

Stereoscopic virtual reality presurgical planning for cerebrospinal otorrhea

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ABSTRACT

نحن هنا بصدد نشر تقرير حالة معقدة لسيلان الأذن الدماغية النخاعي التلقائي، والذي تم علاجه من خلال 5 عمليات جراحية في الماضي. كان السبب الرئيسي للمحاولات الفاشلة الماضية هي عدم قدرة تحديد موقع الناسور. ولهذا الوقت، أجريت خطة منظار لما قبل الجراحة الافتراضية لتحديد موقع الناسور بدقة، وإجراء العملية الجراحية، الذي أكد خلال وقت العملية الفعلي. أن المعالجة المتداخلة في المحيط الافتراضي للمنظار يجعله أسهل من قبل لتحديد قرار خطة علاج سيلان الأذن الدماغية النخاعي.

We present a complicated case of spontaneous cerebrospinal otorrhea, which had not been cured despite undergoing 5 surgical interventions in the past. The disability to identify the location of the fistula was the main crux of the past failures. On this occasion, stereoscopic virtual reality presurgical planning was applied to identify the exact location of the fistula and a surgical simulation was performed, and was later confirmed during the actual operation. Interactive manipulation in a stereoscopic virtual environment makes the decision making process easier in the treatment of cerebrospinal otorrhea.

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Persistent CSF otorrhea is uncommon and those who need neurosurgical interventions have a dismal outcome due to an increased frequency of bacterial meningitis and low-pressure headache when treatment fails. Therefore, successful treatment depends on properly diagnosing CSF otorrhea and locating the fistula that

allows the CSF leak. First, a diagnosis of CSF otorrhea is obvious when there is CSF leakage from a perforated tympanic membrane into the external auditory meatus. However, for some, the tympanic membrane remains intact, and CSF leaks via the pharyngotympanic tube mimicking CSF rhinorrhea.¹ Therefore, CSF otorrhea should be included into the differential diagnosis of CSF rhinorrhea to avoid a misdiagnosis and delay in treatment. Second, the location of the fistula, which allows the leakage of CSF, is often difficult to localize. Finding the exact location of the fistula is a prerequisite of a successful neurosurgical repair. However, this is often hampered by the complexity of the temporal bone, which has many fine foramina and cavities, and each one of these fine structures can harbor a fistula. To complicate matters further, there may be more than one fistula causing the CSF leak.² Therefore, selecting the proper neurodiagnostic techniques is critical to localize the fistula. Traditional CT, MRI, and CT cisternography may not reveal the location of the fistula due to limited information from the 2-dimensionality (2-D) of these techniques and the static images they provide. Having a set of dynamic information that can be visualized in 3-dimensional (3-D) space would be an appealing approach to this problem. Virtual reality simulation is used with increasing frequency for enhancing the procedural skills of technically complicated tasks, such as operating an airplane, driving an automobile, sailing a boat, and constructing a building. Neurosurgeons also adopted this advanced technology for complex procedures.³⁻⁵ The Dextroscope (Dextroscope®, Volume Interactions Pte. Ltd., Singapore) is a recently developed interactive stereoscopic virtual reality simulator, and it has proven utility in complex neurosurgical procedures.⁶ It employs patient-specific neuroradiology data, which can be transferred into a workstation, to generate a fused

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3-D model of the cranium. Specific cranial structures could be selected, shaped, and colored by using various segmentation and visualization tools on the workstation. These capabilities would allow the development of novel neurosurgical approaches, and to optimize the outcome of complex neurosurgical procedures by formulating the optimal presurgical planning, allowing preoperative rehearsal, and predicting potential complications during the actual procedure. Furthermore, neurosurgical trainees and residents can practice simulated procedures using the stereoscopic 3-D vision and interactive manipulation of computer-generated human cranium models in the virtual environment.^{3,6-8} It is important for developing their neurosurgical skills particularly for areas of the head with complicated anatomy, and for complex operative procedures.

In this report, we describe an innovative application of an interactive stereoscopic virtual reality simulator, the Dextroscope, for presurgical planning and surgical rehearsal in a patient-specific repair of CSF otorrhea.

