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Image-guided Lateral Suboccipital Approach: Part 2—Impact on Complication Rates and Operation Times

OBJECTIVE: Image-guidance systems are widely available for surgical planning and intraoperative navigation. Recently, three-dimensional volumetric image rendering technology that increasingly applies in navigation systems to assist neurosurgical planning, e.g., for cranial base approaches. However, there is no systematic clinical study available that focuses on the impact of this image-guidance technology on outcome parameters in suboccipital craniotomies.

METHODS: A total of 200 patients with pathologies located in the cerebellopontine angle were reviewed, 100 of whom underwent volumetric neuronavigation and 100 of whom underwent treatment without intraoperative image guidance. This retrospective study analyzed the impact of image guidance on complication rates (venous sinus injury, venous air embolism, postoperative morbidity caused by venous air embolism) and operation times for the lateral suboccipital craniotomies performed with the patient in the semi-sitting position.

RESULT: This study demonstrated a 4% incidence of injury to the transverse-sigmoid sinus complex in the image-guided group compared with a 15% incidence in the non-image-guided group. Venous air embolisms were detected in 8% of the image-guided patients and in 19% of the non-image-guided patients. These differences in terms of complication rates were significant for both venous sinus injury and venous air embolism ($P < 0.05$). There was no difference in postoperative morbidity secondary to venous air embolism between both groups. The mean time for craniotomy was 21 minutes in the image-guided group and 39 minutes in non-image-guided group ($P = 0.036$).

CONCLUSION: Volumetric image guidance provides fast and reliable three-dimensional visualization of sinus anatomy in the posterior fossa, thereby significantly increasing speed and safety in lateral suboccipital approaches.

KEY WORDS: Complications, Operation time, Sigmoid sinus, Suboccipital approach, Three-dimensional volumetric image guidance, Transverse sinus, Venous air embolism

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The lateral suboccipital approach is a common surgical route to pathologies in the cerebellopontine angle. Its boundaries and most prominent landmarks, the transverse and sigmoid sinus, are hidden behind the cranial bone.

Although delicate and fragile, clear identification of the border of the sinuses is crucial for unrestrained exposure in this approach (40, 41, 44). Dural adhesions and emissary veins add to the challenges in dissection and preservation of these vital structures. Injury to the venous sinuses increases the risk of intraoperative venous air embolism (VAE) and potential postoperative morbidity, especially when the operation is performed with the patient in the semi-sitting position (4, 12, 15, 43).

With an image-guidance system prepared for volumetrically rendered radiographical images to visualize the sinuses of the posterior fossa three-dimensionally, basing the approach upon the patient's individual anatomy should be considerably facilitated. However, there is no systematic clinical study available that focuses on the influence of this image-guidance technology on outcome parameters. Therefore, we investigated the impact of our navigated approach on complication rates for intraoperative VAE and related postoperative morbidity, as well as on operation time for lateral suboccipital craniotomy in the semi-sitting position.

METHODS

Patient Population

Two hundred consecutive patients with pathologies involving the cerebellopontine angle were studied retrospectively. The data collection started in November 2005 and included, backward in a consecutive manner, all operations performed before this assigned time. As soon as the data for 100 cases were collected for one of the two groups (image guided versus non-image guided), additional data were collected only for the other group until the number of 100 cases was reached as well. We investigated pre- and postoperative medical information, surgical and clinical reports, anesthesiology and intensive care unit protocols, as well as navigation protocols and surgical video recordings of these cases.

Data Collection

The following were included as preoperative variables: patient sex and age, site of the lesion, tumor pathology, as well as years of training of the surgeon who performed the craniotomy. Intraoperative findings that were recorded were use of the navigation system, damage to the transverse and/or sigmoid sinuses and/or to major emissary veins, and air embolism. We also recorded the time necessary to complete the craniotomy, which was defined as starting with the skin incision and ending when the dura mater was opened. In cases in which navigation was used, the time necessary for image rendering and processing was recorded, as was the setup and registration time for the navigation system in the operating room.

