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First Clinical Experience in applying XperGuide in Embolization of Jugular Paragangliomas by Direct Intratumoral Puncture

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Purpose: The purpose of this study is to introduce a novel image-guided technique utilized in the embolization of jugular paraganglioma tumors, using preoperative diagnostic scans and planning together with perioperative X-ray fluoroscopy in a combined image.

Methods: A lesion center and an entry skin point on the patient are selected and connected with a straight line, which resembles the most ideal lesion access trajectory to be followed during the needle insertion. The skin entry point and the corresponding line location are selected such that it avoids the impenetrable bones and vital anatomical structures. Two viewing incidence angles are defined to guide the cranial needle insertion: the entry view, tangent to the planned trajectory, and the progression view perpendicular to the path.

Results: The proposed method was applied in two patients with jugular paragangliomas in order to navigate needles to the lesion location and subsequently embolize the tumors. The perioperative registration took less than 8 sec. Using this method, it was possible to guide the needle within 5 mm of the planned path.

Conclusion: The fluoroscopic needle navigation, overlaid on the corresponding soft tissue of the underlying anatomy, combined with a planned path, has been shown to be an accurate and efficient tool for needle guidance. The patient pose varied between the preoperative data and the fluoroscopy guided intervention, but this did not hinder the procedure.

Percutaneous Punctures, Needle Guidance, X-ray fluoroscopy - CT fusion, Paraganglioma, Glomus Tumor, Head and Neck Neoplasms, Embolization

Paragangliomas, also known as glomus tumors, are highly vascularized neoplasms of neural crest origin that arise from the glomus cells, which are chemoreceptor organs in the walls of blood vessels that have a role in regulating blood pressure and blood flow. Glomus cell are located in aortic bodies near the aortic arch and the carotid bodies, situated close to the bifurcation of the carotid arteries. The glomus cells are a part of the paraganglion system composed of the extra-adrenal paraganglia of the autonomic nervous system, derived from the embryonic neural crest. Paragangliomas are most frequently located in the abdomen (85%) and the thorax (12%), and only 3% are found in the head and neck region. Glomus tumors are multiple in 25% of patients, and are usually considered benign. However, in about 3% of cases they are malignant and have the ability to metastasize [1–3]. Glomus tumors can be treated by surgical excision, radiation therapy, or a combination of those. Especially for large tumors, surgical removal is often associated with substantial intraoperative bleeding rate, due to their vascular nature [2, 4–8]. In order to reduce the intraoperative blood loss, preoperative transarterial embolization has proven to be beneficial [9–13]. However, in many cases the devascularization remains incomplete because of the extensive angioarchitecture and considerable arteriovenous shunting of the lesions. Therefore, direct percutaneous puncture and the injection of acrylic glue or cyanoacrylate has been described as an effective alternative [14–19].

In this article we describe a novel approach to the planning of the puncture trajectory, and the interventional needle guidance. Our method relies on C-arm fluoroscopy for the real-time guidance, while we also intend to integrate soft-tissue information, in order to use an optimal path. Since the proposed method does not rely on a stereotactic frame or markers, the strain on the patient is reduced, and the procedure duration shortened [20, 22].

Methods and materials

Procedural technique

Prior to patient puncturing, the optimal needle paths are drawn on a preoperative computed tomography (CT) dataset. Determination of the most optimal needle trajectory is initiated by marking the ultimate needle point, located in the lesion center (Figure 1). A line is drawn in the 3D patient space towards the skin boundary, continuously checking whether it traverse the vital anatomical structures or impenetrable bones.

When the line is defined, the puncture point located on the patient skin is defined as the entry point of the virtual trajectory (Figure 2). The inspection of the line is performed by doing soft tissue stacking perpendicular to the line’s spatial location (oblique cross reformat stack). Multiple trajectories can be stored in this way. This planning phase is meant to be performed ahead of the intervention execution or peri-procedurally in the case additional lesion access is needed.

