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Navigation-guided core needle biopsy for skull base and parapharyngeal lesions: a five-year experience

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Abstract. The aim of this study was to evaluate the diagnostic accuracy of navigation-guided core needle biopsy for skull base and parapharyngeal lesions. Twenty patients with skull base and parapharyngeal lesions were included in this study. The preoperative design and intraoperative real-time image guiding was done using an optical navigation system. A spring-loaded semi-automatic biopsy gun and biopsy needle were used for specimen harvesting. Accuracy was established on the basis of the postoperative pathology. All patients underwent needle biopsy successfully without any immediate or delayed complications. The subzygomatic approach was adopted in all cases. The number of passes ranged from three to five. The diagnostic accuracy was 90% (18/20). Navigation-guided core needle biopsy offers an easy approach for the diagnosis of skull base and parapharyngeal lesions, with a high yield of specimens and good patient tolerance.

Key words: core needle biopsy; skull base; tumour; navigation.

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Lesions arising from the skull base and parapharyngeal space are clinically rare and their management is highly challenging. Conventionally, preoperative pathological diagnosis remains a standard requirement for better counselling and therapy. With a sufficient amount of specimen obtained by open biopsy, the pathologist will be able to diagnose such lesions easily. However, because of the deep location and difficult surgical approach for the skull base region, the inherent risks and difficulties of performing an open biopsy would not be greatly different from those of a radical resection. Besides, this would require general anaesthesia and would leave a surgical wound, also restricting its application in certain population groups.

Although ultrasound-guided core needle biopsy (CNB) is recommended as an excellent technique in the diagnosis of cervicofacial masses because of its simplicity, safety, and minimally invasive nature[1,2], it is not feasible for the skull base region due to the osseous intervention and impaired observation of the complex neurovascular structures. Some reports have described computed tomography (CT)-guided core biopsy for skull base lesions[3,4]; however, the additional risk of radiation exposure for the surgeon and the patient is not negligible. Magnetic resonance imaging (MRI)-guided biopsy for head and neck masses is not in

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widespread use because of the confined space configuration, expensive cost, and the need for MRI-compatible needles[4].

The incomparable advantage of image-guided navigation is the correspondence between the surgical field and preoperative planning images, which can provide the possibility of real-time adaptation of the needle trajectory and recognition of the accurate location of the needle with simultaneous three-dimensional (3D) imaging of the vascular and bony structures surrounding the primary tumour. Furthermore, the procedure is free of intraoperative radiation exposure. Despite the accuracy and efficacy of various CNB procedures for head and neck lesions being described extensively in the literature[1–3,5–7], the diagnostic utility of the technique guided by optical navigation has not yet been reported. This study was performed to present the authors' optimal procedures for navigation-guided CNB for skull base and parapharyngeal lesions and to determine the diagnostic accuracy.

Materials and method

Patients

Twenty patients who underwent navigation-guided CNB between December 2013 and December 2018 were enrolled in this study. Each patient was informed of the risks and consented to the procedure. This study was approved by the local institutional review board. The medical records of all of these patients were reviewed retrospectively. There were seven male patients and 13 female patients, with a mean age of 50 years (range 12–78 years). Accuracy was assessed based on the final pathology results after surgical excision.

Biopsy platform

The Kolibri optical navigation system (Brainlab AG, Feldkirchen, Germany) is composed of a dedicated computer workstation, an infrared camera, and other equipment accessories (Fig. 1a). A spring-loaded semi-automatic biopsy gun (Bard Magnum; Bard Inc., Covington, GA, USA) and 14–18-gauge side-notch biopsy needle with a variable needle throw (forward feed, 15 or 22 mm) (Bard Peripheral Vascular Inc., Tempe, AZ, USA) were used for specimen collection (Fig. 1b).

Workflow

Data acquisition

Data acquisition was done through enhanced CT with/without MRI data. The CT data (slice thickness 0.75 mm) were transferred to the computer console in DICOM format (Digital Imaging and Communications in Medicine). The CT scan included the area from the calvarium to the clavicle to avoid missing any intracranial or external tumour boundaries. The forehead and nasal tip were also included during the scanning process in order to ensure the success of the patient's surface registration.