The indication to use a navigation system was independent of the surgeon or of patient-specific findings. Most of the time, the system was used upon availability. All craniotomies were performed by a neurosurgeon in training under the supervision of a senior neurosurgeon. The surgeons who performed craniotomies were well trained to use the navigation system for preoperative surgical planning and intraoperative guidance. All participating surgeons had performed at least 10 suboccipital craniotomies with and without navigation before participating in this study.

Image Acquisition

A computed tomographic (CT) scan (1-mm slice thickness) with additional delayed contrast injection for visualization of the venous system (venous CT angiography [vCTA]) was obtained in all patients. In the image-guided group, seven to nine adhesive skin fiducial markers were placed on the forehead, at the mastoid tips, and in the retroauricular area of each patient before imaging. Software designed for surgical image-guidance (Image Guidance Laboratories, Palo Alto, CA) was used to volumetrically render three-dimensional (3-D) images in which skin, bone, and intracranial structures could be visualized at the same time by opacity modulation. The spatial course of the transverse-sigmoid sinus complex was recorded while varying the perspective of the 3-D model interactively and modulating the translucency of surfaces.

Neuronavigation

The patients were brought into the semi-sitting position for surgery. The digital reference frame faced the infrared camera that was mounted on the side of the surgery. The target registration error was estimated by comparing the position of the navigation probe on a non-registered fiducial or well defined bony landmark with the localization of the corresponding site in the reconstructed triaxial images. According to the 3-D renderings, the transverse and sigmoid sinus, the bone sutures, and the position of the mastoid sulcus were drawn onto the patient's skin for a skin incision (*Fig. 1*).

FIGURE 1. *The location and course of the transverse-sigmoid sinus transition in relation to the asterion is drawn on the patient's skin for the skin incision. The information about these landmarks is obtained by fine-tuned opacity modulation of volumetric three-dimensional images and is then transferred to the patient following the probe of the guidance system.*

After soft tissue preparation, image guidance was used to reevaluate the course of the sinuses. In cases in which an orthoclastic craniotomy was performed, the gap was refilled with methylmethacrylate at the end of surgery. In osteoplastic procedures, the first burr hole was placed close to the transverse-sigmoid transition with a safety margin of a few millimeters. After rough bone preparation, the accuracy of the system was always reevaluated to exclude errors from digital reference frame dislocation or shifting of the patient's head before the more delicate dissection of emissary veins and sinus edges was accomplished (*Fig. 2*). Microsurgical tumor removal was performed by the senior authors (MS, MT) under electrophysiological neuromonitoring of auditory and facial nerve function.

Anesthesiological Aspects and Monitoring

Intraoperative monitoring included electrocardiography and continuous measurement of the arterial blood pressure and superior vena cava pressure. The tip of the central venous catheter was located within the right atrium so as to aspirate any invaded air during embolism. Furthermore, continuous measurement of the end-expiratory CO_2 concentration, body temperature, diuresis, and the arterial oxygen saturation (oximetry) were performed. To avoid clinical consequences of air embolism by early recognition, precordial Doppler ultrasonography was initiated because of its high sensitivity.

The occurrence of microbubbles in the Doppler and/or a sudden and sustained decrease of the end-expiratory CO_2 concentration were defined as VAE. As soon as these signs occurred, the surgical field was irrigated, the jugular veins were compressed, air was aspirated by means of the atrial catheter, the surgical table was inclined cranialward, and the end-expiratory pressure was increased.

