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ORIGINAL ARTICLE

Three-dimensional appearance of the lips muscles with three-dimensional isotropic MRI: in vivo study

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Abstract
Introduction Our knowledge of facial muscles is based primarily on atlases and cadaveric studies. This study describes a non-invasive in vivo method (3D MRI) for segmenting and reconstructing facial muscles in a three-dimensional fashion.
Methods Three-dimensional (3D), T1-weighted, 3 Tesla, isotropic MRI was applied to a subject. One observer performed semi-automatic segmentation using the Editor module from the 3D Slicer software (Harvard Medical School, Boston, MA, USA), version 3.2.
Results We were able to successfully outline and three-dimensionally reconstruct the following facial muscles: *pars labialis orbicularis oris, m. levatro labii superioris alaeque nasi, m. levator labii superioris, m. zygomaticus major and minor, m. depressor anguli oris, m. depressor labii inferioris, m. mentalis, m. buccinator, and m. orbicularis oculi.*
Conclusions 3D reconstruction of the lip muscles should be taken into consideration in order to improve the accuracy and individualization of existing 3D facial soft tissue models. More studies are needed to further develop efficient methods for segmentation in this field.

Keywords Three-dimensional · Facial muscles · Lips · 3D MRI · Three-dimensional reconstruction · Segmentation

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Introduction

The majority of existing three-dimensional (3D) soft tissue models of the human face and lips [1–6] regard the space between the bone and skin as homogeneous. However, this space contains different structures such as adipose tissues, muscle fibers, vessels, nerves, and glandular structures. Each of these structures has a different coefficient of elasticity and is, present in various shapes and sizes. The oversimplification of the soft tissue model means that such models can be used for visualization or animation but they are not as useful in clinical setting. It is imperative that we develop segmentation and reconstruction strategies for the various components that comprise the face in order to increase the accuracy and individualization of 3D soft tissue models of the face. We present a feasibility study for the segmentation and 3D visualization of the lip muscles from patient data acquired with a 3D isotropic T1-weighted MRI.

Methods

We used 3D MRI data derived from the 3D atlas study of the soft tissues of the orbits. The study was approved by the local ethics committee (B40320084307) and, was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki. The subject gave his informed consent prior

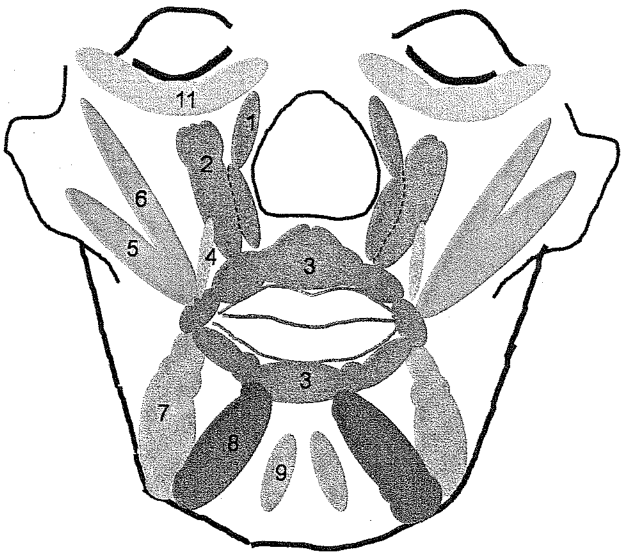

Fig. 1 Normal distribution of facial muscles activating the lips: m. levator labii superioris alaeque nasi superficial (*1*), m. levator labii superioris (*2*), m. pars labialis orbicularis oris (*3*), m. levator anguli oris (*4*), m. zygomaticus major (*5*), m. zygomaticus minor (*6*), m. depresssor anguli oris (*7*), m.depressor labii inferioris (*8*), m. mentalis (*9*), m. orbicularis oculi (*11*)

