Evaluation of an MR compatible head fixation device using a custom-made 3D printed frame in combination with a thermoplastic head mask

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Target audience: Researcher, which need minimal head motion during MR scans.

Purpose: The aim of the study was to construct an MRI compatible frame for fixation of a commercial plastic head mask and to evaluate the achievable degree of fixation using this kind of immobilization in comparison to standard fixation using head clamps mounted on the head coil.

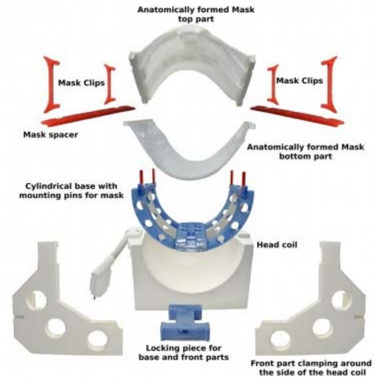

Fig. 1 Explosion graphics of frame and head mask together with lower part of head coil.

Methods: A commercially available thermoplastic head mask (BrainLab head mask, Brainlab AG, Feldkirchen Germany), generally used for fractionated radiotherapy of head tumors, was adapted to a healthy volunteer following the standard procedure of the manufacturer. An additional jaw fixation [1] was added to further improve the repositioning accuracy of the mask system. A custom made frame for the fixation of the mask within the MR head coil (12-channel head coil, Siemens Healthcare, Erlangen, Germany) was designed (Fig.1) and printed in several parts using a 3D printer (Ultimaker, UltimakerB.V., Geldermalsen, The Netherlands) and polyacetide (PLA) material. The spacers between the upper and lower parts of the mask as well as the mask clips were also manufactured with the 3D printer. Using this frame several MRI experiments were performed in a 3T MRI (Tim Trio, Siemens Healthcare, Erlangen, Germany). Repositioning accuracy of mask fixation (MF) was investigated in back-to-back (b2b) scans as well as with mask removal (rp) and compared to fixation with standard head clamps attached to the head coil (not shown in Fig. 1). The scans were performed on three different days (D1…D3). Differences in absolute table position between days were taken into account. A MP-RAGE sequence [2] was applied covering the whole head with 1 mm isotropic resolution (TE 2.63 ms, TR 2530 ms, TI 1100 ms) in order to obtain high gray-white matter contrast images. Robust inverse consistent image registration [3] was used to determine the translation that occurred between all scans. The translation and the rotation angle around the Euler axis were calculated to quantitatively assess the degree of transformation between each data set. In a second study the stability of fixation during fMRI (EPI BOLD, TE 35 ms, TR 3770 ms, 2 mm isotropic resolution, 49 slices, 100 volumes) was investigated. We performed two scans with mask fixation (MF) and two scan with clamp fixation (CF). One additional fMRI scan with mask fixation was performed and the subject was asked to perform movements as much as possible (MF(motion)). Motion parameters were determined by means of absolute translation and rotation angle around the Euler axis taken from the registration parameters obtained from the realignment pre-processing step in SPM8 (registration to first volume).

Results: Performing the movement analysis without repositioning we obtained a maximal absolute translation of 0.4 mm with mask fixation and 0.7 mm with clamp fixation in the back-to-back scenario and a maximal rotation of 0.3° and 0.4°, respectively. With repositioning (subject was removed from the head coil and re-positioned again, these values changed to 0.2 mm and 0.2° for mask fixation and 4.4 mm and 7.3° for clamp fixation. Comparing the maximal translation and rotation between scans with mask fixation acquired on different days and also including repositioning of the frame we obtained a maximal translation of 5.8 mm and maximal rotation of 1.3°. For comparison, the repositioning parameters for scans with clamp fixation between different days ranged between 8.4-34.8 mm in translation and 5.1-10.3° in rotation. The evaluation of fMRI motion correction with clamp fixation in comparison to mask fixation showed significantly lower translation and rotation for mask fixation (cf. blue and light blue lines in Fig. 2). The experiment with mask fixation and voluntarily performed head movements during acquisition showed translations up to nearly 1.5 mm and maximum rotation by 1.4°, which exceeded the values obtained for fMRI motion correction with clamp fixation only. However, after the motion was stopped (after volume 75) rotation returned to a minimal value and the shift remained stable.