Statistical Analysis

Statistical analysis was performed using SigmaStat 2.0 software (SPSS, Chicago, IL). *T*- and χ^2 tests were used to compare two inde-

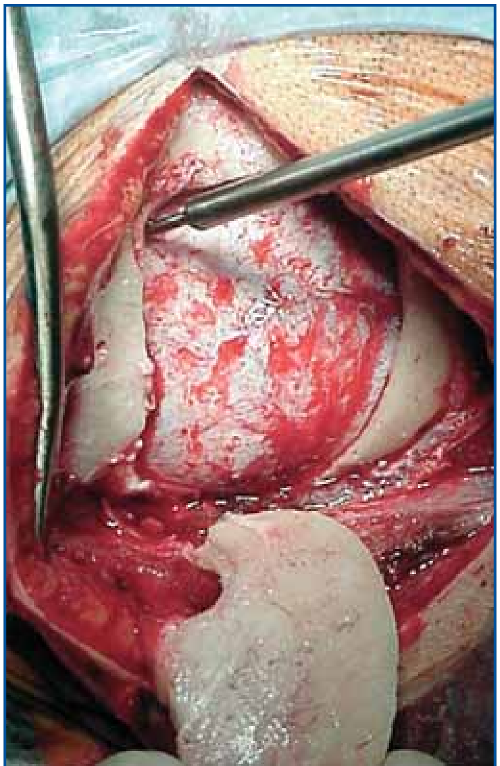

FIGURE 2. *The burr hole is placed at the level of the transverse sigmoid transition with a safety margin of approximately 5 mm in this case. After an osteoplastic craniotomy is performed, the accuracy of the system is reevaluated to exclude shifting errors before the delicate sinus edges are dissected.*

pendent populations, including their parametric proportions. The level of significance (*P*) was set at a probability value of less than 0.05.

RESULTS

Image Guidance

3-D volumetric image rendering proved to be a reliable method to simultaneously visualize bony and venous structures in each individual patient. In all cases, the intraoperative findings matched the spatial relationships in the 3-D reconstructions.

With the location of the landmark structures drawn on the skin, the incision and the craniotomy could be custom-tailored to each patient's individual anatomy (*Figs. 1* and *2*). The real-time display of the transverse and sigmoid sinus complex by the guidance system matched the operative sites with an estimated precision of less than ± 2 mm in accuracy maps obtained after physical registration. The mean target registration error amounted to 1.4 mm (± 0.5 mm) for CT scans in all navigated cases.

When the burr hole was placed directly below the transverse sinus close to the transverse sigmoid transition (TST), there was no damage to these venous structures related to drilling. The TST and the edges of the sinuses were precisely exposed in all patients.

Patient Population

The mean age for all patients was 47 years (range, 11–78 yr). No significant difference in age was observed between the image-guided group (48 yr; range, 11–78 yr) and the non-image-guided group (46 yr; range, 20–72 yr). There was also no preference of the tumor site in either the image-guided group or the non-image-guided group, with 43 and 47% tumors on the right side, respectively. Female patients comprised 48% of the image-guided group and 54% of the non-image-guided group. The tumor pathologies were similar in both groups, with 88 vestibular schwannomas, 10 meningiomas, and two epidermoids in the image-guided group and 95 vestibular schwannomas and five meningiomas in the non-image-guided group.

Complications

Injury to the transverse-sigmoid sinus complex occurred in 4% of the patients in the image-guided group and in 15% of the patients in the non-image-guided group. In all of these cases, sinus injury was followed by VAE. The overall incidence of VAE was 8% in the image-guided group and 19% in the non-image-guided group. These differences in terms of complication rates were significant for both venous sinus injury and VAE (χ^2, 7.02; degrees of freedom, 2; $P < 0.05$).

In all cases, the invaded air during embolism could be recognized by precordial Doppler ultrasonography and aspirated via the central venous catheter, which was located within the right atrium. Nonetheless, VAE caused intraoperative hypotension in one patient in the image-guided group and in two patients in the non-image-guided group. However, these findings were transient and did not lead to postoperative VAE-related morbidity such as pulmonary edema or paradoxical air embolus.

Craniotomy and Image Guidance

The surgeons performing the craniotomy had a mean neurosurgical training experience of 3 years (range, 2–4 yr). There was no significant difference between the image-guided (mean, 2.9 yr; range, 2–4 yr) and the non-image-guided groups (mean, 3.1 yr; range, 2–4 yr). The mean time for craniotomy was 21 minutes (range, 14–36 min) in the image-guided group and 39 minutes (range, 19–52 min) in the non-image-guided group. This difference in the mean values of the two groups was significant (t, -2.513; degrees of freedom, 8; $P = 0.036$).