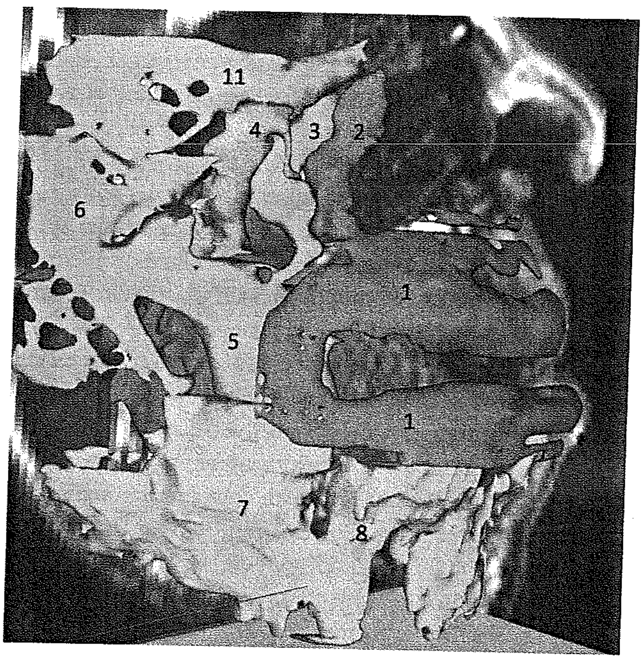

Fig. 2 Right profile view; m. pars labialis orbicularis oris (*1*), m. levator labii superioris alaeque nasi superficial (*2*), m. levator labii superioris (*3*), m. levator anguli oris, (*4*), m. zygomaticus minor (*5*) and major (*6*), m. depressor anguli oris (*7*), m. depressor labii inferioris (*8*), m. orbicularis oculi (*11*)

to inclusion in the study. The identifying information of the subject under study was omitted.

The MRI protocol parameters were T1-weighted, 3 Tesla, and isotropic voxels (1mm × 1mm × 1mm), with an acquisition time of 7 min. The patient was asked to concentrate on

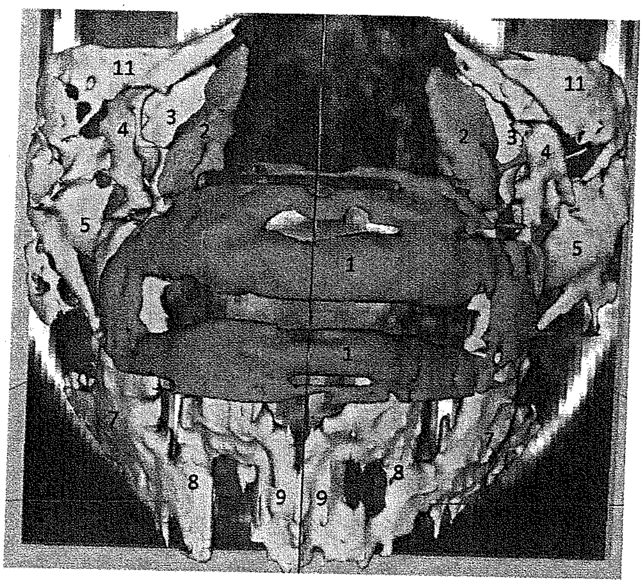

Fig. 3 Anteroposterior view

closing his eyes during data acquisition. We used the Editor module of the 3D Slicer open-source software (Harvard Medical School, Boston, MA, USA) [7–10] for semi-automatic segmentation of the lip muscles. One observer performed the segmentation with the 3D Slicer software. The 3D visualization was automatically obtained within the 3D Slicer software.

Results

The normal distribution of the lip muscles is presented in Fig. 1. The muscles of the lip can be divided into two classes, the muscles of dilatation and the muscles of constriction. The constriction muscle of the mouth is the *Pars labialis orbicularis oris.* The dilatation muscles of the mouth are distributed into two layers: superficial and deep. The superficial layer contains seven muscles: *m. levator labii superioris alaeque nasi, m. levator labii superioris, m. zygomaticus minor and major, m. risorius, m. depresssor anguli oris, and m. platysma,* while the deep layer contains four muscles: *m. levator anguli oris, m. buccinator, m. depressor labii inferioris,* and *m. mentalis.*

The muscles we successfully segmented and 3D reconstructed were:

1. m. pars labialis orbicularis oris (Figs. 2, 3, 4, 5)
2. m. levator labii superioris alaeque nasi (Figs. 2, 3, 4, 5)
3. m. levator labii superioris (Figs. 2, 3, 4, 5)
4. m. levator anguli oris (Figs. 2, 3, 4)
5. m. zygomaticus major (Figs. 2, 3, 4, 5)
6. m. zygomaticus minor (Figs. 2, 3, 4, 5)

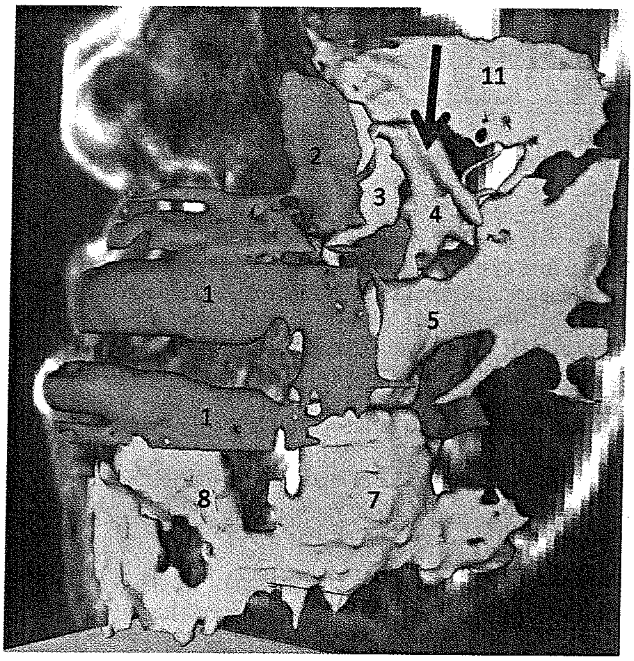

Fig. 4 Left profile view. The *arrow* shows the 3D reconstruction of the left facial artery