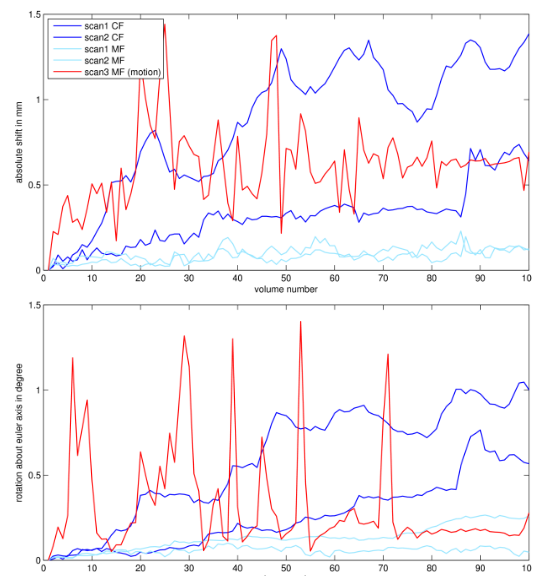

Fig. 2 Translation and rotation parameters for fMRI scans with clamp (CF) and mask fixation (MF) as well as mask fixation with heavy motion (MF(motion)).

Discussion: We have evaluated a custom made frame to hold a commercial head fixation mask in an MR head coil in terms of repositioning accuracy as well as degree of immobilization. The repositioning shift between different days (5.8 mm) was found to be low, but not sufficient for e.g. stereotactic planning. This might be due to inaccurate fixation of the frame to the head coil. Without moving the frame, the repositioning accuracy is very high with sub millimeter shifts (<0.4 mm) and rotations close to zero (<0.3°). In back-to-back scans, a cooperative subject achieves the same very low scan-to-scan transformation with clamp fixation, although the values for mask fixation were found to be lower in general. The functional experiments showed that mask fixation can significantly reduce motion, which is important for long fMRI experiments especially with high resolution. If the subject moves heavily, the mask fixation limits the amount of possible movement to <1.5 mm in translation and <1.5° in rotation. But, more important is the fact that mask fixation brings the subject back into the right position after movement. Taken all results together, this immobilization approach is not only interesting for repositioning experiments but also for the acquisition of very high resolution images with long acquisition times (e.g. > 30 min). The benefit of this kind of immobilization was also demonstrated in the acquisition of HARDI data with a fragmented acquisition scheme [4] or with high resolution MR imaging for treatment of glottis carcinoma [5]. It will also help to study different imaging artifacts like susceptibility induced phase shifts, while minimizing subject motion. The next step will be to construct individual head masks based on structural MRI head information, which can also be reproduced using 3D printing. Technically, this approach might be more laborious, but would lead to lower material cost and would allow for more individual adapted masks.

References: **[1]** E. Lopatta, et al., *Strahlenther. Onkol.*, vol. 179, no. 8, pp. 571–5, Aug. 2003. **[2]** J. P. Mugler and J. R. Brookeman, *Magn. Reson. Med.*, vol. 15, no. 1, pp. 152–7, Jul. 1990 **[3]** M. Reuter, H. D. Rosas, and B. Fischl, *Neuroimage*, vol. 53, no. 4, pp. 1181–96, Dec. 2010. **[4]** S. B. Vos, et al., in Proc. Intl. Soc. Mag. Reson. Med. 21, 2013, p. 3195. **[5]** J. J. Bluemink, et al., in Proc. Intl. Soc. Mag. Reson. Med. 21, 2013, p. 3442.