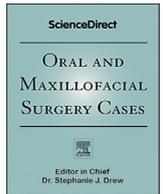




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Removal of small foreign bodies from the maxillary sinus using CT image-guided surgical navigation and rapid paired-point registration and calibration with reference markers on an occlusal splint

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ABSTRACT

Computed tomography (CT)-guided surgical navigation is useful for removing foreign bodies from the maxillofacial region. Accuracy and speed of registration and intraoperative calibration are essential for functional intraoperative navigation. A case in which foreign bodies were removed from the maxillary sinus using paired-point registration and calibration with reference markers on an occlusal splint for CT-guided surgical navigation is reported. A 49-year-old woman presented with spontaneous right cheek pain. Panoramic radiography showed two foreign bodies in her right maxillary sinus. Under general anesthesia, an occlusal splint with reference markers was set on the maxillary dental arch, and the anterior wall of the maxillary sinus was exposed. Foreign bodies were identified using an infrared optical Kick[®] Navigation System (Brainlab AG, Munich, Germany). The anterior wall of the maxillary sinus closest to the foreign bodies was penetrated with a trephine bur, the foreign bodies were removed, and the wound was completely closed. Several repeated calibrations were required to obtain accurate positional information about the foreign bodies during the surgery, but these were completed within 30 seconds. Histopathological findings and the postoperative clinical course indicated that the spontaneous right cheek pain was due to maxillary sinusitis with granulomatous inflammation caused by the foreign bodies. CT-guided surgical navigation using an occlusal splint with reference markers was useful for locating the foreign bodies in this patient, and rapid calibration allowed accurate positional information to be obtained during surgery to remove them from the maxillary sinus.

1. Introduction

A computed tomography (CT)-guided surgical navigation system has been reported to be useful for removing foreign bodies from the maxillofacial region [1–11]. An accurate registration and calibration process is essential for successful intraoperative navigation. Although positional information is generally acquired from reference devices attached to the patient and surgical instruments, intraoperative 3D coordinates of the patient can become destabilized depending on how reference devices are fixed. Therefore, a simple way to calibrate intraoperative 3D coordinates of the patient to accurately determine location during surgery is needed.

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The inadvertent deposition of endodontic products into the maxillary sinus causes various clinical symptoms such as sinus pain and pressure, acute and chronic sinusitis, pain on mastication, and tenderness to palpation [12–15]. Such clinical symptoms can be relieved using CT-guided surgical navigation to remove foreign bodies from the maxillary sinus [16]. However, the instability of reference devices adversely affects navigation accuracy when objects are very small. Removal of small foreign bodies from the maxillary sinus using CT-guided surgical navigation and an occlusal splint with radiopaque reference points for navigation registration is described.

2. Presentation of case

2.1. Patient information

A 49-year-old Japanese woman presented with a chief complaint of right cheek pain in April 2017. She stated that her dentist had started a root canal treatment of her maxillary second molar three months previously. Spontaneous right cheek pain started one month after the root canal treatment was started. The patient was referred to our clinic due to refractory pain. Her personal and family medical histories were unremarkable. Although the patient did not present with nasal discharge or any other nasal symptoms, she had severe percussion pain in the right maxillary second molar. A panoramic radiograph showed a low-density lesion in the right maxillary sinus, and there were two higher-density masses that suggested foreign bodies (Fig. 1). Therefore, right maxillary sinusitis with displaced foreign bodies was diagnosed. The foreign bodies were removed from the maxillary sinus using CT-guided surgical navigation.