7. m. depresssor anguli oris (Figs. 2, 3, 4, 5)
8. m. depressor labii inferioris (Figs. 2, 3, 4, 5)
9. m. mentalis (Figs. 2, 3, 4, 5)
10. m. buccinator (Fig. 5)
11. m. orbicularis oculi (Figs. 2, 3, 4, 5).

Additionally, we found m. zygomaticus major to be bifid [11] on both sides. We also segmented the inferior part of the m. orbicularis oculi. We were unable to locate m. risorius, a muscle that may be unconstant. We did not segment or reconstruct m. platysma to allow better visualization of other lip muscles.

Discussion

Facial soft tissue models were developed in order to aid in facial reconstruction in forensic medicine [2], postoperative prediction in maxillofacial surgery [4–6], and the animation of faces of virtual humans (animated speech) [3]. Facial soft tissue models tend to characterize the space between skin and skull as being homogenous [2–6]. Although, some models do include representations of the facial muscle [1], the representation of these muscles is often derived either from visual anatomical depictions of facial muscles [1] or from the visible human project (dead body) [12]. Furthermore, cadaveric studies show great variability in midfacial muscles [13]. To address this important question of variability, we developed a method that incorporated the individual's

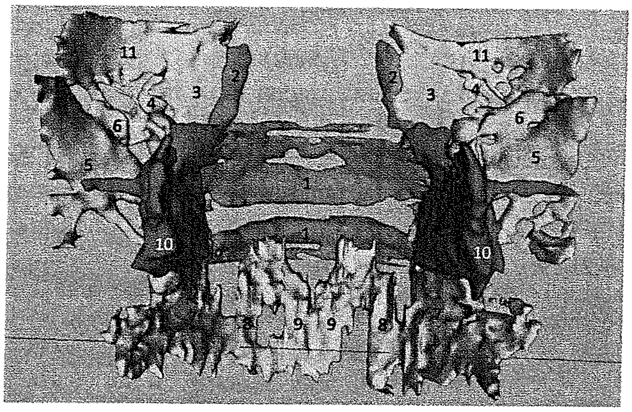

Fig. 5 Posteroanterior view of the lips muscles and *m. buccinator* (*10*)

facial muscle information into the model, instead of using a generic 3D representation of the facial muscles derived from anatomical atlases. Moreover, only an in vivo methodology allows for diagnosis and treatment planning in such conditions as facial nerve palsy with concomitant atrophy of midfacial muscles. Mapping in vivo atrophied muscles in order to reinnervate them with nerve grafts [14] could be of great help in restoring human facial expressions in patients who suffer from such palsies [15].

We encountered problems in the separation between m. levator labii superioris alaeque nasi and m. levator labii superioris on two-dimensional slices (axial, sagittal or transverse). Only the 3D reconstruction allows us to finally distinguish the layers (Figs. 4, 5). Also, we found it difficult to distinguish between the muscles at the level of the modiolus. The modiolus is the junction between the muscles pars labialis orbicularis oris, m. levator anguli oris, m. risorius, and m. zygomaticus minor and major. The definition of the inferior limit of the m. buccinator in relation to the m. depressor labii inferioris was arbitrary. We also had difficulty distinguishing m. zygomaticus minor and major. However, 3D reconstruction helped us to understand the overarching structure and distribution of these muscles. The facial artery (left) was embedded in the muscles at the anterior portion of m. levator labii superioris alaeque nasi and m. levator anguli oris (Fig. 4, arrow).

Principal limitations of semi-automatic segmentation with the 3D Slicer from isotropic T1-weighted 3D 3T MRI were the need for specific anatomical knowledge, and the fact that it is a time-consuming procedure. It was also impossible to use a threshold pixel value with the MRI imaging to automatically and quickly underline the lip and facial muscles.

In conclusion, this article increases our understanding of how to combine human variability and generic models in the field of midfacial muscle anatomy. We were able to identify, segment and 3D reconstruct almost all muscles associated with the lips from an individual in vivo 3 Tesla 3D, T1-weighted, isotropic MRI coupled with the 3D Slicer open-source software. Our technique could especially contribute to diagnosis in patients with facial nerve palsy with subsequent treatment planning to restore facial expressions. Further developments in order to find faster segmentation methods for the lip and face muscles.

Conflict of interest statement We have no conflict of interest for this study. We have full control of all primary data and we agree to allow the journal to review our data if requested.

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