

# Brainstem navigation with Intraoperative anatomical landmarks registration: Technical note

## *Navegação do Tronco Cerebral com Registro Intraoperatório dos Pontos Anatômicos. Nota técnica*

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### ABSTRACT

**Background.** Cranial navigation in brainstem surgery can be especially challenging due to registration method limitation and complex anatomic orientation. Surface anatomical landmarks are not available and fiducial registration usually needs image acquisition at the day of surgery. Intraoperative registration is often used during spinal navigation with safe and reliable accuracy. We present our technique of navigation for brainstem lesions surgeries using intraoperative anatomical landmarks for registration. **Methods.** From March 2008 to November 2018, 38 patients underwent suboccipital midline approaches for removal of brainstem and/or fourth ventricle lesions with frameless navigation. We performed CT scan and MRI sequence with gadolinium enhancement for each patient a day before the operation. The CT/MRI image fusion and surgical planning was performed in Brainlab® workstation. Navigation registration was performed after skin incision and external skull base anatomical landmarks exposure. **Results.** The anatomical landmarks used for registration was based on bone structures visible on CT images. The accuracy flaw was insignificant for brainstem navigation, especially for the roof and lateral limits of the fourth ventricle. The image-guided system was very useful for tumor localization and removal in all cases. **Conclusions.** Intraoperative anatomical landmarks registration is a fast and safe method for brainstem navigation. The brainstem is a fixed encephalic structure and the shifting is insignificant. Anatomical landmarks (inion, foramen magnum, nuchal lines, C1 posterior arc) and a careful surgical planning are necessary in order to avoid accuracy loss.

**Key-words:** Brainstem; Brainstem lesions; Fourth ventricle; Image-guided surgery; Intraoperative procedure; Neuronavigation

### RESUMO

**Introdução.** A navegação craniana em cirurgia do tronco encefálico pode ser especialmente desafiadora devido à limitação do método do registro e à complexa orientação anatômica. O registro por pontos anatômicos não está disponível e o registro por fiduciais adesivos geralmente necessita da aquisição da imagem no dia da cirurgia. O registro intraoperatório normalmente é utilizado durante a navegação espinal com segurança e precisão confiáveis. Apresentamos nossa técnica da navegação para cirurgias das lesões do tronco encefálico utilizando pontos anatômicos intraoperatórios para o registro. **Métodos.** De março a novembro de 2018, 38 pacientes foram submetidos a acesso suboccipital da linha média para remoção de lesões do tronco encefálico e/ou do quarto ventrículo com neuronavegação. Todo paciente foi submetido a tomografia (TC) e ressonância magnética (MRI) com uso de gadolínio, um dia antes da operação. A fusão da imagem do CT/MRI e o planejamento cirúrgico foram realizados na estação de trabalho BrainLab®. O registro de navegação foi feito após a incisão da pele e exposição dos pontos anatômicos externos da base do crânio. **Resultados.** Os pontos anatômicos utilizados para o registro basearam-se em estruturas ósseas visíveis nas imagens tomográficas. A falha da exatidão foi insignificante para a navegação do tronco encefálico, especialmente para o teto e os limites laterais do quarto ventrículo. A navegação foi muito útil para a localização e a remoção do tumor em todos os casos. **Conclusões.** O registro intraoperatório por pontos anatômicos é um método rápido e seguro para a navegação do tronco encefálico. O tronco encefálico é uma estrutura encefálica fixa e o deslocamento é insignificante. Pontos anatômicos (inion, forame magno, linhas nuchal e arco posterior de C1) e o planejamento cirúrgico cuidadoso são necessários a fim de evitar a perda de exatidão.

**Palavras-chave:** Tronco encefálico; Lesões do tronco encefálico; Quarto ventrículo; Cirurgia guiada por imagem; Procedimento intraoperatório; Neuronavegação

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## INTRODUCTION

Neuronavigation provides intraoperative guidance to the neurosurgeon, leading to find target lesions and intracranial structures. Although intracranial navigation is becoming standard for neurosurgical practice, several factors impact upon the accuracy of image-guidance in surgery<sup>1,2</sup>. Poor accuracy in target localization can be related to the quality of image modality, registration method and intraoperative changes caused by brain shift, tissue displacement and cisternal drainage<sup>3,4,5,6</sup>.