Case Report. The patient was a 42-year-old man with an initial history of CSF rhinorrhea starting 7 years prior to his presentation. He had no antecedent systemic illness, head trauma, intracranial neoplasm, or cranial nerve disturbances. His neurological examination was normal except for slight hearing loss. He underwent 2 tandem repair operations at a local hospital via an extensive sub-frontal extradural approach and a transnasal, transsphenoidal approach; but neither helped. Following poor results, these operations led to the realization by his local neurosurgeons that he did not have a simple cerebrospinal rhinorrhea. A third operation was performed a year later, via a left sub-temporal extradural approach, which resulted in the cessation of CSF rhinorrhea, but led to left-sided CSF

otorrhea. Two years later, a fourth repair procedure, via a left suboccipital, retromastoid, subdural approach, and a fifth operation, via a left trans-labyrinthine approach, both failed to control his CSF otorrhea. While undergoing these complex basal skull procedures, his functional hearing was preserved. Because of the poor results in controlling his CSF leaks despite 5 extensive operations, he decided to halt any further repair procedures. Seven years after his initial diagnosis, he developed a series of bacterial meningitis and he sought additional neurosurgical consultations. A CT cisternography demonstrated leakage of contrast into the external auditory meatus suggesting the presence of a fistula connecting the subarachnoid space and the external ear (Figure 1). However, it was still difficult to determine the exact location of the fistula by viewing the 2-D images from CT cisternography. Unexpectedly, his CSF leak stopped after CT cisternography, presumably from blockage of the fistula by contrast medium. However, further surgical intervention resumed after CSF otorrhea recurred. First, a patient-specific standard axial lamellate helical CT scan and a CT cisternography were performed, fused, and imported into the Dextroscope® workstation (Volume Interactions Pte. Ltd., Singapore), according to previously described procedures.⁶ Briefly, imaging processing was carried out by generating a patient-specific 3-D stereoscopic cranium model. This model was simultaneously displayed on a monitor (1024 × 768 pixels) and reflected via a mirror into the user's stereoscopic glasses. Electromagnetic sensors conveyed hand motion information, including the positions of a 6-D controller in the left hand and a stylus in the right hand, which was integrated into the computer. This integration allowed the user, or virtual neurosurgeon, to use various tools (cloning, extracting, contouring, and so forth) to visualize the virtual operation while

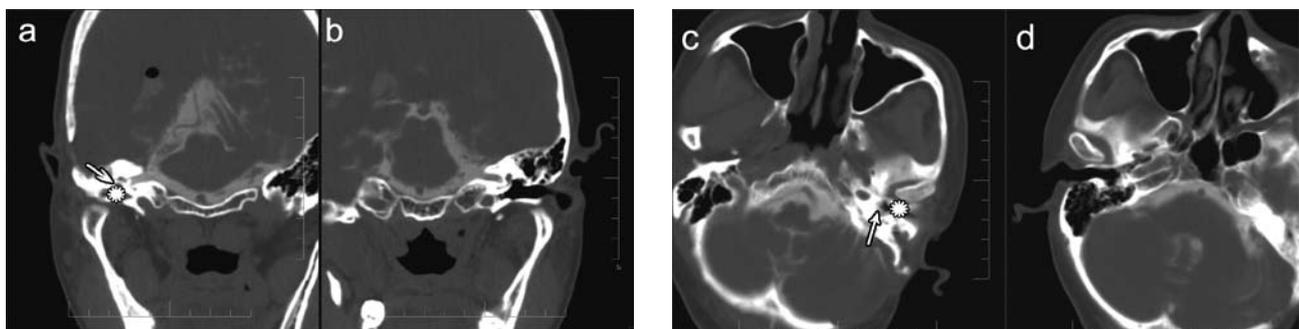


Figure 1 - The CT cisternography showing a suspected fistula (arrows) respecting 2-D CT imaging data set. a) coronal view of affected side, b) coronal view of contrasted side, c) axial view of affected side, d) axial view of contrasted side. The CT cisternography used a 16-row multi-slice CT scanner (GE LightSpeed 16; GE Healthcare, Waukesha, WI, USA). The imaging data set was acquired in coronal sections covering the entire volume of temporal bone with the following parameters: thickness 2.5 mm, tilt 22.0 degrees, exposure time 1.0 s, matrix 512×512 pixels, field of view 240×240 mm. * - contrast medium.

manipulating with virtual instrumentations (picking, cropping, cutting, drilling, and so on). The anatomic structure of interest was then extracted and displayed on the monitor. For this patient, we initially performed virtual neurosurgery using the Dextroscope by first obtaining a 3-D stereoscopic cranium model from high-resolution head CT. We found a bone defect at the surface of the left arcuate eminence, which was not seen on the opposite side (Figure 2). But, this finding alone was not sufficient to detect the location of the fistula if the dura covering this bone defect was intact, preventing the leakage of CSF. To better identify the fistula, we fused the CT cisternography images with the high-resolution anatomic CT images to generate a 3-D cranium model, and we detected leakage of

contrast through the bone defect into the left external auditory meatus (Figures 3 & 4). The structure of the left tympanic cavity and ossicles was normal (Figure 4), and this finding may explain preservation of his hearing. During pre-surgical planning and rehearsal in the virtual environment, we identified that a left sub-temporal extradural approach was the best approach to expose and to repair the fistula (Figure 5). Therefore, we adopted this approach in the actual operation, and we found the corresponding fistula, as well as the bone defect, fistula, meningocele, and ulceration of cutaneous covering of the external acoustic meatus (Figure 6a) as seen in the virtual operation (Figure 5). As expected, we observed CSF leaking through the bone defect and the identified fistula. We meticulously repaired the fistula

