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Changes in face topography from supine-to-upright position—And soft tissue correction values for craniofacial identification☆

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ABSTRACT

Soft tissues of the human face hang from the skull under the downward vector of gravity. Subsequently, the fall of the tissues is not likely the same between supine, prone or upright positions with ramifications for soft tissue measurements such as average soft tissue thicknesses used in craniofacial identification. Here we use high-resolution Dimensional Imaging® DI3D stereo-photographs (Glasgow, Scotland) to map the shape change between upright and supine position in the same 62 participants and encode the surface shell differences as greyscale pixel intensity values. Statistical tests were conducted using MANOVA at 31 craniometric landmarks, with posture as the independent factor in a repeated measures design, and sex, somatotype and age (two groups of <50 and >50 years) as independent factors in a between subjects design. Results indicate that facial morphology changed in characteristic fashion between the positions: when supine, the soft tissue extruded inferior and lateral to the eyes (Δ_{min} = +1.2 mm; Δ_{max} = +3.0 mm, $p < 0.05$) and retracted lateral to the mouth and around the nasolabial fold (Δ_{min} = −1.0 mm; Δ_{max} = −2.4 mm, $p < 0.05$). These patterns were more marked in older subjects (posture = $p < 0.01$, $\eta^2 = 0.55$; and age = $p < 0.01$; $\eta^2 = 0.29$). By calculating mean heat maps for the faces, this study clearly demonstrates that posture influences the cheeks/eyes as well as the nasolabial fold, thereby holding broader ramifications for face morphology than previously reported. Since many prior facial soft tissue thickness studies report data for supine subjects, correction factors are provided for converting supine facial soft tissue thickness data to upright estimates. Out-of-sample performance tests of posture-corrected supine means derived from two CT samples (using upright B-mode ultrasound data from living subjects as ground truths) confirmed the utility of the correction factors for landmarks that fall in zones affected most by the posture change (lower standard errors after correction). The standard error improvements were −0.9, −0.6, −0.5, and −1.4 mm respectively for the mio-mio′, go-go′, zy-zy′ and mr-mr′ landmarks (reductions indicated by the negative sign).

1. Introduction

Although tethered to the skull, human facial soft tissues are in part mobile structures, hanging from their bony scaffold under the earth's downward vector of gravity. This generally imposes a constant state of deformation on the facial soft tissues when standing or sitting upright. With movement from one posture to another (e.g., prone/supine/upright) the soft tissues are subject to changing stresses and strains with different orientations relative to gravity that result in subtle changes of face shape [1,2] (Fig. 1).

Patterns of facial contour change with posture carry importance for disciplines concerned with facial soft tissue form, such as craniofacial identification [2] and surgery [1], because measurement in one position (e.g., supine) may not be directly applicable to another (e.g., upright). For example, in facial approximation, attempts are made to estimate the upright facial morphology from the skull [3–5], yet facial estimation data may be derived from subjects whose faces have been measured in the supine position [6–9]. One specific example in this context is the collection of supine CT face scans to serve as upright models in computerized face prediction programs [10,11]. This potentially adds error to the methods, an important consideration in the craniofacial identification domain where advanced 3D medical imaging techniques are generally thought to represent (or oversold as) the highest fidelity

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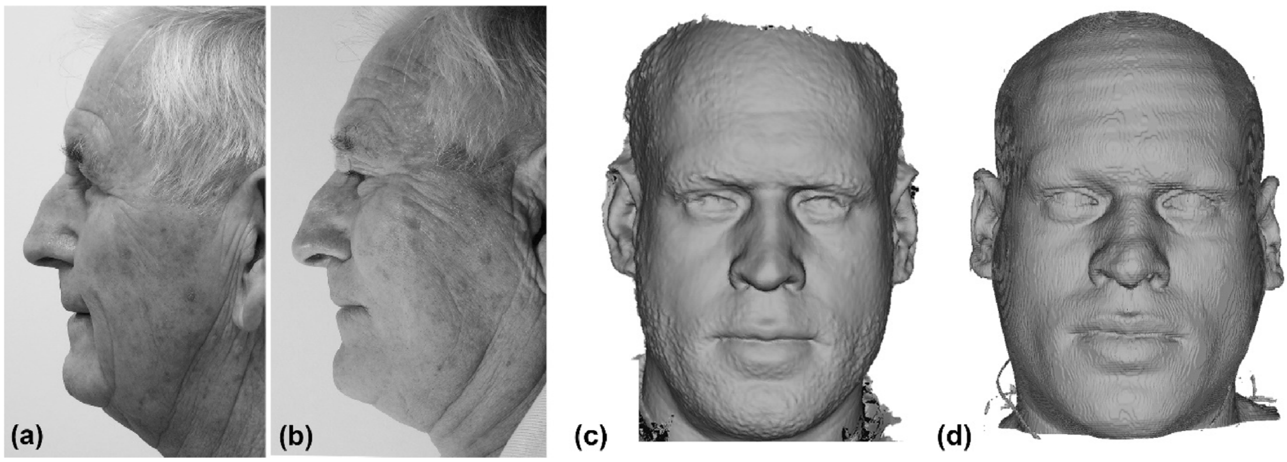

Fig. 1. Cursory observations of face change with posture change recorded in 2D and 3D: (a) photograph of a 65 year old male — standing upright; (b) Same 65 year old subject photographed laying down but in the face up position (supine)—NB. Image (b) has been rotated 90° counter clockwise to facilitate comparison to (a); (c) 3D image (DI3D stereophotograph) of the second author (CS) standing upright; and (d) 3D image (helical CT scan) of the same author (CS) in supine position.

data above other measurement methods [8,12–22] irrespective of any other complexities added by the 3D medical imaging approach.

