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Abstract

This study aimed to describe longitudinal palatal shape changes in post-stroke patients when compared to a sample of healthy subjects through linear measurements and geometric morphometrics. The 3D palatal scanned models of seven stroke patients having a 1-year post-stroke follow-up were matched with seven control subjects of the same age group (range 50-87 years). Intercanine, intermolar distances and palatal height were measured. 3D images were also analysed through geometric morphometrics to assess changes in the shape of the palate from T0 to T1 (1 year after the stroke). Principal component analysis was used to describe shape morphology changes, and visual colour maps were used to qualitatively assess differences between T0 and T1. No changes were detected nor in linear measures neither in palatal shape in healthy subjects from T0 to T1. The palates of stroke patients showed no linear differences either. However, when visualising shape changes through colour maps, the lateral aspects of the palatal vault were slightly narrower in T1, with respect to T0 in stroke patients. This may be attributed to altered tongue [...]
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SUMMARY This study aimed to describe longitudinal palatal shape changes in post-stroke patients when compared to a sample of healthy subjects through linear measurements and geometric morphometrics. The 3D palatal scanned models of seven stroke patients having a 1-year post-stroke follow-up were matched with seven control subjects of the same age group (range 50–87 years). Intercanine, intermolar distances and palatal height were measured. 3D images were also analysed through geometric morphometrics to assess changes in the shape of the palate from T0 to T1 (1 year after the stroke). Principal component analysis was used to describe shape morphology changes, and visual colour maps were used to qualitatively assess differences between T0 and T1. No changes were detected nor in linear measures neither in palatal shape in healthy subjects from T0 to T1. The palates of stroke patients showed no linear differences either. However, when visualising shape changes through colour maps, the lateral aspects of the palatal vault were slightly narrower in T1, with respect to T0 in stroke patients. This may be attributed to altered tongue function following the stroke.

KEYWORDS: adult, neurosensory functioning, stroke, biometric analysis, palate, longitudinal

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Introduction

Oral-health-related quality of life is well impaired in hospitalised stroke patients due to disease-related psychosocial limitations, but also oro-facial functional impairment (1). When comparing the masticatory function of perioral muscles of normal subjects and stroke patients, the latter showed no difference regarding bite forces, at the level of the masseters, but they registered lower lip forces (2, 3). From an intra-oral perspective, the altered tongue movements seem to play a major role in dysphagia, which is a very common symptom in stroke patients (4, 5). In particular, tongue pressure against the hard palate during swallowing is altered, and this has a consequence in propulsion of the bolus into the pharynx (6–8). The swallowing function of tongue in patients with (4, 5) and without stroke (9, 10) was evaluated using a T-shaped sensor sheet adhering to the hard palate. Konaka et al. found characteristic (diminished) tongue pressure patterns and the disappearance of the normal pattern of tongue movements during oro-pharyngeal swallowing in stroke patients with dysphagia (4). Hori et al. reported a decrease in maximal tongue pressure in post-stroke patients when compared to healthy subjects (11). It is well documented that tongue position and its pressure against the hard palate may have an important role in modelling the shape of the palate in growing patients (12, 13) and in healthy (14) or syndromic adults (15). Concerning healthy young adults, Cheng et al. reported on a correlation between the magnitude of tongue movement and the palatal depth and dental arch length, but not the palatal width (14). Hashimoto et al. studied influence of tongue pressure on palatal morphology in adults with Down syndrome by means of two-dimensional (2D)
linear measurements describing palatal height, width and depth (15). Hypotonicity and difficulty in motor control of the tongue were found to be associated with a reduced palatal sagittal length and vertical depth in patients with Down syndrome when compared to controls, together with an increased palatal slope in the coronal section.

Although lingual function could be associated with palatal morphology (16), so far no study examined possible changes in the palatal morphology after functional oro-facial aberration as it may occur in stroke and post-stroke patients. The possibility of digitising three-dimensional (3D) digital models from plaster casts allows not only evaluating standard 2D linear measures in predetermined zone of the palate, but extends the evaluation of the palatal morphology to the whole of its shape.

This study aimed to describe longitudinal palatal morphology changes in post-stroke patients when compared to a sample of healthy individuals, through linear distances and geometric morphometrics (3D analysis).

Materials and methods

Study participants

Stroke patients were recruited from the Division of Neurorehabilitation of the Department of Clinical Neurosciences of the University Hospitals of Geneva, Switzerland.