2.2. CT-guided surgical navigation

A dental gypsum model and an occlusal multi-purpose, pour-type resin splint (Procast DSP; GC, Tokyo, Japan) with five small hollows on the labial side for the maxilla were prepared preoperatively. A radiopaque light-cured composite resin (Filtek™ Supreme Ultra Flow Composite Resin; 3M Japan Ltd., Tokyo, Japan) was placed in the hollows (Fig. 2). To use the splint as a reference for navigation surgery, cone beam computed tomography (CBCT) images were acquired (KaVo 3D eXam, KaVo Dental Systems Japan, Yao, Japan) with the patient wearing the occlusal splint. The images showed thick mucosa at the right maxillary sinus floor and an oval foreign body ($4 \times 2 \times 1 \text{ mm}^3$) located next to the thickened mucosa. Another foreign body ($9 \times 2 \times 1 \text{ mm}^3$) was identified in the superior wall of the maxillary sinus. Radiopaque reference markers at the occlusal splint were easily identified on the CBCT images, which were analyzed using an IGS Planning Work Station (Brainlab AG, Munich, Germany) with integrated software (iPlan CMF 3.0). The foreign bodies were accurately identified on CBCT images, and preoperative surgical simulation and preparation were performed with iPlan CMF 3.0. The five radiopaque points on the occlusal splint on CT images were registered as intraoperative reference landmarks. These data, including preoperative surgical preparation, were imported into the infrared optical Kick® Navigation System (Brainlab AG). A reference frame for the navigation system was positioned on a headband immediately before the surgery and placed on the patient. The occlusal splint with reference markers was then fitted to obtain actual real-time intraoperative positional information. The five reference markers on the occlusal splint were paired with the corresponding reference points on the CBCT images for paired-point registration. The accuracy of the positional information was maintained by repeated paired-point calibration between reference points on the occlusal splint and the CBCT images if misregistration occurred during the surgery.

2.3. Surgical procedure

The first step of the surgery was paired-point registration with reference markers on an occlusal splint. After the anterior wall of the maxillary sinus was exposed (Fig. 3A), paired-point calibration was performed. The positions of the foreign bodies were identified using a navigation pointer linked to a CBCT image (Fig. 3B). The anterior wall of the maxillary sinus closest to the foreign bodies was penetrated using a trephine bur, and the foreign bodies were removed. The wound was closed after curettage around the sites where the foreign bodies had been located. The surgical duration was 1 hour and 55 minutes, and intraoperative bleeding was minimal. Several calibrations were completed within 30 seconds each to ensure accurate intraoperative positional information about the foreign bodies.



Fig. 1. Initial panoramic X-ray findings. White arrows: radiopacity in the right maxillary sinus and at the apex of the root of the right maxillary second molar.



Fig. 2. Registration of the occlusal splint. The occlusal splint comprising a multi-purpose pour-type resin is based on a maxillary dental gypsum model of patient. Five reference points are positioned on the labial side of the splint, and a radiopaque light-cured composite resin is placed in the reference points. White arrow, radiopaque reference points.

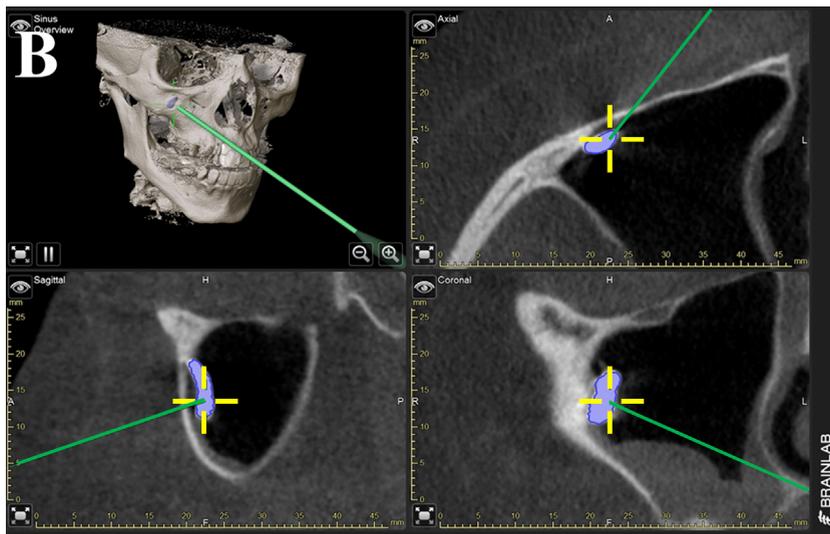


Fig. 3. Intraoperative images. Positions of foreign bodies confirmed using navigation pointers (A). Three-dimensional coordinates of foreign bodies navigated using preoperative real-time CBCT images (B).