At the beginning of the intervention a 3D soft-tissue cone-beam CT (XperCT) dataset is acquired with the C-arm X-ray system (Philips Allura Xper FD20; Best, the Netherlands), and the preoperative CT dataset is co-registered to the perioperative XperCT according to the Mutual Information criterion [21]. Since the C-arm system is used to obtain the XperCT data, as well as the 2D fluoroscopy data, the relation between their respective coordinate systems is inherently known, as long as there is no patient motion. As a consequence, the image-based registration of the CT and XperCT datasets also registers the CT and C-arm coordinate systems.

After the automatic registration has been completed and validated by the physician, the path vector is sent to the C-arm, and the geometry viewing incidence is steered to be tangent to the planned path: the entry view. Since this view is tangent to the needle trajectory, the path is foreshortened to a single point. When the needle is positioned at the entry position and its orientation is tangent to the fluoroscopy image, it can be inserted. The C-arm viewing incidence is then steered to be perpendicular to the planned path: the progression view. In this orientation, the needle can be navigated along the planned trajectory.

The live fluoroscopy image is overlaid with the planned needle trajectory and fused with an oblique slice of the soft-tissue data, perpendicular to the viewing incidence and passing through the target point. The overlay image is real-time updated for any change in viewing incidence (L-arm angle, rotation, angulation), field of view, and source-image distance [20]. The entry view is compensated for parallax distortion. The projection of the planned path and soft-tissue information is aided considerably by the fact that modern C-arm systems use flat X-ray detectors, which do not posses any pincushion deformation of the image, contrary to their image intensifier predecessors.

The entry view and progression view steps are repeated for all planned puncture paths. The views can be selected at table side. Optionally, new paths can be planned during the intervention. After the insertion, a new XperCT can be acquired and registered to verify the needle position with regard to the soft-tissue structures and anatomical landmarks.

Patients and materials

Two patients with a jugular paraganglioma tumor were selected for treatment according to the described method. Embolization by needle puncture was preferred over surgical excision because of the surgical treatment related difficulties: highly vascularized tumor tissue and the associated trauma. The patients were treated with percutaneous intratumoral injection of Onyx in order to embolize the lesion. Each puncture was performed under high-quality X-ray roadmapping. The treatment was performed under general anesthesia, which considerably reduces the risk of patient motion. Patient motion introduced in the course of the procedure would lead to misalignment of the fused image data. Catheter angiography was used to visualize the tumor location and to confirm the successful embolization of the capillary lesion network. Figure 3 shows examples of pre- and post-embolization vasculature. No additional imaging techniques, such as ultrasound, were used.

For both patients two needle trajectories were planned using a preoperative CT angiography scan (16-slice Siemens Somatom Sensation, data sets consisted of 256 and 271 slices respectively of 512^2 pixels, voxel size: 0.42 * 0.42 * 0.70 mm^3, H50s filter, arterial phase).

Results

The registration with the perioperative XperCT reconstruction took less than 8 seconds, due to the efficient calculation of the Mutual Information criterion by employing the processing power of the graphics hardware (Figure 4). Maeda et al. have shown that in phantom studies a target point can be reached with a gap of 3.8 $\pm$ 1.9 mm [22]. For the two patients it proved to be possible to guide the needle within 5 mm of the planned path, using the fluoroscopy fused with soft-tissue visualization (Figure 5). For the first patient (female, 63 years) one additional path was planned during the intervention in order to maximally embolize the tumor, and for the second patient (female, 64 years) three additional trajectories were planned.

As embolic agent the currently available Onyx 18, a nonadhesive liquid embolic agent comprised of 6% EVOH copolymer dissolved in dimethylsulfoxide, was used. To puncture, a 22-gauge spinal needle (Terumo; Tokyo, Japan) was employed.