Previously, there has been some concern with the congruency of upright versus supine facial soft tissue thicknesses (FSTT), but investigations have been limited to ultrasound—the only soft tissue thickness method permitting ready and safe test-retest measurement of living subjects [23–25]. Investigations of posture effects on FSTT derived from ultrasound data began with Manhein et al. in 2000 [23], who investigated differences between sitting and reclined subjects measured with B-mode ultrasound. Out of several landmarks examined, only one (suborbit) reportedly displayed changes, but magnitude of the change goes unmentioned. Also using B-mode ultrasound, Baillie et al. [24] report statistically significant differences at four of ten measured landmarks with most differences being small in magnitude (menton = +2.6 mm, zygomatic arch = +0.7 mm, infraM2ridge = −1.3 mm, and gonion = +1.1 mm; positive values show supine > upright [i.e., extrusion of tissue when supine]; negative values show supine < upright [i.e., tissue retrusion when supine]). Lastly, Stephan and Preisler [25] found only two out of 14 FSTT landmarks they investigated to display posture changes in excess of 1 mm (the largest being 1.5 mm increase at gonion in the supine position). While the lack of ionizing radiation in B-mode ultrasound readily permits test-retest data collection, the method may not be ideal for measuring posture changes because this measurement technique holds substantial measurement errors (e.g., 5–35% relative technical error of measurement [25–27]) making it difficult to detect differences between postures and possibly explaining the infrequent detection of differences listed above in regards to the facial soft tissue thickness data.

Lateral photographs [1] and motion-tracking technology [28] have also been used to attempt to document posture changes in the face, but again with limits. Using 90 subjects and an analysis of 12 measurements derived from 16 landmarks on profile photographs, Hoogeveen et al. [1] report a more prominent chin in the supine position with an associated displacement of the upper lip by 0.7 mm posteriorly and 1.2 mm cranially. Six of their eight measured linear distances also showed statistical significance on two-tailed paired t-tests (no adjustment for multiple tests), however, the size of the mean difference never exceeded 1.3 mm in any case.

A limitation of the Hoogeveen et al. [1] study is that it examines only the median line of the face and thereby only provides a small snapshot of the global face change because it does not concern the entire facial surface. This was addressed in part by Marin et al. [28] who used 52 motion-tracking markers attached to the face of 10 subjects. Marin et al. [28] studied facial surface movement from upright to supine position and recorded these observations in a finite strain map of traction and compression via the motion tracking device. They noted maximal traction (15%) in the intra-orbital and oral regions and maximal compression (10%) in the temporal and zygomatic regions of the face [28]. These results suggests stretching and thinning of the tissue in the intraorbital and oral regions with possible thickening at regions of compression, but since the topography of the face surface was not specifically recorded the surface shape changes ultimately are speculative.

Advances in photography and computer processing power have recently seen new non-contact 3D face recording devices (such asDI3D®, 3DMD® and Vectra® systems) that enable measurement of face anatomy in 3D with high precision (<0.5 mm error [29–32]). Being non-contact, these methods are well-suited to measuring posture changes across the face because there is no risk of any extraneous tissue distortion during measurement and the changes can be mapped pixel-by-pixel, in 3D, across the entire facial surface [2,33–35]. The first study to use such non-contact methods was undertaken using holographic methods [2], but results unfortunately were not published. Vandermeulen et al. [33] next provided a heat-map of posture change recorded using two different imaging modalities (CT scan [supine] and 3D laser scan [upright]) but only for a single subject. Recently, Bulut et al. [35] used a Polhemus® Fastscan Laser scanner (Vermont, USA) to map changes between upright and supine position in a sample of 44 individuals, and found posture changes in the region of the nasolabial fold only. A disadvantage of the laser scanner is that it cannot capture the entire facial surface instantaneously, rather the scans are dynamically built as they are taken and a series of wipes across the face until the full area of interest is recorded. Consequently, the method is subject to inaccuracies arising from subject movement during the scanning process which takes several seconds. Instead, stereo-photogrammetry can be used for non-contact instantaneous image acquisition of the entire face surface, the data are highly accurate [29–32], and unlike CT the process is radiation free (enabling multiple image captures of the same subjects). Stereo-photogrammetry uses multiple 2D cameras at different known viewpoints to record the subject, from which 3D form can be precisely calculated [29–32].

In 2008, See et al. [34] used stereo-photogrammetry to track face shape changes from upright to supine position in 15 subjects with a Canfield® Vectra® system (Parsippany, USA). Posture