Preoperatively, there was a mean time of 11 minutes (range, 7–21 min) necessary for image rendering and processing. The mean setup and registration time for the navigation system in the operating room was 14 minutes (range, 10–25 min).

DISCUSSION

The most common neurosurgical approaches for lesions in the cerebellopontine angle are based on lateral suboccipital or retrosigmoid craniotomies (9, 26, 30, 36, 40, 57). With the transverse and sigmoid sinuses, the boundaries of this approach are anatomically well defined (27, 39, 44). As these venous structures are carved inside and hidden behind the cranial bone, superficial bony landmarks have traditionally been used for orientation and localization (10, 16, 24, 28, 37, 44, 51). More recently, cadaveric studies have shown a large variety of superficial landmarks in relation to the transverse and sigmoid sinuses, such as the insertion of the semispinalis capitis muscle, the superior nuchal line, the inion, and the mastoid process, all of which may be applied for localization and protection of the TST (11, 28, 31, 37, 38, 39, 46, 47, 50, 51, 52).

The major drawback of using normative data sampled from anatomic dissections is that, lacking precise information on the individual case at hand, the anatomy of the patient can only be estimated. Consequently, neurosurgeons usually work their way to the sinus starting from a distant, but all the more safe, burr hole, never being precisely sure when they will encounter the fragile border of the sinus before actually seeing it. This observation helps to explain one of the findings of our study that the craniotomy took longer in the group of cases performed without image guidance (39 min versus 21 min in the image-guided group).

To overcome these shortcomings and to improve approaches to the cranial base, neuronavigation has been evaluated in experimental studies (7, 42, 54), and 3-D CTA has been introduced to surgical planning for cranial base operations (45, 53, 54). With the advent of the 3-D volume rendering technique, these issues can be addressed with the option of gradually changing the opacity of the outer layers, such as the cranial bone, to visualize intracranial structures such as the vascular anatomy (8, 13, 19, 20, 23, 25, 32, 33, 35, 49, 53, 56, 57). Alternatively, the vascular anatomy, e.g., the sinuses themselves, may be turned into landmarks projected onto the surface of the cranium by intraoperative image guidance. This would allow for the changing of image modalities from a CT angiogram to a magnetic resonance angiogram excluding x-ray exposure.

Although image-based, stereoscopic virtual reality models are already in use for planning specific surgical procedures and for teaching purposes in neurosurgery (2, 3, 9, 12, 13), most studies that evaluate preoperative neurosurgical planning have focused on 3-D visualization capabilities of the applied software (1, 17, 18, 21, 22, 32, 50, 60).

However, the ability to modulate the opacity of the cranial bone to visualize intracranial structures and to use this information intraoperatively has not been explored for its surgical impact during lateral suboccipital approaches. More specifically, there is no other report on the impact of volumetric image guidance on complications during craniotomies in the posterior fossa.

In the present study, we identified a significant reduction of intraoperative complications commonly associated with suboccipital craniotomies performed in the semi-sitting position. Both injury to the transverse sigmoid sinus complex and VAE occurred less often in the image-guided group, with incidences of 4 and 8% of the cases, respectively, than in the non-image-guided group, which has incidences of 15 and 19% of the cases, respectively. However, all of these complications could be controlled intraoperatively by standard surgical and anesthesiological techniques (e.g., irrigation of the surgical field, closure of the site of air invasion under compression of jugular veins, aspiration of air by means of the atrial catheter) and did not lead to long-term morbidity for the patients in the present series.