Using the described XperGuide technique allowed to steer the embolization needle with a higher confidence to the planned target locations for injection of the embolic agent and reduced the risk of puncturing the carotid artery. The availability of the real-time position of the needle over the planned needle path (and any deviations) and the anatomical landmarks in the CT dataset reduces the need for intermediate angiography, and therefore reduces the use of iodine contrast medium and X-ray dose compared to traditional fluoroscopy guided direct puncturing. No post procedure complication was established during the one year checkup.

Discussion

Ultrasound guidance is considered as the first line imaging technique while performing needle punctures. However, due to the presence of the massive occipital skull base bone and ultrasound interference with the bony anatomy, other imaging modalities are used for guidance in the head and neck region, such as static CT images, CT fluoroscopy or X-ray fluoroscopy, or optionally stereotactic navigation. All mentioned approaches posses their limitations. CT based procedures are limited by the patient access area within the gantry. Additionally, the needle path that can be planned and tracked is restricted to the axial planes imaged by the CT modality. Static CT images further lack real-time feedback. Another option is X-ray fluoroscopy, which produces less X-ray dose and offers fewer restrictions in patient access compared to CT fluoroscopy. However, this modality but does not provide any soft-tissue information.

The fluoroscopy navigation overlaid with the planned path, as proposed in this article, has been shown to be an accurate tool for needle guidance. The procedure is performed in the angio lab, using C-arm fluoroscopy. No additional navigation equipment, special devices or special needles are required, which means that there is no necessity to invest in additional equipment and training, delivering a cost-efficient procedure. The fact that the presented method does not use any stereotactic frame or markers reduces the strain on the patient and facilitates the work flow management. The procedure can be carried out more efficiently, compared to CT guidance.

The described technique offers the advantage over traditional angiographic X-ray guided punctures that the needle is accurately inserted along a path, which was planned on a three-dimensional soft-tissue dataset. Furthermore, the soft-tissue data, as well as the planned needle path, are visualized together with the real-time fluoroscopic image of the needle that is being inserted. The presence of this combined information increases the confidence during guidance and allows for a more accurate deliverance of the embolic agent at the destination location in the tumor.

The patient pose differed between the preoperative CT and the fluoroscopy guided intervention, in order to obtain optimal access to the planned trajectory proximate to the ear (Figure 6), but this did not form a complicating factor. The registration step was not hindered by the difference in pose, and conveyed the planned paths and CT soft-tissue information into the coordinate system of C-arm. The needle accessibility of an intracranial location, however, can be limited by the topology of the skull.

Conclusion

We present a method for planning and guiding needle insertion by combining X-ray C-arm fluoroscopy and 3D soft-tissue information. The entry point view and the progression view together allow a complete assessment of the present needle position with regard to the planned trajectory. The fusion with the soft-tissue dataset incorporates information that is missing in the fluoroscopy image in a readily accessible manner.

Since all the involved equipment is already available in the angio suite, and there are no additional constrains to the pre-interventional CT acquisition, the described method can be easily and cost-efficiently incorporated.

First clinical experience in applying the proposed guidance in the percutaneous embolization of paragangliomas by intratumoral needle injection of an embolic agent has been obtained. The procedure is considered to be sufficiently accurate, successful and aids in reducing the procedural time.