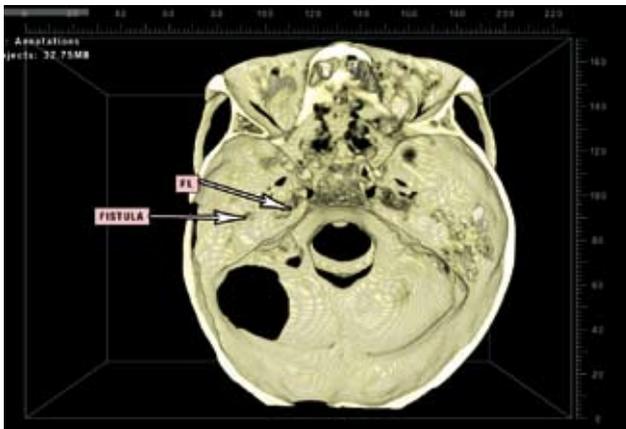


Figure 2 - Snapshot showing a bone defect (suspected fistula) at the surface of the left os petrosum, approximately 15 mm outside the left foramen lacerum (FL), from the vertex view.

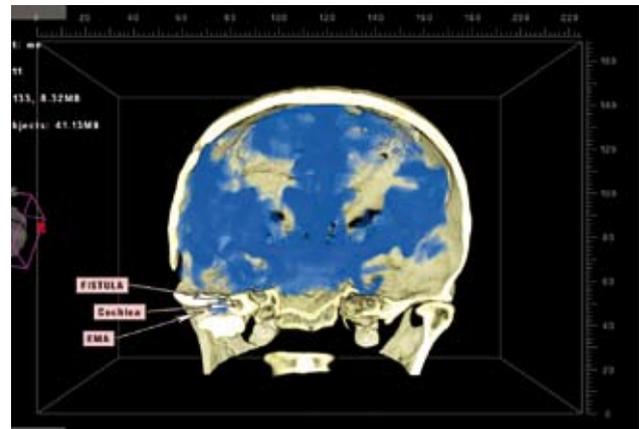


Figure 3 - A 3-D reconstruction of infused imaging data sets of CT and CT cisternography, from the coronal view. The contrast medium was colored blue, leaking into the left external acoustic meatus (EAM).

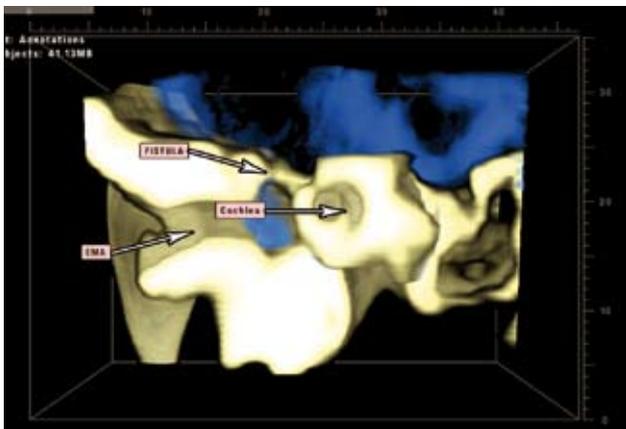


Figure 4 - Snapshot showing the fistula (amplified local anatomic structure of Figure 3). The fistula was on the left side of the ossicular chain and communicated with the external acoustic meatus (EAM). The contrast medium (colored in blue) leaks into the EAM through the exact location of the fistula.

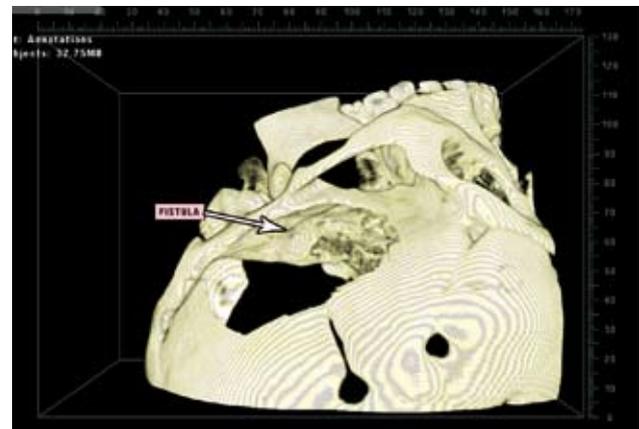


Figure 5 - Snapshot showing the fistula from the operative view (via a left sub-temporal extradural approach).

