Quantitative Assessments of Facial Soft-Tissue Mobility by means of Watershed Segmentation and Constrained Elastic Registration in Upright Accelerated 3D MRI

Marco Vicari[1], Stefan Heldmann[2], Hans Meine[1], Frank Hug[3], Juergen Hennig[4], and Niklas Iblher[3]
[1]*Fraunhofer MEVIS, Bremen, Germany,* [2]*Fraunhofer MEVIS, Luebeck, Germany,* [3]*Department of Plastic and Hand Surgery, University Medical Center Freiburg, Freiburg, Germany,* [4]*Department of Radiology, Medical Phyisics, University Medical Center Freiburg, Freiburg, Germany*

Target audience: Physicians interested in quantitative evaluations of positional MRI data under physiological weight-bearing. MRI developers interested in accelerated upright MRI at low field by means of variable-density k-space undersampling and constrained reconstruction. Image analysis developers interested in interactive tissue segmentation by watershed transformation and constrained elastic registration.

Purpose: Cutting-edge reconstructive and aesthetic craniomaxillofacial skeleton surgery has strongly benefitted from facial morphometric analysis by means of three-dimensional imaging tools, both for evaluation, planning and intraoperative navigation[1]. Face surface optical scans are an option for this, but MRI provides a deeper insight in tissue morphology, thanks to its sensitivity to soft tissues and to the possibility of 3D tomographic acquisitions. Moreover, upright MRI allows investigations of tissue mobility, by comparing imaging in lying and sitting, i.e., in natural stance under gravity. In the following, a comprehensive method of accelerated upright 3D MRI and elastic registration of segmented anatomic compartments is presented, aimed at quantitative assessments of facial soft-tissue mobility, as a function of age and physiological weight-bearing.

Methods: This clinical study was approved by the local institutional review board and all volunteers gave informed consent. Fifty-one female healthy volunteers were recruited: twenty-eight aged 19 to 34 years (mean=25.3, standard deviation (SD) = 3.3) and twenty-three aged 49 to 64 years (mean=53.3, SD=3.7).

A 3D steady-state FID sequence with TR/TE=12 ms/6 ms, FOV=240*280*240 mm^3, matrix=344*400*136 and 2D phase encoding oversampling=125% was implemented on a 0.25 T MRI system[2] (G-scan, Esaote S.p.A., Genoa, Italy). Gradients support 20 mT/m with a slew rate of 25 mT/m/ms. Imaging in lying and standing positions was possible thanks to the open C-shaped permanent magnet that can tilt together with the examination bed. Flip angle (80°) was optimized in terms of SNR and soft tissue CNR. The anterior-posterior direction was chosen for phase encoding in order to minimize both the off-resonance effects at the level of the nose tip, which is close to the edge of the homogeneity region of the magnet, and the ghosting artefacts on cheekbones due to blinking (if any). A prototype 4-channel phased-array RX head-dedicated coil was used. Imaging was performed using elliptical view and variable-density k-space undersampling with constrained image reconstruction, providing an overall accelerating factor of 2 and a resulting acquisition time of 6’40” per imaging volume. Indeed, scan acceleration well suits the requirements of high spatial resolution of thin fat layers in reasonable examination times, such to limit possible motion artifacts, especially in sitting position. To this regard, the upper part of the head was also fixed inside the RX coil with small cushions, taking care not to press any face compartment of interest. In order to allow reliable quantitative evaluations, 3D geometric distortion correction of gradient non-linearity was applied on the reconstructed images. Then, soft-tissue layers at the nose and cheek level were segmented by means of a fast, semi-interactive watershed transform algorithm[4] (IWT). Finally, corresponding segmentations in lying and sitting positions were elastically registered by means of a Lagrangian approach with prior-knowledge constraint optimization[5].

Fig. 1: Low-field MRI examination in lying (left) and sitting (right) position with an open C-shaped permanent magnet. A phased-array head-dedicated RX coil is used.

Results: The overall image quality was suitable for compartment segmentations and their elastic registrations between lying and sitting position, as shown in Fig. 2. Volunteer examination was not successful in 4 cases, due to susceptibility artifacts (signal voids) produced by metal dental implants, and in one further case due to volunteer anxiety. Some image smearing due to head motion was present in 4 volunteers and only in sitting position.

Discussion: Deformation vector fields from elastic registration of segmented compartments in high-resolution upright 3D MRI carry full quantitative information not only of surface features but also about mobility within tissue compartments (see Fig. 2). The definition and measurements of anatomical landmarks characterizing facial soft-tissue mobility will be the target of the second stage of this clinical study.

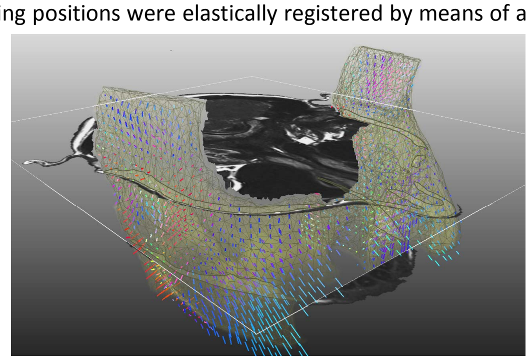

Fig. 2: Cheek and nose soft-tissue layer segmentation in supine position, superposed to corresponding MRI. The deformation field vector from supine to sitting position is shown with standard color-coding scheme for visualization of directional information (Left-Right direction: red, Head-Foot: green and Anterior-Posterior: blue).

Conclusion: The shown technique is a novel and promising approach to reliable quantitative evaluations of the complex 3D anatomy of the face structure, as a function of aging and gravity. Relevant clinical applications include orthodontics, cleft and facial palsy surgery and, especially, aesthetic facial surgery, because of the ability to quantitatively measure mobility of tissue compartments rather than just surface features.

References: 1. Iblher B. *et al*., Plast. Recon. Surg. 2013, 131(2):372-381; 2. Trequattrini A. *et al.* IEEE Trans. On Appl. Supercon. 2006, 16:1505–1508; 3. Lustig M. et al. MRM 2007, 58:1182-1195; 4. Hahn h. *et al.*, Proc. SPIE Med. Imag. 2003, 5032:643-653; 5. Haber E. *et al.*, Linear Algebra Appl. 2009, 431:459–470.