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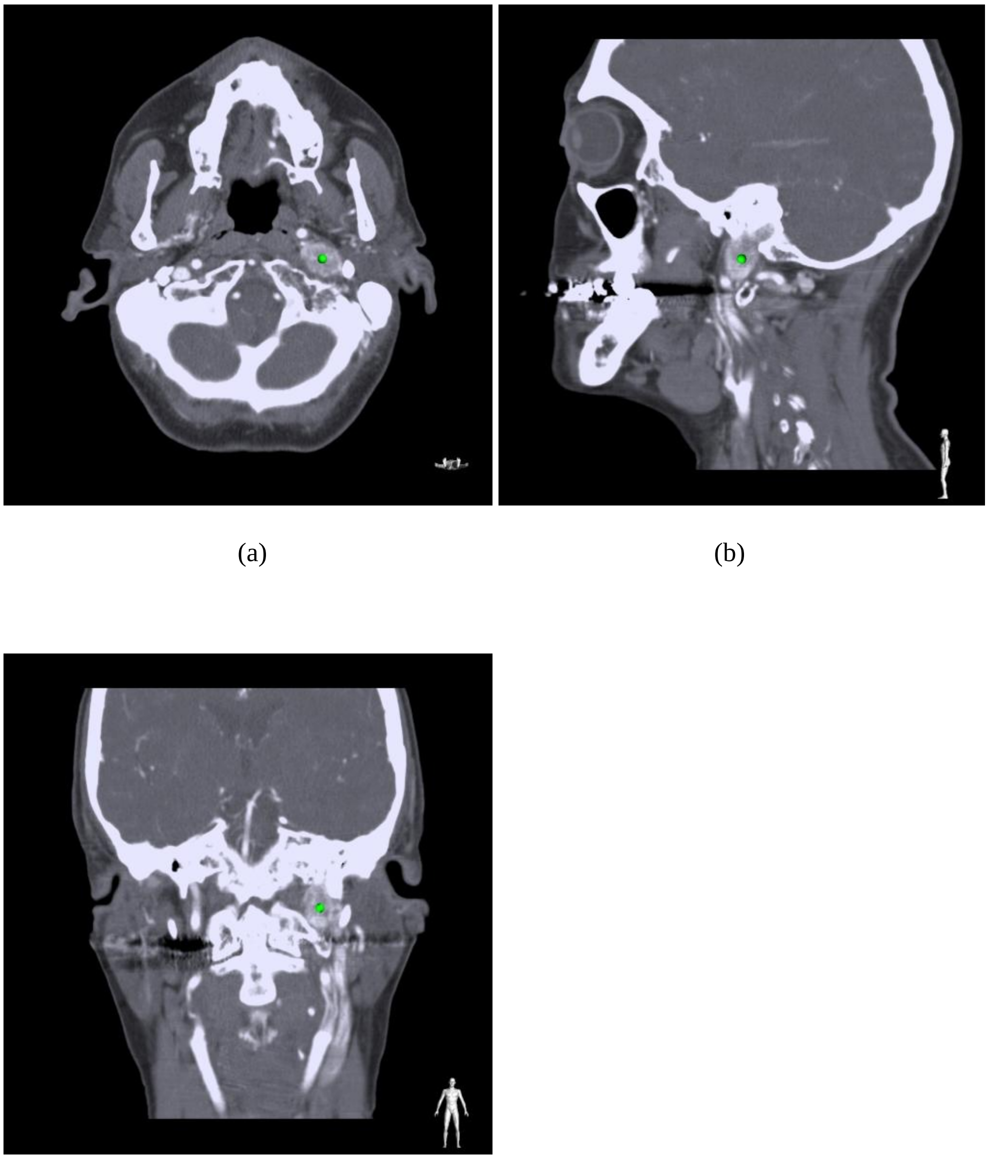


(c)

Fig. 1. The target point (green) in the glomus tumor is marked. (a) Axial view. (b) Sagittal view. (c) Coronal view.

