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Intra-operative quantification of the surgical gesture in orbital surgery: Application to the proptosis reduction

V. Luboz [a], P. Swider [b,*], D. Ambard [b], F. Boutault [b,c], Y. Payan [a]

[a] *TIMC-IMAG Laboratory, UMR CNRS 5525, Faculté de Médecine, 38706 La Tronche, France*
[b] *Biomechanics Laboratory EA 3697/IFR30, Purpan University Hospital, 31059 Toulouse cedex, France*
[c] *Maxillofacial Surgery Department, Purpan University Hospital, 31059 Toulouse, France*

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Abstract

Background. Proptosis is characterized by a protrusion of the eyeball due to an increase of the orbital tissue volume. To recover a normal eyeball positioning, the most frequent surgical technique consists in the osteotomy of orbital walls combined with a loading on the eyeball to initiate tissue decompression. The first biomechanical models dealing with proptosis reduction, validated in one patient, have been previously proposed by the authors.

Methods. This paper proposed an experimental method to quantify the intra-operative clinical gesture in proptosis reduction, and the pilot study concerned one clinical case. The eyeball's backward displacement was measured by an optical 3D localizer and the load applied by the surgeon was simultaneously measured by a custom-made force gauge. Quasi-static stiffness of the intra-orbital content was evaluated.

Findings. The average values for the whole experiment was 16 N (SD: 3 N) for the force exerted by the surgeon and 9 mm (SD: 4 mm) for the eyeball backward displacement. The averaged quasi-static stiffness of the orbital content was evaluated to 2.4 N/mm (SD: 1.2) and showed a global decrease of 45% post-operatively.

Interpretation. The protocol and the associated custom-designed devices allowed loads, induced displacements and macroscopic stiffness of the orbital content to be measured intra-operatively. The clinical relevance has been demonstrated in a pilot study. To our knowledge, no study has been published allowing the clinical gesture in proptosis reduction to be quantified intra-operatively.

Associating an enlarged database and validated patient-related predictive models will reinforce the surgical efficiency and patient comfort contributing to diagnosis and intra-operative guidance.

Keywords: Orbital surgery; Proptosis; Experimental method; Computer assisted planning

1. Introduction

Computer assisted surgery (CAS) aims at assisting surgeons to improve diagnosis, therapeutic gestures and follow-up implementing rational and quantitative approaches (Taylor et al., 1996). The ultimate goal is to increase safety and accuracy leading to a minimally invasive surgery for patient comfort. In this strategy, numerical models can assist surgical planning and techniques provided they are validated (Payan, 2005). Implementing patient-related models seemed to be a relevant strategy but a lack of knowledge in physiological boundary conditions and loads, and tissue material properties still drastically limit the reliability of predictive models (Viceconti et al., 2005).

Recent years showed the increase of studies dealing with the *in vitro* or *in vivo* tissue biomechanical characterization (Miller et al., 2000; Ottensmeyer et al., 2004; Gerard et al., 2005; Hendriks et al., 2006). Very recent studies concerned intra-operative measurement procedures (Jenkinson et al., 2005; Gosling et al., 2006), and this endeavoured to answer

* Corresponding author.
E-mail address: swider@cict.fr (P. Swider).

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the need to better identify and quantify the clinical gesture. The clinical relevance of our approach has fallen in this framework relating to maxillofacial pathologies and more particularly proptosis reduction.

Proptosis is characterized by the increase of the volume of the orbital content mostly due to an endocrinal dysfunction (Saraux et al., 1987). The protrusion of the eyeball induces aesthetical problems and physiological disorders such as abnormal cornea exposition and pathological loading of the optic nerve, orbital blood vessels and ocular muscles. It may induce the alteration of visual acuity up to blindness. Once the endocrinal situation is stabilized, a surgical reduction of the proptosis is usually needed to decompress the orbital content. The commonly used technique is the "bone removal orbital decompression (BROD)" (Adenis and Robert, 1994). It aims at increasing the volume of the orbital cavity with an osteotomy (*i.e.* a bone resection) of the orbital walls (Stanley et al., 1989). The soft tissues are partially evacuated through the osteotomy to form a hernia and the surgeon may manually apply a controlled load on the eyeball to favour the decompression process (see Fig. 1c). Limited cuts in the outer membrane containing the orbital soft tissues allow the physiological liquid to flow towards the maxillary and ethmoid sinus regions. The backward displacement of the eyeball to recover the normal position is initiated and it is fully reached after the complete reduction of orbital tissue inflammation.