The application of image-guidance in cranial surgery can be especially challenging in posterior fossa due to the limitations of the registration method and the anatomical complexity of deep structures. Although impossible to measure inside 'in vivo head', the application accuracy can be assessed intraoperatively using detectable anatomical targets and by performing accuracy checks<sup>7</sup>. With most infrared navigation systems, there are three types of registration: surface matching (SM), fiducials markers (FM) and anatomical landmarks (AL). Surface matching uses the patient's forehead, eyes and nose. It is almost impossible to perform on prone position and the accuracy is jeopardized in posterior fossa surgery due to distortion. Fiducial markers can be skull implanted or adhesive to the scalp and must be applied to the patient before the scan, often in the morning of surgery, delaying the procedure, as well as the need of another images acquisition. The anatomical landmarks method use anatomical skin points such nasion, tragus and eyes epicanthus. All methods seem to have similar accuracy<sup>3,4,8</sup>. Updating of navigation intraoperatively was previously described using intraoperative image systems with adhesive fiducials<sup>9,10</sup>. The use of anatomical landmarks for intraoperative registration has been seen only in spine navigation<sup>11,12,13</sup>.

On the present study, we report our technique of registration for image-guided surgery of brainstem lesions using anatomical landmarks acquired intraoperatively, after skin incision and bone exposure.

## MATERIAL AND METHODS

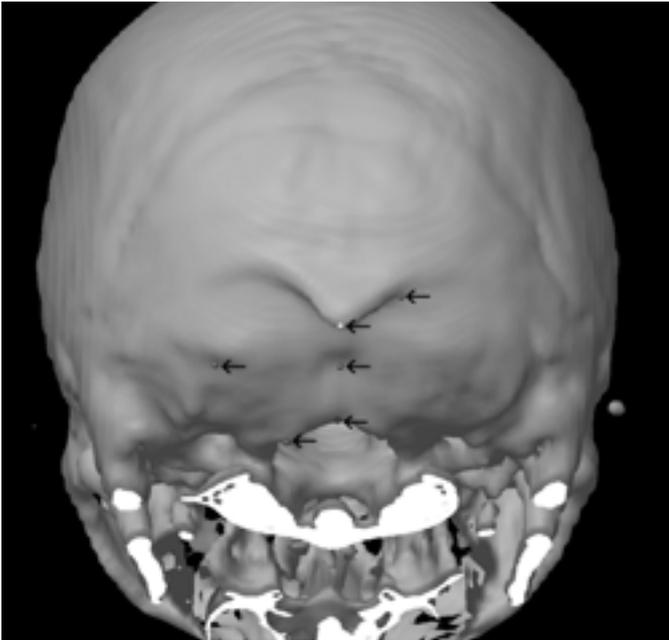
From March 2008 to November 2018, 38 patients underwent midline posterior fossa approaches in prone position for removal of intracranial tumors with frameless navigation and intraoperative monitoring. There were 10 cases of brainstem cavernomas, 6 cases of medulloblastoma, 18 cases of posterior fossa gliomas and 4 cases of epidermoid cyst of the fourth ventricle. CT scan and MRI sequence with gadolinium enhancement was performed for each patient a day before the operation for surgical planning.

The MRI and CT images were uploaded in the Brainlab® neuronavigator for surgical planning in the operation room, while anesthetic preparation/induction. After MRI/CT image fusion, five anatomical landmarks were determined over the CT images, all of them on external skull surface, avoiding skin structures. Every point should be identified precisely (i.e.: foramina, angles etc.) in order to avoid accuracy loss during intraoperative registration. In the suboccipital midline approach, theinion, inferior nuchal line on the midline, foramen magnum borders and midline posterior tubercle of C1 were useful and easy-to-find landmarks (Fig. 1). Object creation of relevant intracranial structures (i.e.: fourth ventricle, lesion, arteries etc.) in the surgical planning was performed to optimize tridimensional guidance.