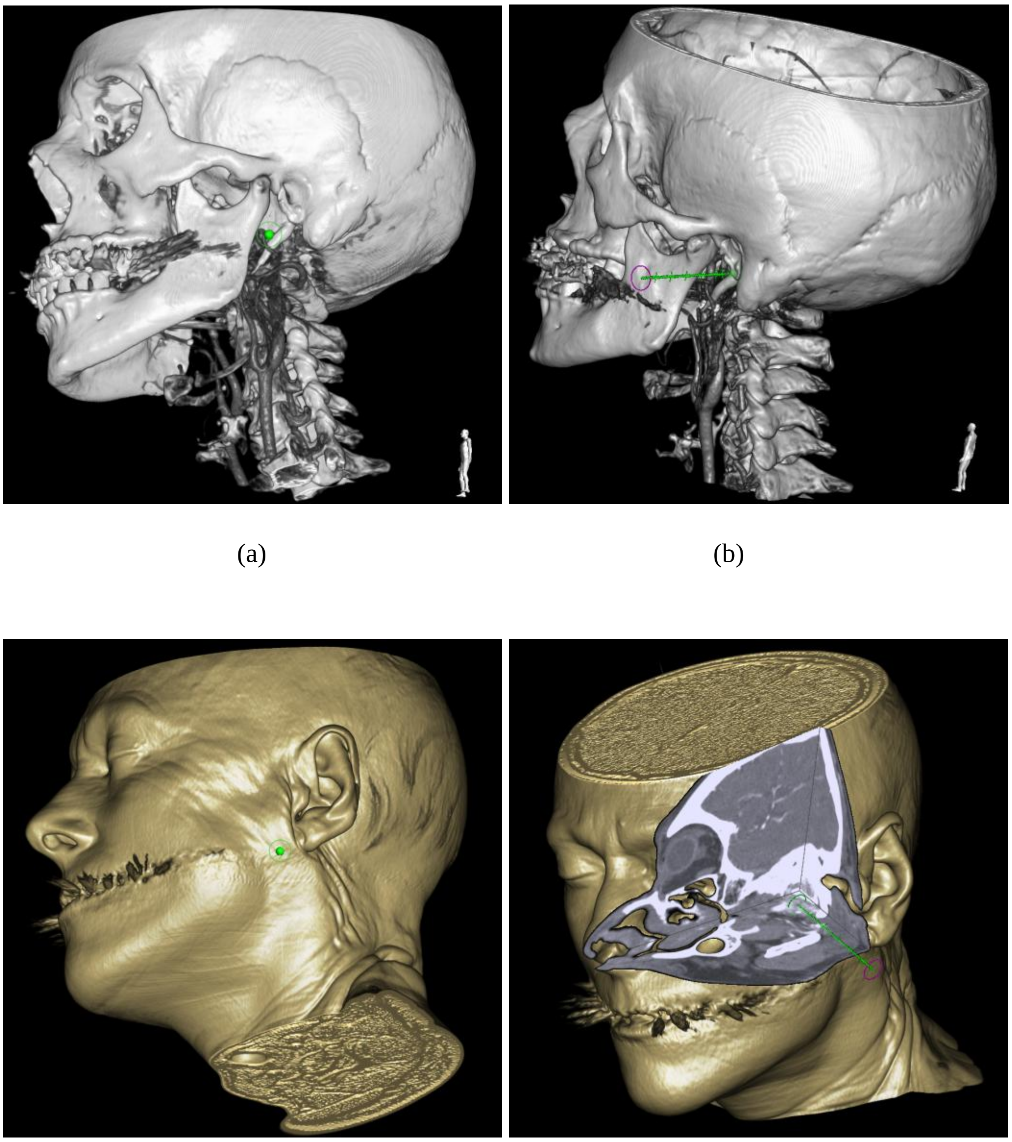
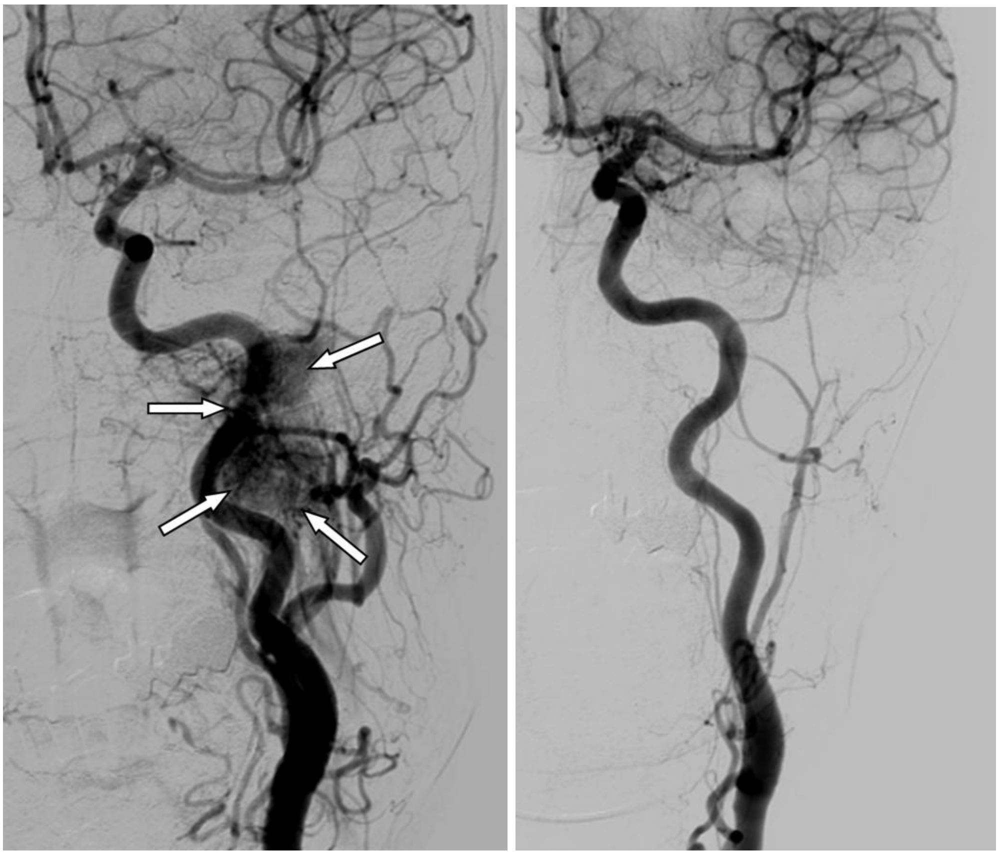
