.

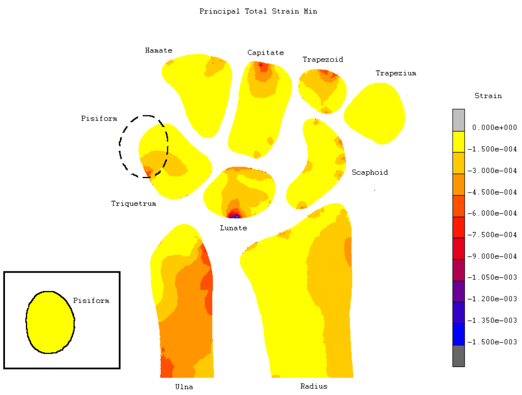

Figure 1: Minimum principal strains results for the minimum grip loading.

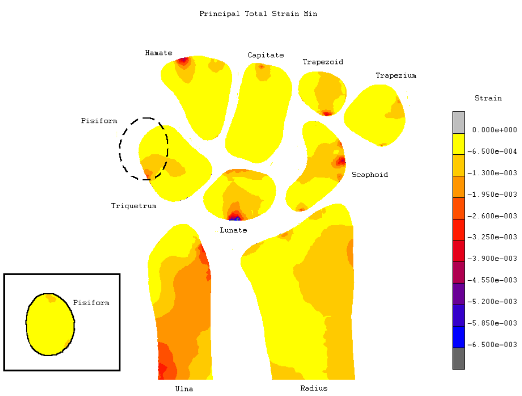

Figure 2: Minimum principal strains results for the maximum grip loading.

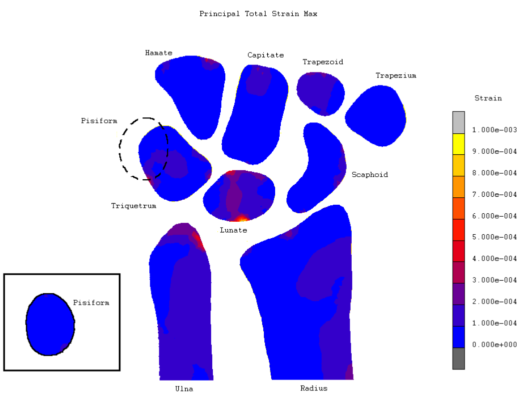

Figure 3: Maximum principal strains results for the minimum grip loading.

Concerning minimal and maximal principal strains values, in sagittal aspect, the difference observed between the minimum and maximum gripping load cases, was on average an order of magnitude higher.

In both load cases the bones most mechanically requested were, in the forearm, the ulna and, in the carpal, the lunate, the hamate and the capitate.

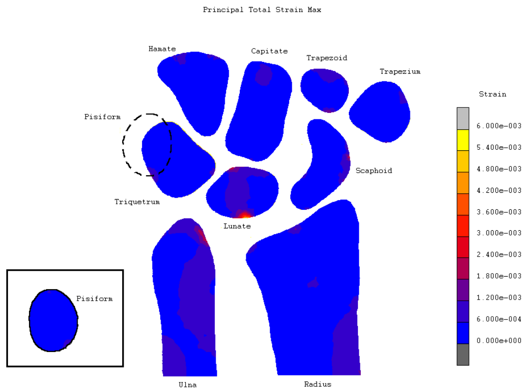

Figure 4: Maximum principal strains results for the maximum grip loading.

The ulna suffered a greater deformation in the lateral zone, the area in which it articulates with the radius.

The lunate suffered a greater deformation in the proximal zone, the area in which it articulates with the radius and the ulna.

The capitate and hamate suffered a greater deformation in the distal zone. The capitate in the area where it articulates with the metacarpal 3, and the hamate in the area that articulates with metacarpals 4 and 5.

The bone which was less mechanically requested, was the trapezio.

CONCLUSIONS

The numerical results show that the bones most mechanically requested in the carpal were the lunate, the hamate and the capitate, and the bone most mechanically requested in the forearm was the ulna.

The carpal bones suffer higher values of deformation in the joints where they interacted with the bones of the hand and forearm (carpometacarpal and radiocarpal joints, respectively), than where they interact with each other (midcarpal joint).

The forearm bone, ulna, suffers higher values of deformation in the area where it interact with the radius.

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