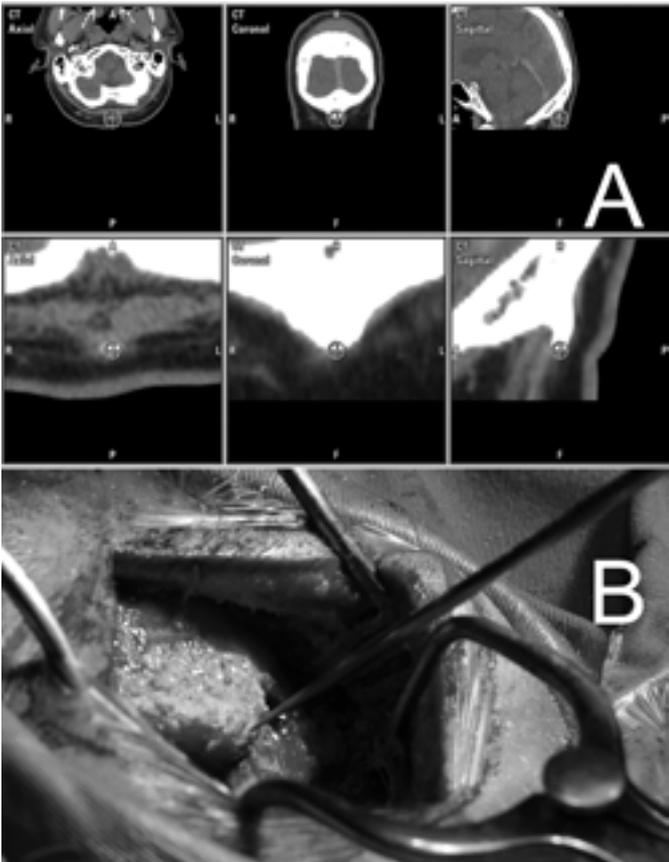
With the surgical planning and anesthesia done, the patient was prepared for the skin incision. Suboccipital midline approach was performed in prone position with head on neutral position, slightly flexed. In all cases, Mayfield clamp was used to fix the head, and the registration star was attached to the clamp.

After skin incision and bone exposure, the five bone anatomical landmarks were exposed on the operatory field. Using a pre-calibrated pointer, the registration was performed before craniotomy (Fig. 2). The neurosurgeon who performed the surgical planning also executed the registration.

After dural opening and cerebellar retraction, the accuracy check was performed with the pre-calibrated pointer aiming the intracranial deep structures and comparing the real position with the virtual images showed in the navigator. In the infracerebellar approach, the navigation of the roof of the fourth ventricle and brainstem structures was used for accuracy check, comparing the virtual position displayed on screen with



**Figure 1.** Workstation images showing the three-dimensional reconstruction of the skull with the five anatomical landmarks for the intraoperative registration. These points were chosen during the surgical planning in the operation room.

