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ADVANCES IN METHODOLOGIES AND METRICS FOR COMPARISON OF BIOLOGICAL COMPUTATIONAL MODELS

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Finite elements analysis (FEA) allows simulating the biomechanical behaviour of biological structures, in order to understand how they react under different loads. This technique has been shown very useful in palaeontology, as it allow researchers to test their functional hypothesis. In spite of its great power, only in the best of circumstances one can compare the behaviour of models that differ in size and shape. Some of the FE models described in the literature assume the hypothesis of being 2D lying in a plane [1]–[3]. Although a planar model is not entirely reflective of the morphology of the vertebrate bone structures, it can be used as a first approximation to study its behaviour. This is due to the fact that it allows us to reduce the computational analysis time and the reconstruction process, design a strategy to deal with subsequent 3D and more detailed models [1] and reducing time in the computational analysis and in all the geometrical processes of reconstruction.

Up to date, several studies have focused on comparing models of different species and the interest in the comparative analysis is increasing with the common usage of the FEA in biomechanics. The 2D procedure is specially suitable for comparing models of different species when the number of specimens is large [4], [5] and the duty of creating and analysing the models could be highly reduced with it. The main interest of FEA comparative analysis is to model the shape of specimens in order to infer functional morphology and relating it to different adaptations (e.g. diet, swimming, etc.). In line with this, and according to Dumont and co-authors [6] “The inevitable rise of studies that compare finite element models brings to the fore two critical questions about how such comparative analyses can and should be conducted: (1) what metrics are appropriate for assessing the performance of biological structures using finite element modelling? And, (2) how can performance be compared such that the effects of size and shape are disentangled?”

With the aim of answering this question, new and challenging methodologies to use in planar models are presented, discussed and their application demonstrated. Firstly, a new method to compare planar models is discussed. It is based on the modification of the values of the forces applied by taking into account the particularities of the elasticity plane models (plane strain and plane stress equations) using a quasi-homothetic transformation [7]. The method is applied in a set of different bovine jaws where a Finite Element Analysis was developed using ANSYS FEA Package v.14.5 for Windows 7 (32-bit system) in order to obtain the stresses and deformations of the planar models to compare them.

Secondly, a new metric is presented in order to being able to compare the results obtained for distributed values in the whole model, as the equivalent Von Mises stresses, in different species using a quantitative indicator. This metric, called Equivalent Stress Centroid (for the stresses) or Equivalent Strain Centroid (for strains) is based in the calculation of a centroid value of all the Von Mises stresses obtained in the whole model and it is clearly independent of the number and topology of the elements of the generated mesh. The method is applied in a set of different jaws of the mammalian order Xenarthra where, a Finite Element Analysis was developed using ANSYS FEA Package v.14.5 for Windows 7 (32-bit system) in order to obtain the stresses and deformations of the planar models and compare them using this new metric.

The discussion of this methodologies concludes that the quasi-homothetic procedure and the centroid value are consistent in front of the changes of geometry, mesh and boundary conditions of the FEA model. And, moreover, the new approaches proposed are shown to be extremely useful when exploring the effect of the shape in front of the strength and the stiffness of vertebrate bone structures which can be modelled as two-dimensional finite element models.

REFERENCES

[1] E. J. Rayfield, "Cranial mechanics and feeding in Tyrannosaurus rex.," *Proc. Biol. Sci.*, vol. 271, no. 1547, pp. 1451–9, Jul. 2004.

[2] S. E. Pierce, K. D. Angielczyk, and E. J. Rayfield, "Patterns of morphospace occupation and mechanical performance in extant crocodilian skulls: a combined geometric morphometric and finite element modeling approach.," *J. Morphol.*, vol. 269, no. 7, pp. 840–64, Jul. 2008.

[3] T. M. Fletcher, C. M. Janis, and E. J. Rayfield, "Finite Element Analysis of Ungulate Jaws: Can mode of digestive physiology be determined?," *Palaeontol. Electron.*, vol. 13, no. 3, 2010.

[4] J. Fortuny, J. Marcé-Nogué, S. De Esteban-Trivigno, L. Gil, and À. Galobart, "Temnospondyli bite club: ecomorphological patterns of the most diverse group of early tetrapods.," *J. Evol. Biol.*, vol. 24, no. 9, pp. 2040–54, Sep. 2011.

[5] J. Fortuny, J. Marcé-Nogué, L. Gil, and À. Galobart, "Skull mechanics and the evolutionary patterns of the otic notch closure in capitosaurs (Amphibia: Temnospondyli).," *Anat. Rec. (Hoboken).*, vol. 295, no. 7, pp. 1134–46, Jul. 2012.

[6] E. R. Dumont, I. R. Grosse, and G. J. Slater, "Requirements for comparing the performance of finite element models of biological structures.," *J. Theor. Biol.*, vol. 256, no. 1, pp. 96–103, Jan. 2009.

[7] J. Marcé-Nogué, D. DeMiguel, J. Fortuny, S. De Esteban-Trivigno, and L. Gil, "Quasi-homothetic transformation for comparing the mechanical performance of planar models in biological research.," *Palaeontol. Electron.*, vol. on press, 2013.