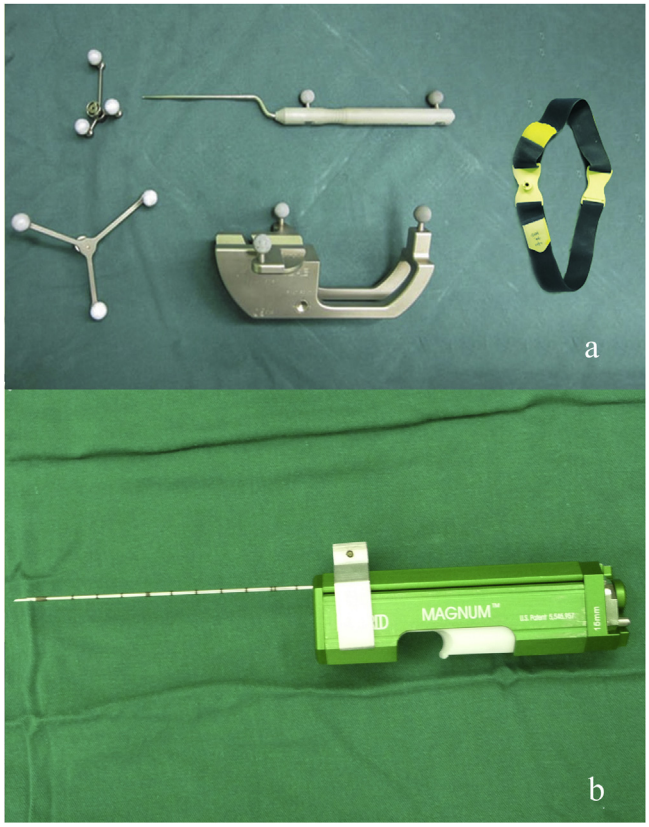

Fig. 1. Overview of the biopsy equipment. (a) The navigation equipment accessories including a headband with reference unit, two reference arrays, a pointer, and an instrument calibration matrix. (b) The biopsy gun with needle.

Preoperative design

All DICOM data were transferred to iPlan CMF 3.0 software (Brainlab AG, Feldkirchen, Germany). The craniofacial skeleton and skin were segmented automatically after selection of the corresponding inherent thresholds. The vessels, mainly the carotid artery and jugular vein, were segmented via manual tracing methods using the enhanced CT images. The boundaries of the tumour were carefully identified by at least two experienced surgeons, and manual segmentation was subsequently performed. 3D reconstruction was applied for each segmented object (Fig. 2). The optimal area for pathological examination was determined and marked as the target specimen according to imaging manifestations and clinical symptoms. An adjacent point at the boundary between the tumour and adjacent tissues was chosen as the shooting point with a 15 or 22-mm shooting distance. The throw distance depends on the dimension of the target, strictly keeping the specimen notch within the tumour without passing through the tumour margin. An optimal trajectory path was chosen based on the judgement of the lowest possibility of injury to the adjacent structures, shortest puncture distance, appropriate distance away from well-known vessels, and avoidance of the barrier structures (Fig. 2). The trajectory at the skin surface was set as the puncture point. The entire plan was saved and exported to the navigation workstation in the operating room.

Patients and instrument registration

A non-invasive reference headband was used to rigidly fix the reference base in the forehead area, in order to make the reference base with reference array stable. The rigidly fixed dynamic registration frame could track the position of the head in real time, such that immediate compensation

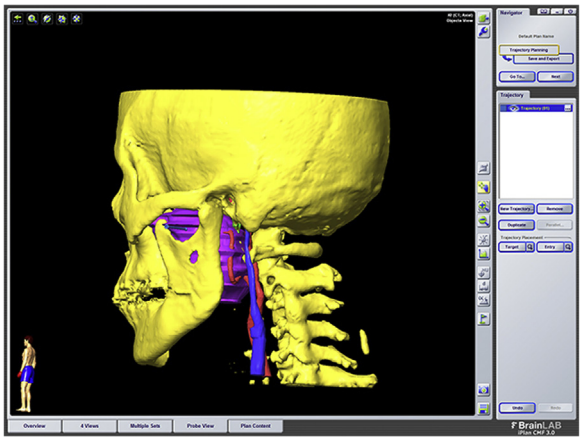

Fig. 2. Planning of the needle trajectory (blue line), with the segmented tumour (purple colour), jugular vein (blue colour), and carotid artery (red colour).

for head movements could be made for the needle trajectory without the necessity for re-registration. If the reference headband loosened during the procedure, then re-registration was necessary. A non-touch scan was done in the forehead and zygomatic area to align the patient's face information with imaging data of the navigation plan. The registration accuracy was double-checked manually before being accepted. Another reference array was aligned to the spring-loaded semi-automatic biopsy gun. The distance from the needle tip to the reference array and the diameter of the needle were measured and recorded by an instrument calibration matrix for registration (Fig. 3). Once the process was done, the registration accuracy of the needle was confirmed for real-time navigation on the screen.

Needle biopsy

The puncture point was marked on the skin under the guidance of the navigation pointer. Local anaesthesia was then applied around the marker point. Under the real-time image guidance, the biopsy needle was directed in the designed trajectory and carefully pushed forward until the tip of the needle arrived at the shooting point. With the guidance of the virtual overshot tip, the direction was double-checked to confirm that the tip of the needle could get the specimen as planned (Fig. 4). After the spring was released, the inner channelled needle was advanced into the lesion to cut and withdraw the specimen back into the outer cylindrical cuff. The needle was then withdrawn and the specimen was released from the needle notch.