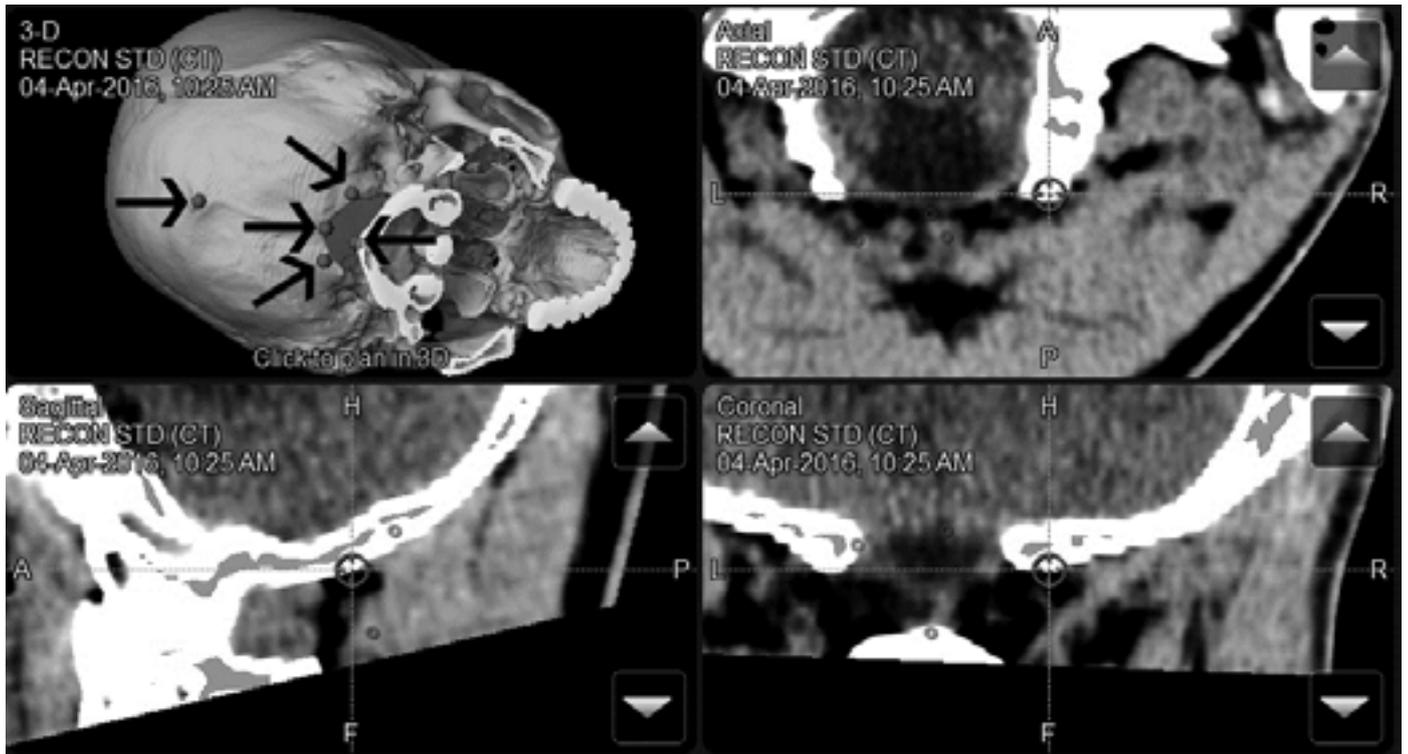


**Figure 2.** Intraoperative registration, showing the anatomical landmarks acquisition. A. Inion displayed on the CT scan; B. Navigation pointer at the Inion.

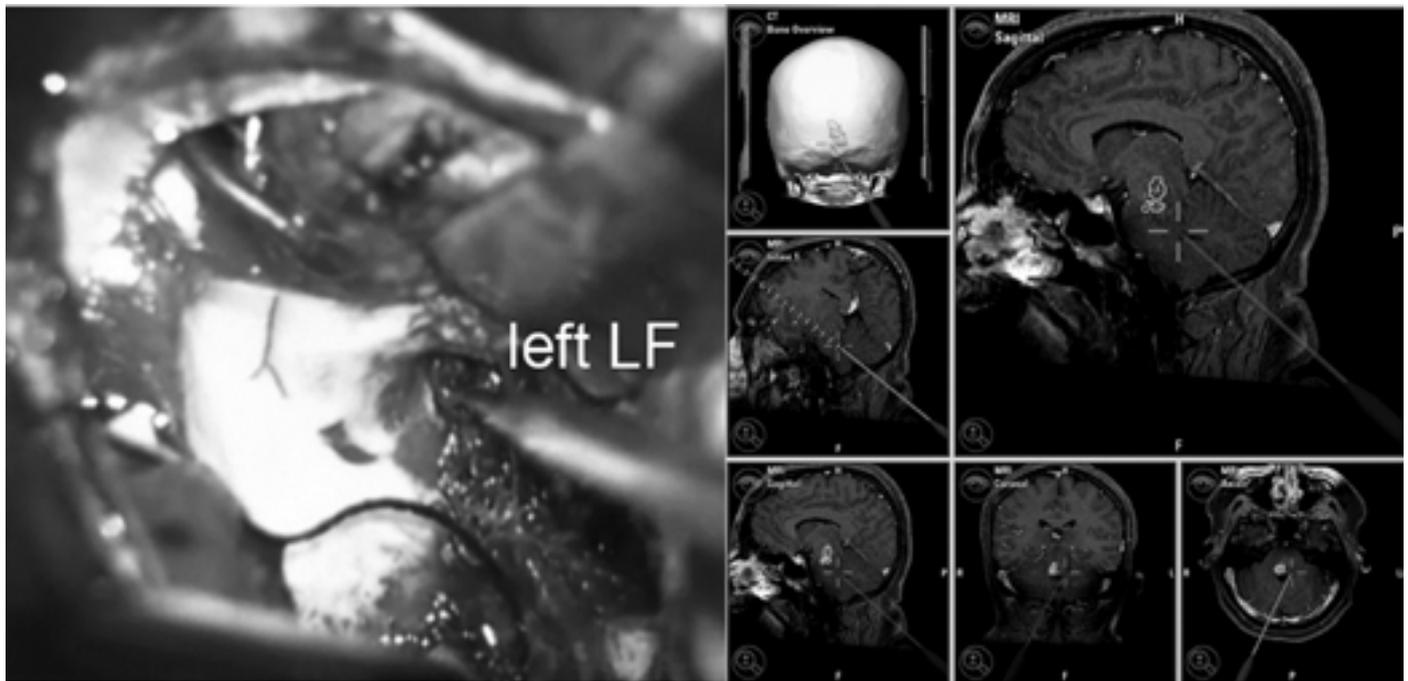
the real structures. In the subtentorial supracerebellar approach, the quadrigeminal plate and the cerebellar tentorium were the structures used for accuracy check. Measurement of deep structures to determine accuracy flaw, comparing the virtual with real position, was performed with microsurgical dissector and pre-calibrated pointer.