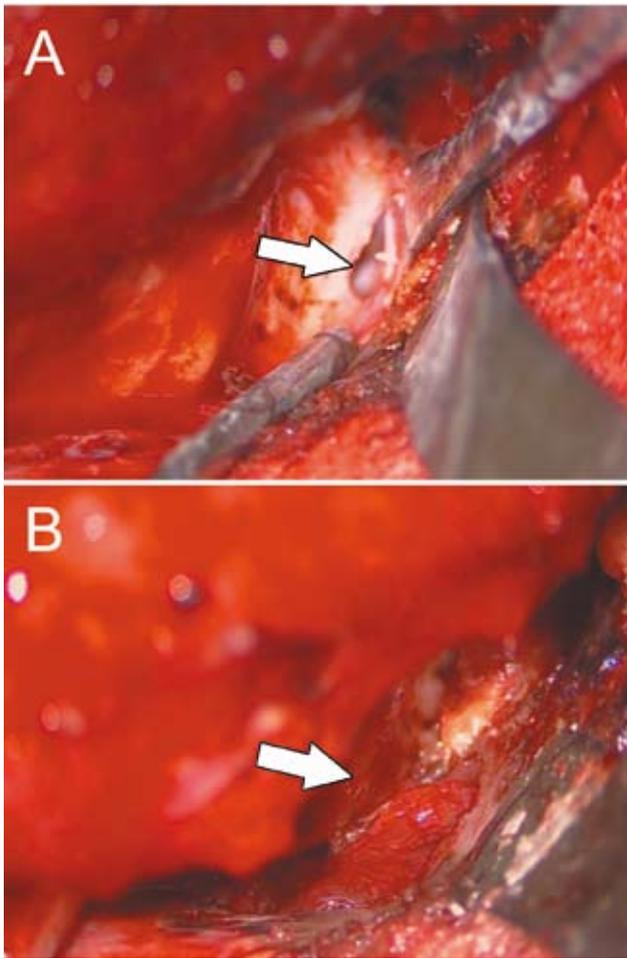


Figure 6 - Intraoperative photography verifying the fistula (arrows) indicated in a) the simulated surgery, b) taken after the fistula was repaired with self adipose tissue.

with autologous adipose tissue (Figure 6b). In the next 6 months, he showed no signs or symptoms of CSF otorrhea or meningitis.

Discussion. To repair a CSF leak from the skull base, identification of the fistula by neuroimaging is paramount before the actual operative procedure. Typical neuroimaging modalities used include high-resolution plain CT (best for detecting bone defects), T2-weighted MRI, 3-D reconstructed CT imaging, and CT cisternography, but each has its limitations in identifying the fistula. Plain CT is best used to detect bone defects such as fractures; but its 2-dimensionality provides insufficient spatial resolution to locate the exact position of the fistula. The MRI is preferred to delineate the brain tissue, reactive, or inflammatory tissue in the brain or meninges, meningoencephalocele, and CSF space. A reconstructed 3-D CT imaging data set offers better visualization of the skull base and bone

defects, as well as their relationship to the surrounding soft tissues. Because having a bone defect does not correlate with the existence of a fistula, 3-D CT still offers insufficient information for exact localization of the fistula. The CT cisternography, despite its inherent risks such as infection, allergy on account of contrast agent injection, and/or patient's discomfort, offers direct visualization of the CSF leak. But, the 2-D images on CT cisternography provide only vague spatial localization of the fistula. These routine examinations may be useful in some simple cases, but in cases when there were more than one fistula causing the CSF leak,² or when CSF otorrhea mimics CSF rhinorrhea,¹ more advanced technologies are needed.

Stereoscopic virtual reality simulation is the latest technology applicable for the treatment of CSF leak in the skull base. In this report, we described an innovative application of interactive 3-D stereoscopic virtual reality simulator for presurgical planning and surgical rehearsal in patient-specific treatment of CSF otorrhea. We could, first, identify the fistula by fusing the high-resolution CT and CT cisternography images, because the 3-D stereoscopic view offers better delineation of the fistula by high-resolution CT or CT cisternography available in 2-D or reconstructed 3-D images. Second, the simulation in the stereoscopic virtual reality environment offers presurgical planning and rehearsal before the actual operative procedure, allowing the neurosurgeon to anticipate potential complications and probably offering better outcome.

Although the bony structures in the skull base do not deform when manipulated during the operative procedure, the surrounding soft tissue, including brain, blood vessels, and nerves, may deform during manipulation and thus lose their spatial registration. Therefore, simulation of soft tissue deformation and finding proper spatial registration of the deformed tissues is an improvement needed in stereoscopic virtual reality neurosurgery.

In conclusion, multi-modality infusion of patient-specific imaging data sets with stereoscopic visual perception might supply optimal delineation of the complex anatomic structure. Furthermore, the interactive manipulation for surgical simulation in a stereoscopic virtual environment realizes the best possible outcome for individual treatment of cerebrospinal otorrhea.

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