2.4. Histopathological findings and elemental analysis of foreign bodies

The removed foreign bodies were white hard matter (Fig. 4). Histopathological findings of the tissues around the foreign bodies showed epithelialized maxillary sinus membrane-like fibrous granulation tissue and chronic inflammatory cell infiltrate consisting mainly of neutrophils (Fig. 5). Elemental analysis of the foreign bodies showed mostly zirconium, oxygen, and carbon.



Fig. 4. Resected specimens. White foreign bodies are hard and brittle, with smooth surfaces.

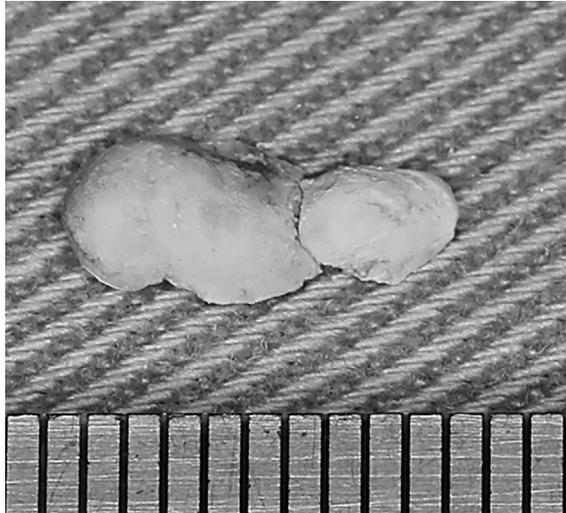


Fig. 5. Histopathological findings of resected tissues with foreign bodies (hematoxylin-eosin stain; $\times 100$).

2.5. Postoperative follow-up

Postoperative panoramic radiography confirmed the complete removal of the foreign bodies (Fig. 6). The patient's postoperative course was uneventful. There was no sinusitis or hypoesthesia of the branches of the maxillary nerve. Two weeks after the surgery, the percussion pain in the right maxillary second molar had disappeared. At the half-year follow-up, the patient was free of postoperative infection or other adverse events.

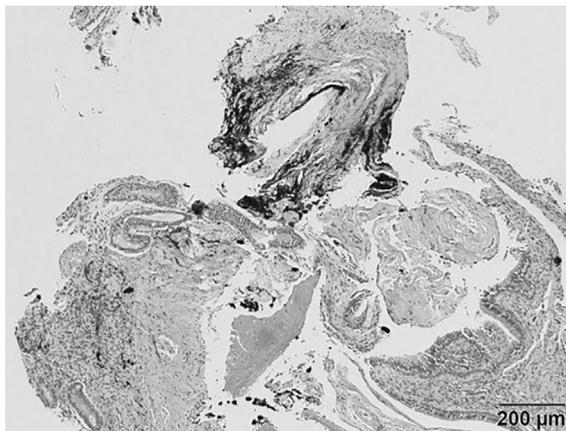


Fig. 6. Postoperative panoramic X-ray findings. Radiopaque lesions are absent in the right maxillary sinus. Fibrous granulation tissue with maxillary sinus membrane-like epithelialization is seen along with inflammatory cell infiltrate, consisting mainly of neutrophils, in the fibrous tissue. Another portion shows bone-like hard tissue fragments and dark brown foreign bodies.