## RESULTS

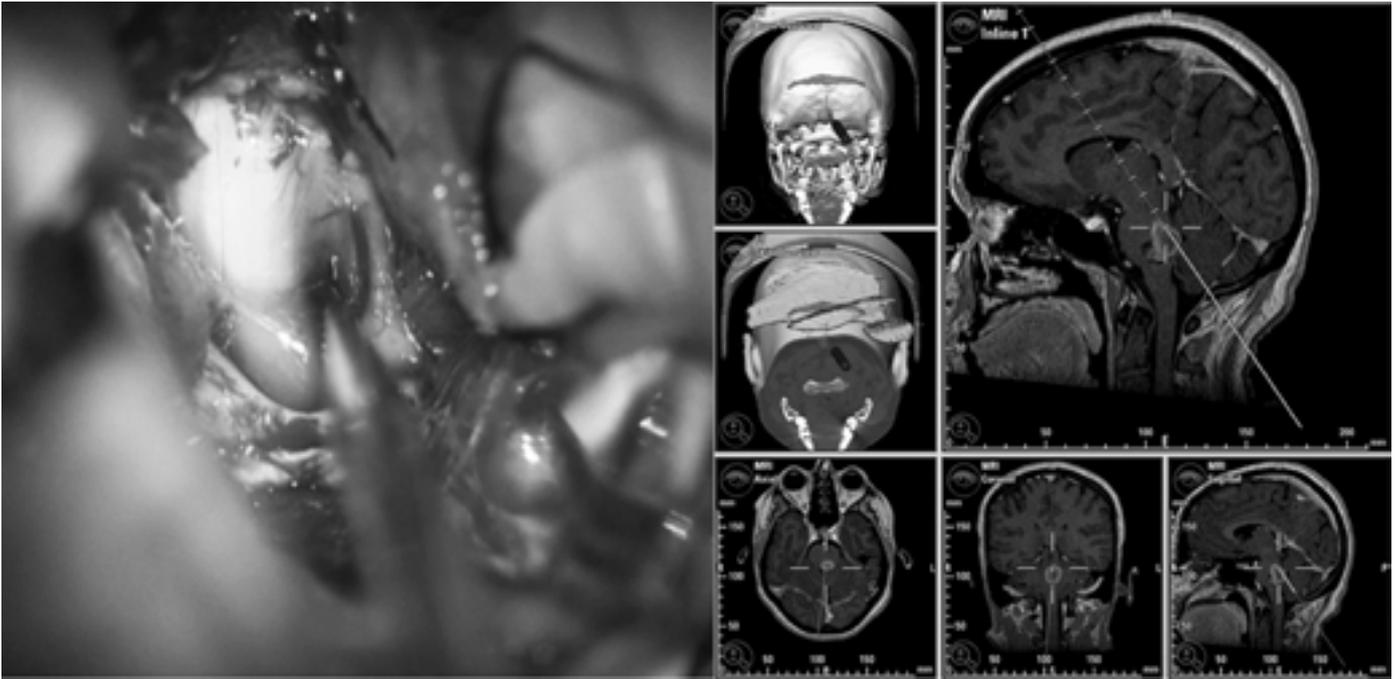
The five anatomical landmarks used for registration were identified after skin incision and bone exposure, before craniotomy (Fig. 3). In all cases, time for intraoperative registration was inferior of two minutes. The accuracy was satisfactory for navigation on brainstem, especially the structures of the fourth ventricle (Fig. 4) and the cavity after tumor removal (Fig. 5). Fused MRI and CT images had no accuracy difference during navigation. The findings with surgical microscope view comparing with the position displayed on navigator screen showed reliability in all cases. The cerebellum was the only structure with impaired navigation by shift after cisternal drainage. There was no mortality and no complication related with the method.