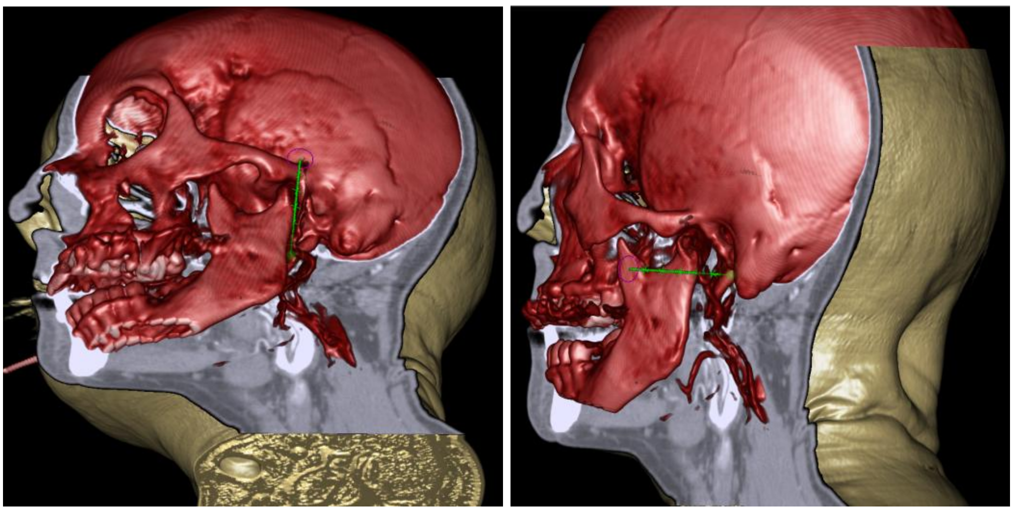