3. Discussion

Several reports have described foreign bodies in the maxillary sinus associated with dental treatment [12–15]. Most foreign bodies associated with root canal treatments are small, and they are difficult to identify and remove when deeply embedded in the maxillary sinus [12]. Furthermore, failure to remove such foreign bodies can result in sequelae, such as maxillary sinusitis [14,15]. Very small (width, approximately 2 mm; maximum thickness, 1 mm) foreign bodies were identified in the maxillary sinus of the present patient on CBCT. It was thought that blind removal of the foreign bodies from the maxillary sinus would have a high risk of fracture and scatter, and, thus, they were accurately located and safely removed using CT-guided surgical navigation, which is a support technique that reduces surgical duration in complex anatomic areas [17–19].

The navigation system is also useful for head and neck surgery because the three-dimensional position of a lesion or target can be determined intraoperatively [20,21]. Foreign bodies such as broken needles [1–3], projectiles [4–6], displaced teeth [7,8], and fragments of dental material [9–11] can be identified and removed using CT-guided surgical navigation. Although the accuracy of detecting foreign bodies of a specific size is assured, the ability of CT-guided navigation to detect very small objects is compromised by positional shifts of patients or reference instruments. Nevertheless, much smaller foreign bodies than those previously described were accurately located and safely removed from the maxillary sinus in the present case [1–11].

The accuracy of positional information provided by CT-guided navigation about foreign bodies must be maintained to remove them [1–11]. Although the infrared optical CT-guided surgical navigation system has the line-of-sight limitation, it is more accurate and reliable than an electromagnetic system [22]. With an infrared optical CT-guided surgical navigation system, submillimeter accuracy can be achieved with paired-point registration of the external fiducial markers in a specimen face [22]. Since changes occurring at the surgical site during manipulation cannot be visualized by surgeons on images [16], calibration to maintain accuracy is needed for CT-guided surgical navigation. The two main approaches to maintaining the accuracy of navigation registration (calibration) are surface matching, in which the skin surface is scanned using a laser, and paired point registration, which uses markers with a reference instrument [23]. Although surface matching is simple, positional errors associated with the softness and flexibility of the skin result in more problems than paired-point registration [23]. Therefore, paired matching registration was used in the current case. The key to intraoperative accuracy in paired matching registration is the direct [23,24] or indirect [25,26] fixation of a rigid reference frame to the skull or headband, respectively. The accuracy of skull fixation is high, but the present patient did not agree to this invasive approach. Therefore, the reference frame was fixed to a headband, which is less accurate than skull fixation due to interference caused by a surgeon moving the head of a patient intraoperatively. Thus, rapid and simple repeated calibration that matches the spatial coordinates of a patient and the CT image data is required whenever positional information errors occur during surgery. The occlusal splint worn by the present patient during preoperative CT and surgery has five radiopaque reference points that allow rapid and simple recalibration and consistent accuracy. The patient was fitted with a splint, and CBCT images were acquired before surgery. Reference markers at the occlusal splint were easily identified on CBCT images because the markers are radiopaque. Paired-point registration (calibration) was completed within 30 seconds, which allowed repeated calibrations that generated consistently accurate positional information throughout the surgical procedure. Preoperative planning based on CT findings should be registered to the navigation unit within 1 min [27]. Therefore, our methodology for registration and calibration appears appropriate for the minimally-invasive removal of foreign bodies that have migrated into the maxillary sinus.

The present methodology may be useful not only for removal of foreign bodies from the maxillary sinus, but also for any other maxillofacial surgery that requires accuracy and speed. For example, CT-guided surgical navigation for orthognathic surgery has the advantages of avoiding critical structures and the opportunity to reflect on the preoperative surgical planning [20,21,28,29]. However, maintaining the accuracy of the navigation system during the surgery remains problematic. Conventional intraoperative 3D coordinate registration and calibration are complicated and time-consuming. Therefore, the methodology for registration and calibration may be useful for orthognathic surgery. Furthermore, the usefulness of CT-guided resection for ankylotic bone in TMJ gap arthroplasty has been reported [30]. Rapid paired-point registration and calibration with reference markers on an occlusal splint may be valuable in safe surgical excision of the bony ankylosis from the skull base.