Inclusion criteria were the following: hospitalisation for ischaemic or haemorrhagic stroke, presence of a hemi-syndrome with facial palsy, no infectious disease. Extensive description of the patient cohort was described in Schimmel et al. (3). Exclusion criteria were the following: imperfection of the plaster cast of the upper palate either at baseline (T0) or at the 1-year follow-up (T1); absence of at least one canine or first molar; presence of partial or full removable dentures with a palatal coverage.

Thirty-one patients were selected according to inclusion criteria, but only seven were chosen after applying exclusion criteria (mean age 63 years, range 50–87 years). Seven control subjects (mean age 63 years, range 53–75 years) were recruited as volunteers among the dental school staff.

Approval of the Ethics Committee of the University Hospitals of Geneva was obtained, and all participants gave written, informed consent (2, 3).

Methods

Alginate impression of the upper arch was taken at both baseline and at the 1-year follow-up. Plaster casts were digitised by means of a 3D scanner* and stored in a.stl format.

Linear measures were recorded through a special software†. Palatal width was evaluated through intercanine and intermolar distances. They were measured both from an occlusal perspective (canine tip to contralateral tip and mesio-vestibular first molar cusp to contralateral cusp, respectively). Palatal height was also measured as the perpendicular distance of the most high point of the palatal vault from the occlusal plane (15).

To study the shape of the palate, three-dimensional geometric morphometrics (GMM) was applied (17, 18). GMM allow studying the entirety of a shape through definition of a template composed of digitised landmarks and semilandmarks (19, 20). The use of GMM allows understanding the changes in shape not only in preselected areas (i.e. molars and canine transverse distance, palatal height, palatal depth) but also in virtually any point of the surface where a landmark or semilandmark is positioned, thus allowing for a more comprehensive understanding of changes in shape.

A template for data set/collection of homologous landmarks describing a palate was created with Viewbox‡ and used to digitise each upper maxillary digital casts of both patients and control at T0 and T1. Three boundary lines were defined for each palate: a midline passing on the raphe medius, a U-shaped line defining the lower boundary, passing apical to the gingival sulci of each tooth and a posterior boundary, perpendicular to the plane defined by the previous line and passing from distal to the first molars. The extremes of the lines were digitised and 15 semilandmarks were used to define the curvature of each line along the surface. Semilandmarks were automatically placed at equal distances along the lines and, subsequently, on the palatal surface delimited by the described line. A total of 240 landmarks and semilandmarks were registered for each palate (Fig. 1).

*Ortho Insight 3D; Motion View Software LLC, Chattanooga, TN, USA.
†VAM, Vectra; Canfield Scientific, Fairfield, NJ, USA.
‡dHAL software, Kifissia, Greece.
The average of all the data set was calculated, and used as a fixed reference to allow all sliding landmarks of each palate to slide on the surface and become more and more homologous from subject to subject. The procedure was repeated three times to minimise the difference in semilandmark distribution between each subject and the average palatal template.

The average palatal template of patients and of controls was then calculated for T0 and T1. With a warping procedure (21, 22), an ideal surface of palate (originally associated with the palatal template) was adapted to each average data set and exported as an.stl file. The average warped palatal shape of patients at T0 and T1 was superimposed with a best fit method on the whole surface through the VAM software. This procedure allows matching all parts of the surface which were not subject to change and allowed highlighting potential changes between T0 and T1. The mismatch between the average palate at the shape at T0 and T1 was depicted with a colour map tool built in the software. The template of the average palate of patients at T0 and T1 and controls at T0 and T1 was compared for didactic purposes as they make it easy to visualise and quantify area of changes. The zone of changes is detected and statistically analysed through principal component analysis (PCA, refer to next subsection).

Statistics

Mann–Whitney U-test was applied for testing the differences between groups of linear measurements. Descriptive statistics was also calculated. The StatPlus statistical software was used[9].

Results

Results of linear measurements are reported in Table 1. Comparison of linear measures between patients and controls using Mann–Whitney U-test gave no statistically significant differences between the changes that occurred during this 1-year period.

Analysing the initial forms of the palatal shape calculating Procrustes distance between group means, patients at T0 and controls at T0 showed no significant difference \( P = 0.58 \), hence confirming the validity of the control group. No significant differences were found between patients at T1 and patients at T0 \( P = 0.84 \) and between controls at T1 and T0 \( P = 0.96 \).

