A Continuous Biomedical Model to Study Facial Gestures in Speech: Muscle Coordinations and Mechanical Properties

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INTRODUCTION

Many biomechanical models of the human face have been proposed in the literature, mainly developed in the context of computer graphics animation (Sifakis *et al.*, 2006; Gladilin *et al.*, 2001), computer-aided maxillofacial surgery (Chabanas *et al.*, 2003) or speech production (Lucero & Munhall, 1999; Piterman & Munhall, 2001; Gomi *et al*., 2006). Most of them propose to model the face with a volumetric mesh defined by an external (the "visible" part of the face) and an internal surface (the part in contact with the skull), with some point/nodes or layers in between. Mechanics of the tissues (epidermis, dermis, hypodermis, fat and muscles) is then modelled through the relationship between displacements and forces acting on mass points (mass-spring models) or between strains and stresses in the case of finite element models. When using these models to generate movements, two main problems are faced to simulate muscular contractions: (1) how to model muscles fibres and transmit forces or stresses on the 3D mesh; (2) how to coordinate face muscles in order to produce realistic mimics or speech gestures.

This paper aims at contributing to these two issues by presenting a realistic continuous face model in which muscles are implemented as force generating cables between specific anatomical key-points, by studying the impact of some muscles on lip shaping and by testing to which extent tissues stiffening can affect this impact.

METHOD

A 3D Finite Element model of the face soft tissues was built (with ANSYS^{TM} v11 software) out of CT scan of a single subject. It is based on an original model proposed by Chabanas *et al.* (2003) for computer-aided facial surgery. It relies on a volumetric mesh composed of three layers of full and degenerated hexahedral elements. The displacements of some nodes located on the internal surface of the facial mesh are constrained in order to represent attachments of the facial tissues on the skull. In order to ensure an anatomical and physical reliability, muscles courses and insertions are directly defined from medical images and anatomical charts, with the help of a maxillofacial surgeon.

Each muscle is represented by a small set of fibres discretized by piece-wise uniaxial tension cable elements. This model of muscle is independent from the mesh itself. Therefore, further refining or changes of the mesh geometry can be done without necessitating a redefinition of the muscle implementations. The cable elements are controlled in tension by their cross section area, their initial strain and an activation parameter. Muscular fibres tips are linked with the facets of the surrounding mesh elements, to which muscle forces are transferred thanks to the notion of dependencies. When a muscle is activated, the corresponding cable elements tense and pull the mesh elements, causing soft tissue deformations. Contacts between lips and teeth and between upper and lower lip are also taken into account in the model. Teeth are materialized by spline surfaces extracted form the CT data. ANSYS contact elements, which provide collision detection and sliding reaction, are then used to mesh lips and teeth surfaces.

Since biological soft tissues are known to behave non-linearly (Gerard *et al.*, 2005), a simplified 5-parameter Mooney-Rivlin hyperelastic model has been used for the material property. This law varies with muscle activation in such a way that stiffness (determined by the Young Modulus) increases with activation.

RESULTS

Individual influences of the Zygomaticus, Levator Labii Superioris, Orbicularis Oris Peripheralis, and Mentalis on lip shape are assessed. These results well comply with the anatomical predictions in the related literature (Stranding, 2005).

Zygomaticus draws the angle of the mouth upwards and laterally. Levator Labii Superioris elevates the upper lip. Mentalis raises the lower lip, wrinkling the skin of the chin. When Orbicularis Oris Peripheralis (OOP) is activated, it generates at the same time rounding and protrusion. The co-activation of OOP and mentalis increases the amplitude of the lower lip protrusion.

The impact of OOP in our model differs from Gomi *et al.*'s (2006) findings. Indeed, based on simulations carried out with another biomechanical model of the lips, these authors suggested that OOP could generate protrusion but not rounding. A potential explanation of this discrepancy could lie in the different accounts of the elastic properties of activated muscle tissues, which were given by both models. Indeed, in our model, if muscle stiffening associated with muscle activation is disabled, OOP generates mainly protrusion and no rounding. Hence, accounting properly for muscle stiffening seems to be a significant achievement to understand the control of lip shaping.

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