Annales de chirurgie plastique esthétique (2017) xxx, xxx—xxx

Available online at
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com

IDEAS, INNOVATIONS

Comparison between isotropic linear-elastic law and isotropic hyperelastic law in the finite element modeling of the brachial plexus

Comparaison entre loi élastique linéaire isotrope et loi hyperélastique isotrope dans la modélisation par éléments finis du plexus brachial

A. Perruisseau-Carrier [a], N. Bahlouli [b], G. Bierry [c], P. Vernet [a], S. Facca [a], P. Liverneaux [a,*]

[a] *Department of hand surgery, SOS main, CCOM, university of Strasbourg, Icube CNRS 7357, university hospital of Strasbourg, FMTS, 10, avenue Baumann, 67403 Illkirch cedex, France*
[b] *Department of mechanics, university of Strasbourg/CNRS, ICUBE, 2, rue Boussingault, 67000 Strasbourg, France*
[c] *Guillaume Bierry, radiology department, university of Strasbourg, FMTS, 1, place de l'Hôpital, 67000 Strasbourg, France*

Received 25 January 2017; accepted 2 March 2017

KEYWORDS
Brachial plexus;
Augmented reality;
Finite element model;
Biomechanical

Summary Augmented reality could help the identification of nerve structures in brachial plexus surgery. The goal of this study was to determine which law of mechanical behavior was more adapted by comparing the results of Hooke's isotropic linear elastic law to those of Ogden's isotropic hyperelastic law, applied to a biomechanical model of the brachial plexus. A model of finite elements was created using the ABAQUS® from a 3D model of the brachial plexus acquired by segmentation and meshing of MRI images at 0°, 45° and 135° of shoulder abduction of a healthy subject. The offset between the reconstructed model and the deformed model was evaluated quantitatively by the Hausdorff distance and qualitatively by the identification of 3 anatomical landmarks. In every case the Hausdorff distance was shorter with Ogden's law compared to Hooke's law. On a qualitative aspect, the model deformed by Ogden's law followed the concavity

* Corresponding author.
E-mail address: Philippe.liverneaux@chru-strasbourg.fr (P. Liverneaux).

http://dx.doi.org/10.1016/j.anplas.2017.03.002

Please cite this article in press as: Perruisseau-Carrier A, et al. Comparison between isotropic linear-elastic law and isotropic hyperelastic law in the finite element modeling of the brachial plexus. Ann Chir Plast Esthet (2017), http://dx.doi.org/10.1016/j.anplas.2017.03.002

of the reconstructed model whereas the model deformed by Hooke's law remained convex. In conclusion, the results of this study demonstrate that the behavior of Ogden's isotropic hyperelastic mechanical model was more adapted to the modeling of the deformations of the brachial plexus.

MOTS CLÉS
Plexus brachial ;
Réalité augmentée ;
Modèle éléments-finis ;
Biomécanique

Résumé Les techniques de réalité augmentée pourraient aider au repérage des tissus nerveux dans la chirurgie du plexus brachial. L'objectif de cette étude était de déterminer la loi de comportement mécanique la plus adaptée, en comparant les résultats de la loi élastique linéaire isotrope de Hooke à ceux de la loi hyperélastique isotrope d'Ogden, appliquées à un modèle biomécanique du plexus brachial. Un modèle éléments finis été élaboré à l'aide du logiciel ABAQUS® à partir d'un modèle 3D du plexus brachial obtenu par segmentation et maillage d'images IRM à 0°, 45° et 135° d'abduction de l'épaule d'un sujet sain. Ce modèle a été déformé en utilisant les lois de Hooke et d'Ogden pour reproduire les mouvements de l'épaule. Le recalage entre modèle reconstruit et modèle déformé a été évalué quantitativement par la distance de Hausdorff et qualitativement par l'identification de 3 repères anatomiques. Dans tous les cas de figure, la distance de Hausdorff était plus petite avec la loi d'Ogden qu'avec celle de Hooke. Sur le plan qualitatif, le modèle déformé avec la loi d'Ogden suivait la concavité du modèle reconstruit alors que celui déformé avec la loi de Hooke restait convexe. En conclusion, les résultats de cette étude ont permis de montrer que la loi de comportement mécanique hyperélastique isotrope d'Ogden était la plus adaptée à la modélisation des déformations du plexus brachial.

Introduction

Image-guided surgical techniques enable to visualize anatomical structures that are usually invisible at the surface of an organ and/or a patient [1,2]. Some authors have already used augmented reality to guide surgical decisions in several procedures: hepatic metastasis [3], pancreaticoduodenectomy [4], adrenalectomy [5], lung lumpectomy [6], parathyroidectomy [7].

These techniques of augmented reality involve two steps of manufacturing, 3D modelling of the organs and a predictive deformation based on a mechanical behavior model. Among the laws of mechanical behavior, the most commonly used for real-time clinical application is Hooke's isotropic linear elastic law, because it requires little calculation time [8]. The law modeling the biomechanical behavior of nerve structures is Ogden's isotropic hyperelastic law, which requires a long calculation time [9].

During the surgical treatment of traumatic paralysis of the brachial plexus, the identification of nerve structures is sometimes difficult due to the magnitude of the surrounding sclerosis. This difficulty is not only observed in conventional, open surgical techniques [10], but also in minimally invasive surgical techniques [11,12]. Augmented reality techniques could bring a solution to this difficulty. The first step towards the construction of a biomechanical model in order to develop augmented reality for the surgery of the brachial plexus consists in the identification of the most adapted law of mechanical behavior.

The goal of this study was to determine which law of mechanical behavior was most adapted for the modelling of the deformation of the brachial plexus, by comparing the results obtained from a reconstructed model of the brachial plexus to Hooke's isotropic linear elastic law on one hand and Ogden's isotropic hyperelastic law on the other.

Material and methods

Material included a healthy subject and a 1.5-T MRI. T1-wheighted images, centered on the brachial plexus were acquired in axial, sagittal and coronal slices (Fig. 1). Images were acquired at 0°, 45° and 135° of shoulder abduction.

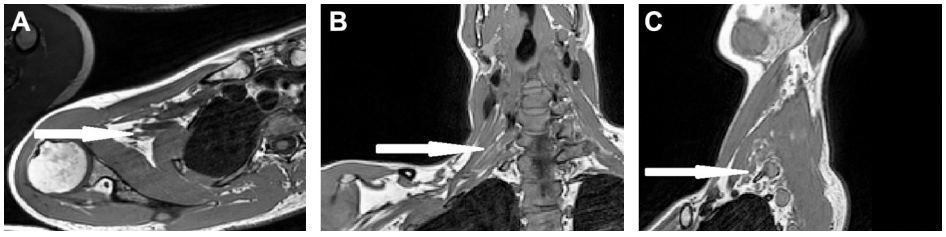

Figure 1 T1-weighted MRI images centered on the right brachial plexus (arrow) of a healthy human subject at 0° of shoulder. A. Axial slice. B. Coronal slice. C. Sagittal slice.

Please cite this article in press as: Perruisseau-Carrier A, et al. Comparison between isotropic linear-elastic law and isotropic hyperelastic law in the finite element modeling of the brachial plexus. Ann Chir Plast Esthet (2017), http://dx.doi.org/10.1016/j.anplas.2017.03.002