This intervention is technically difficult because of the proximity of ocular muscles and the optic nerve, the tightness of the eyelid incision, and the narrowness of the operating field. The surgery must be minimally invasive and having specific tools to improve surgical planning could be very helpful. The authors proposed predictive models leading to clinical rules to assist in the pre-operative planning (Luboz et al., 2004, 2005). Correlations established between predicted results and pre- and post-operative clinical imaging allowed the reliability of the approach to be quantified in terms of geometry, volume, and kinematics.

The missing dimension was the dynamic aspect involving interrelated force and kinematics measures and such was the framework of the presented study where the goal was to investigate the clinical gesture intra-operatively. We hypothesized that measuring simultaneously, the load applied by the surgeon and the resulting kinematics of the eyeball could provide patient-related quantitative data to enrich the clinical knowledge in proptosis reduction. To

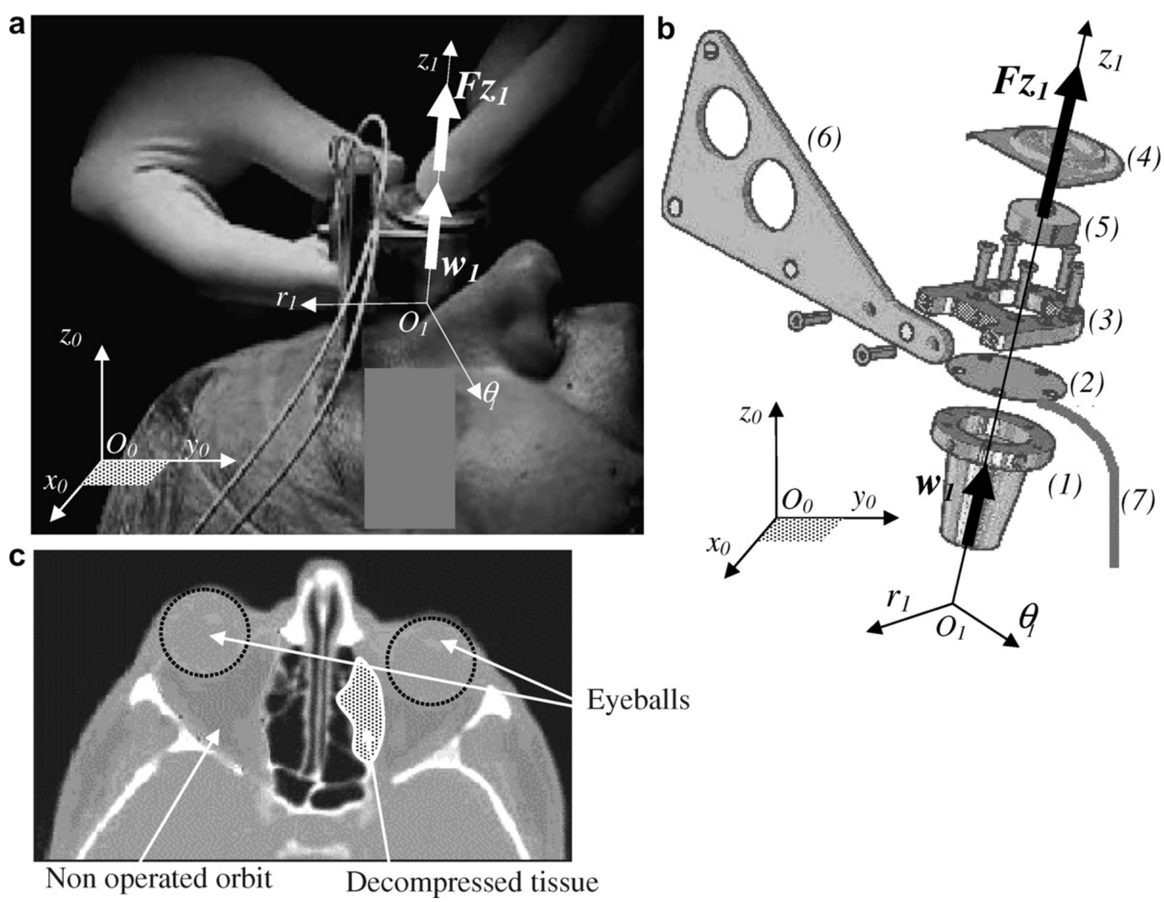

Fig. 1. Clinical procedure and experimental device: (a) intra-operative positioning; (b) technological scheme: (1) aluminum conic base, (2) stainless membrane involving strain gages, (3) stainless ring, (4) stainless shell, (5) silicon cylinder, (6) polymer rigid body for navigation, (7) wires; (c) CT scan of the proptosis and image segmentation.