Even when the surgeon can grasp the exact positional information for a foreign body preoperatively, it is difficult to accurately and quickly identify the foreign body intraoperatively. There are various techniques for localizing an object within soft and hard tissues [31]. Wei et al. reported the usefulness of a customized, computer-designed surgical guide bar that was designed to facilitate removal of a skull base foreign body [32]. However, the determined object location may not have perfect accuracy because this methodology requires many steps for the preoperative plan and designing the instrument [32]. Although intra-operative ultrasound imaging has been suggested to localize foreign bodies [31,33,34], it does not provide precise positioning, and its use in the small oral cavity is limited by the size of the device [24]. Previous reports have successfully used C-arm fluoroscopy to detect and remove foreign bodies in the maxillofacial region [35–38]. Because fluoroscopic images are two-dimensional, they do not provide accurate positional information about the foreign body in three-dimensional spaces such as the maxillary sinus [20]. On the other hand, CT-guided surgical navigation can provide accurate positional information for a foreign body, even in a 3D space [1–11]. Moreover, the problems of the complexity of intraoperative calibration may be solved by our methodology with rapid paired-point registration and calibration with reference markers on an occlusal splint.

The painful symptoms in our patient were apparently due to maxillary sinusitis with granulomatous inflammation caused by foreign bodies according to the histopathological findings and the postoperative clinical course. Moreover, elemental analysis indicated that the foreign bodies included fragments of a removed dental prosthesis. Since complete removal of foreign bodies from the maxillary sinus was quickly archived with minimal invasion, postoperative inflammation was minimal, and the patient was sufficiently satisfied with the treatment.

CT-guided surgical navigation for the removal of foreign bodies has limited applicability when a foreign body is embedded in soft tissue. The system cannot follow the changes in soft tissues during the surgery [1]. Although prompt retrieval is encouraged to prevent migration and potential damage to vital structures, performing such a procedure may result in pushing the foreign body deeper into the soft tissue architecture. Thus, delaying removal for several weeks should be considered to allow the tissue edema to resolve and to allow potential fibrosis to occur around the foreign body, making surgical removal easier [39]. One limitation of using CT-guided surgical navigation for the removal of foreign bodies in the maxillary sinus is determining the optimal time to proceed, because foreign bodies can move in the maxillary sinus at any time. This interferes with the reliability of preoperative imaging and planning. The foreign bodies had remained fixed in the maxillary sinus of the present patient for at least one month, possibly because they were surrounded by fibrous connective tissue or thickened mucosa, which was advantageous for the surgery. Gui et al. recommended a waiting period of at least one month before surgically removing foreign bodies [6]. Another limitation of CT-guided surgical navigation for the removal of foreign bodies is that is only useful for the removal of radiopaque foreign bodies. Moreover, the present methodology has the risk of causing pressure sores under the headband during long surgical procedures. However, pressure sores did not appear within the 2 h of surgery in the present patient. Reducing the number of calibrations during surgery is important to save time. Thus, a more appropriate way of draping and headband fixation to decrease the effect of patient mobility should be considered. In the future, the accuracy of positional information and rapid calibration should also be improved so that the present methodology can be widely applied to maxillofacial surgery.

4. Conclusion

In this case, CT-guided surgical navigation using an occlusal splint with reference markers was useful to locate the foreign bodies in the maxillary sinus. Moreover, rapid calibration allowed accurate positional information to be obtained during surgery to remove the small foreign bodies from the maxillary sinus. The present methodology for registration and calibration may be useful for not only removal of foreign bodies from the maxillary sinus, but also for any other maxillofacial surgery that requires accuracy and speed, such as orthognathic surgery.

Conflicts of interest

The authors have no conflicts of interest to declare.

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