When studying patients at T0 and T1 to determine the main source of variability of the shape between the two time points through principal component analysis (PCA), it appeared that the main source of variability (PCA1, 39% of total differences) consists of vertical changes in the superior area of the palatal vault, coupled with transversal bucco-lingual changes in the lateral side of the palatal vault (Fig. 2). PCA2 (explaining 24% of total differences) consists of sagittal postero-anterior changes in the median zone of the palatal vault.
While analysing patients and control together, we shared data as clusters (group of subjects with similar characteristics) of patients at T0 and T1 and controls at T0 and T1. Considering PCA1 (24% of total variability) and PCA2 (20%) as main axes on a visual representation of the distribution of data, it was evident that only negligible differences were present between controls at T0 and T1, while a slight difference between patients at T0 and T1 was present and it may be attributed mainly to PCA2 (Fig. 3).

A colour map showing the distances between the average palate of patients at T1 and patients at T0 allowed visualising the zones of the palate that presented minor morphological changes (±0.5 mm). The T1 palates of patients were slightly narrower in the lateral aspects of the palatal vault (Fig. 4). The T1 palates of controls were almost identical to their T0 palatal shape (Fig. 5).

**Discussion**

Analysis with traditional linear distances gave no differences between both patients and controls, when comparing T1 and T0. While looking at the palate in a comprehensive way with GMM tools and applying PCA, there were also no statistically significant differences in shape between the palates at T0 and the palates at T1 of both patients and controls. Interestingly, qualitative visual analysis through superimposition and colour maps of the average palates of patients at T1 and T0 (Fig. 4) allows noticing some zones of changes (±0.5 mm) which may be compatible with an altered pattern of tongue pressure as described by Hori et al. (11). These authors found a decrease in the magnitude of tongue pressure at the posterior–lateral part of the palate, especially on the paralysed side (5, 11). As all patients experienced a lowering of the tongue position as a consequence of their medical conditions, the authors propose a

**Table 1.** Descriptive statistics (measures in mm) of T1–T0 changes in intermolar distance (6 + 6), intercanine distance (3 + 3) and palatal height (Pal hgt) for both patients and controls. The Mann–Whitney U-test was applied and P was set at 0.05

<table>
<thead>
<tr>
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<th>ΔT1–T0 patients</th>
<th>ΔT1–T0 controls (C)</th>
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<td></td>
<td>Average</td>
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<td>6-6 V</td>
<td>−0.19</td>
<td>0.87</td>
<td>−0.11</td>
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<td>3-3 V</td>
<td>0.20</td>
<td>0.45</td>
<td>−0.07</td>
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<tr>
<td>Pal hgt</td>
<td>−1.05</td>
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<td>−0.15</td>
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Fig. 2. The main overall source of variability between patients at T0 and T1 (through principal component analysis – PCA1. 39% of total differences) consists of vertical changes in the superior area of the palatal vault, coupled with transversal bucco-lingual changes in the lateral side of the palatal vault. Red and blue lines represent opposite trend of shape morphology.

Fig. 3. Graphical representation of PCA. The dots represent: in red patients at T0, in green patients at T1, in dark blue controls at T0, in light blue controls at T1. The cross is the standard deviation. On the x-axis PCA2, on the y-axis PCA1. Virtually no difference is seen in subjects at T0 and T1, while a difference (not statistically significant) exists in patients when comparing T0 and T1.
possible effect of the altered tongue position and function, as described in the literature (4, 5), on the shape of the palate. The minor changes in shape were detected in the incline of the lateral side of the palatal vault over the 1-year observation period. No change in palatal shape was evinced in control subjects (Fig. 5) analysed over the same time span. The possibility of studying the whole surface of the palatal vault through geometric morphometrics tools allowed to identify these zones of minor changes that would not be normally measured with any standard linear measurements.

Limitations due to the patient sample characteristics allowed including only a very limited number of patients. The presence of full or partial dentures as an exclusion criteria further limited the number of available participants and controls. Even if the power of the study could not be calculated, according to Cardini and Elton, data on mean size and variance of the shape may be fairly accurate even in relatively small samples when applying geometric morphometrics (23). While the limited number of study participants allows only to very careful interpretation, the tendency to a narrowing of the lateral sides of the palatal vault is still intriguing and may intuitively be correlated to the altered tongue function. This trend is interesting; as far as in adults, the effect of the functional aberration is expected to be minor, with respect to growing individuals. In children, an altered function may lead to an altered shape. In an adult, with a lower bone turnover and an absent sutural growth, altered function may still have an influence on the transverse dimension of the palate.

Conclusions
No statistically significant longitudinal palatal shape changes were detected in post-stroke patients when
compared to a sample of healthy subjects nor with linear measurements neither through geometric morphometrics (3D analysis). However, in stroke patients taking into account that the small sample size allows only careful interpretation, minor changes were detected in the incline of the lateral side of the palatal vault over the 1-year observation period, which may be a consequence of an altered tongue function following stroke.

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Disclosure

The authors report no conflict of interest.

References


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