Fig. 2. (a) To establish the path to the target point a 3D view on the skull is used, in order to find a straight path without penetrating any bone tissue. (b) A planned path can be investigated from any orientation. (c) This view permits to view the entry point on the skin. (d) An octant through the planned trajectory is cut out, allowing to inspect the soft-tissue along the path.



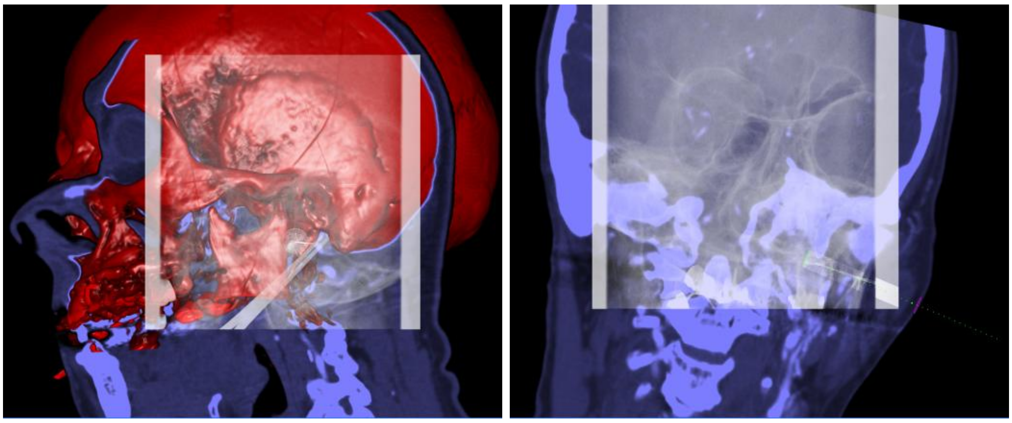
(a) (b)

Fig. 3. Endovascularly injected contrast medium shows the vascularization of glomus tumor (a) before, and (b) after embolization in DSA images. The tumor is indicated by the white arrows.



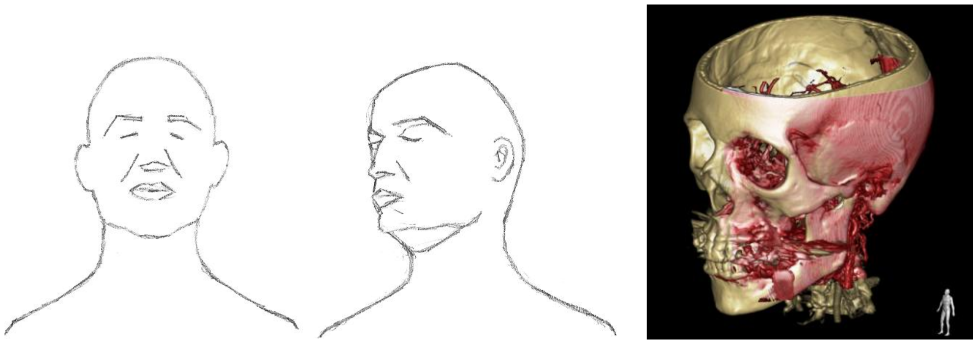
(a) (b)

Fig. 4. The registered CT data (yellow) and the XperCT data (red), together with the planned path. (a) Left oblique view. (b) Posterior oblique view.



(a) (b)

Fig. 5. (a) Entry point view, showing the real-time fluoroscopy image (inner white square overlaid image), the soft-tissue (blue), the skull (red), and the bull's eye target point. The needle is being positioned for entry. When the needle is foreshortened to a single point at the bull's eye it can be inserted. (b) Progression view, showing the real-time fluoroscopy image, the soft-tissue and the planned path. Any vertical deviation from the path can be monitored. In-plane deviations can be checked by switching back to the entry point view.



(a) (b) (c)

Fig. 6. (a) Patient pose in the CT scan. (b) Patient pose on the C-arm table; the head is tilted to gain better accessibility to the needle entry position near the ear. (c) Registered CT data (yellow) and C-arm generated XperCT data (red). The registration can be performed without any manual initialization or interaction.