The rate of VAE in the non-image-guided group of our study (19%) was in the range of reported incidences in the literature, which ranged from 7 to 45% of patients (4, 5, 6, 12, 14, 15, 29, 34, 43, 48, 59). The sites of probable air entrainment are known to be variable. Embolism can occur during surgical procedures and manipulations by invading air entering the open veins of neck muscles or the bone, or the opened venous sinuses or emissary or bridging veins (4, 15). Most of the VAE in this series occurred after transverse or sigmoid sinus opening in four out of eight patients in the image-guided group and in 15 out of 19 patients in the non-image-guided group. Therefore, the reduction of unintended venous sinus opening from 15% in the non-image-guided group to 4% in the image-guided group was paralleled by a decline of VAE from 19 to 8%.

Owing to the intraoperative management protocol for VAE, postoperative VAE-related morbidity did not occur in any of the patients. Therefore, the impact of image guidance on intraoperative complications did not affect postoperative morbidity.

The mean time for craniotomy was 21 minutes in the image guided group and 39 minutes in the non-image-guided group. Nonetheless, this time-saving impact of volumetric image-guidance for suboccipital craniotomy in our series has to be seen in light of the time necessary to prepare the navigation supported procedure.

A mean period of 11 minutes was necessary for image rendering and processing before the operation. In the operating room, an additional mean time of 14 minutes was spent to set up the navigation system and register the patient. Whereas the image preparation time was spent before surgery outside the operating room, the system setup was performed parallel to other surgical preparations and, therefore, did not prolong the overall operation time in most of the cases.

However, these additional preparations must be considered when evaluating the impact of image guidance on operation time. The mean time gain of 18 minutes achieved by image guidance was neutralized by the time spent for these preparations in our study. Until now, this setup has been done by the neurosurgeons themselves. When economic aspects and efficiency considerations are taken into account, one should consider the involvement of other staff members, such as neuroradiologists or technicians, in this preparation process.

CONCLUSION

The real-time images provided by 3-D volumetric image rendering closely match individual patient anatomy. In the lateral suboccipital approach, the advantage of being able to see beyond tissue barriers before actually dissecting them speeds up the surgical procedure and provides additional safety for the patient with ready and accurate localization of the transverse sigmoid sinus complex. In the future, these findings must be confirmed by prospective and randomized studies, especially in the era of evidence-based medicine.

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COMMENTS

This is a timely analysis of patients who underwent operations either with or without the aid of navigation. Gharabaghi et al. have provided a well conducted and extremely painstaking comparison of 100 navigated and 100 non-navigated suboccipital craniotomies in an attempt to provide scientific evidence to justify the use of navigation. As expected, surgery seemed swifter and safer with the aid of navigation, although the actual navigation procedure consumed some of the time that was saved. The authors are to be commended for accepting the difficult and unrewarding task of providing clinical evidence of the efficacy of this navigation technology.

Still, I must raise a critical issue. Evidence-based medicine is fashionable, and it is common to demand empirical data for any clinical statement. Any systematic report becomes superior to common sense or “expert opinion.” The findings in this study correlate very well with common sense, but how would we have interpreted the data if the findings had disagreed? It is important to ask whether the investigators actually provided a “critical experiment,” one which, in the words of Karl Popper, would have had the power to corroborate or falsify their implicit hypothesis. Medical science has repeatedly gone astray as analyses have been much more biased than anyone realizes. I fear that this is a typical case in which a retrospective design risks major bias. Thus, I would not accept that the hypothesis has been corroborated in a strictly scientific sense. On the other hand, a prospective randomized trial would be difficult to conduct, and a retrospective trial can hardly be better conducted. This study will serve the medical community as an argument to accept increased costs to improve surgical safety.

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On the basis of the author’s initial publication, which demonstrated the anatomic variability of the asterion in relation to underlying risk structures, the authors now retrospectively evaluate the impact of neuronavigation on the outcome of suboccipital craniotomies.

To date the neurosurgical community has been struggling to objectively estimate the value of neuronavigation, even though most of us rely increasingly on this technology in daily practice. Despite the fact that Gharabaghi et al. present retrospective data, their report adds a precious piece to a yet incomplete mosaic of information portraying neuronavigation as a priceless tool, which eventually should encourage hospital administration to invest continuously into advanced surgical technologies, such as navigation and intraoperative imaging.

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