**Figure 3.** Registration using the anatomical landmarks intraoperatively. **A.** Display on Neuronavigator screen; **B.** Display on skull anatomical landmark (inion).



**Figure 4.** Navigator screenshot and intraoperative picture showing the pointer in the roof of fourth ventricle. LF Foramina of Luschka.



**Figure 5.** Navigator screenshot and intraoperative picture showing the pointer in the place for incision in the brainstem.

## DISCUSSION

Although navigation systems have become widely used in neurosurgery, its usefulness in certain situations is still limited or even impaired. The quality of image data (image acquisition, slice thickness, CT versus MRI scans, artifacts etc.) is the first step that can influence subsequent surgical accuracy<sup>3,14</sup>. Through image-acquisition protocols, these problems can be avoided. The surgical planning in the workstation is another step where the navigation accuracy could be affected. It is totally operator-dependent and while some surgeons use it systematically, others hardly ever do it. All cases described in this article underwent meticulous surgical planning in order to improve navigation quality.

The registration method and how it will be performed is the most important step on neuronavigation. There are three types of registration methods for navigation<sup>3,4,5,6,7</sup>: a) anatomical landmarks, using at least four anatomical structures, such as tragus, nasion, without the need of a scan immediately before surgery, b) fiducial markers (adhesive or skull implanted), requiring image scan before surgery, c) surface matching method, that consists of a LASER registration with the patient's face. Although there are evidences of similar accuracy between

these methods, skull implanted fiducials seem to be the gold standard with lesser registration error<sup>3,4</sup>. However, this method is invasive and requires additional time and extra expenditure.

There are registration limitations for posterior fossa surgery, especially when it is performed in prone position. In this case, registration with surface matching is impaired by distortion causing loss of accuracy, probably due to the distance from the face to the area of interest. The use of skin anatomical landmarks may also be impaired by the difficulties to identify the precise anatomic reference points in suboccipital midline skin region. The registration with fiducial markers is safe and widely used, despite the disadvantages previously described.

The use of anatomical landmarks on skull base for navigation registration can be performed after skin incision. This method is often used during navigation in spinal procedures<sup>13,15</sup>. Once the necessary landmarks are exposed on the operatory field, the registration can be performed easily and flawless. It avoids a possible variation in the anatomic landmarks identification that occurs at the skin surface registration. The use of foramina, angles, and the beginning or end of sutures on bone surface as anatomical landmarks provides a more logical consistency in registration. As these points are closer to the area of interest than skin points, it favors the registration to a better accuracy for targets in deep structures<sup>2</sup>. We choose the utilization of

five points in case of loss of one anatomical landmark after bone exposure, even in all related cases we had all points well identified.

During suboccipital midline approach, cerebellum navigation has an increased accuracy error after cisternal drainage<sup>16</sup>. However, brainstem is still a fixed structure and the brain shifting does not seem to interfere with the registration. In the present study, the tumor localization was performed accurately. The navigation was also useful to determine the place for incision in the roof of the fourth ventricle. Although we perform registration with skin anatomical landmarks in navigation for retrosigmoid approaches<sup>17</sup>, the use of intraoperative registration in craniocervical approaches in our service also seems to use better anatomical points for navigation registration in lateral skull base surgery.

There were two possible biases identified in the intraoperative anatomic landmark registration. The first is a possible 1 to 2 mm error in MRI to CT correlation after fusion<sup>3</sup>. This was not measurable in any case from this study and appears to be insignificant. The other bias was the usage of anatomical landmarks on C1 vertebral surface. According to the head's fixed position for surgery, the relationship with skull base and C1 may be different from the image data used for navigation. With the neck flexed, the distance of the posterior arch of C1 to the foramen magnum can increase when compared to the neutral position. Rotation is not a problem, since the occiput-C1 joint do not have this movement. With the use of several points as landmarks, this source of registration error is probably corrected. It may also induce a registration error, especially in cases of excessive head flexion. We had no problem with it in our series; however, it may be an important aspect to be considered about the method.

## CONCLUSIONS

Intraoperative registration with skull anatomical landmarks is an easy and reliable method for brainstem navigation. The accuracy flaw is insignificant and may not interfere in the identification of brainstem structures. This method can be a safe and faster alternative for registration with fiducials with minimal accuracy flaw.

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