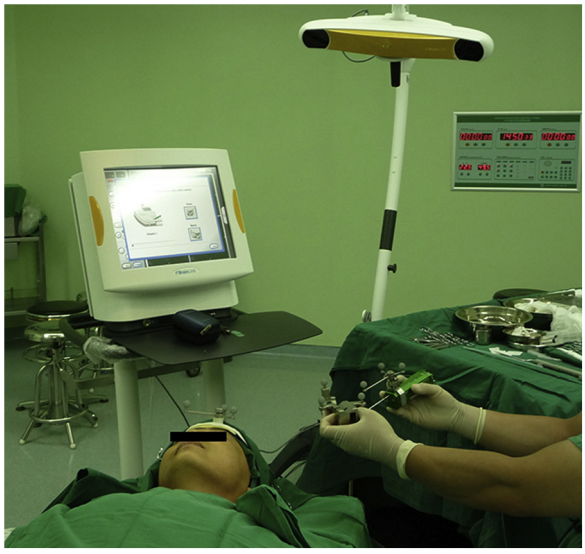

Fig. 3. Patient and instrument registration.

Postoperative management

All specimens obtained were immediately evaluated by macroscopic inspection to check the adequacy of the material. If the specimen was equivocal, frozen section examination was suggested for quality check. If the histological results of frozen sections suggested normal tissues or were not consistent with the preliminary clinical diagnosis, repeated procedures were performed to obtain more specimens. Generally, three to five pieces of specimen were harvested for each patient at one time. The specimens were fixed in 10% formalin as soon as possible and sent for routine pathological examination.

When the biopsy was finished, the small puncture wound was manually compressed for 5 minutes and subsequently bandaged with a sterile dressing. All patients were observed intensively for 1 hour, with special consideration for delayed haematoma or central neural damage. Oral antibiotics were given twice on the day of the operation.

Results

All of the patients underwent needle biopsy successfully without any immediate or delayed serious complications, such as haematoma, trismus, or severe pain. The mild swelling and discomfort usually disappeared within 3–4 days post biopsy surgery. The subzygomatic approach was adopted in all cases. The number of specimen pieces obtained ranged from three to five. The diagnostic accuracy was 90% (18/20) based on these 20 cases (Table 1). Regarding the postoperative pathology, two biopsies were not consistent. One patient (case 2) was reported to have a cystic neoplasm, but the final diagnosis following surgical resection was vascular malformations. The lesion in the other patient (case 16) was located in the pterygopalatine fossa and maxillary sinus (Fig. 5), and was primarily diagnosed as chronic inflammation by CNB. The trismus had not improved after 1 week of anti-inflammatory therapy and exploratory surgery was subsequently performed for biopsy. The final diagnosis proved to be poorly differentiated mucoepidermoid carcinoma and definitive surgery and postoperative adjuvant radiotherapy were subsequently performed. The treatment of these two patients was not adversely affected by these diagnostic issues. The patient with the malignancy was well at the 2-year follow-up.

Discussion

Incisional biopsy is the standard method for the diagnosis of various tumours in clinical practice. However, it is not always

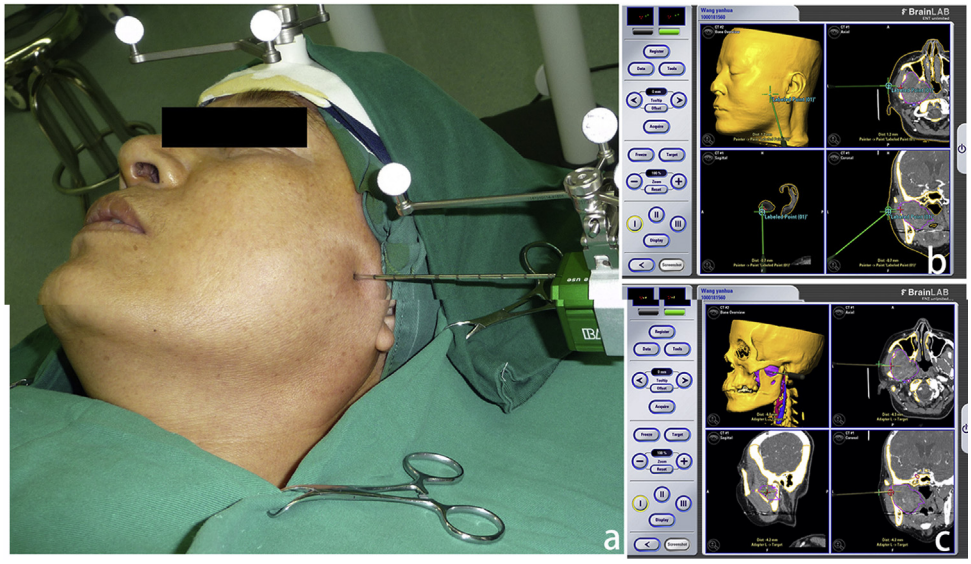

Fig. 4. Puncture guided by navigation in real time. (a) Needle pushed forward into the soft tissues. (b) Guided to the puncture point. (c) Guided to the shooting point.

Table 1. Results of core needle biopsy guided by navigation.

Patient number	Age (years)	Sex	Location	Frozen section	Histological diagnosis from core needle biopsy	Needle passes	Postoperative diagnosis
1	52	F	Parapharyngeal space	Neurogenic tumour	Schwannoma	3	Schwannoma
2	12	M	Lateral skull base	-	No tumour seen	4	Vascular malformations
3	48	F	Pterygopalatine fossa	Adenoid cystic carcinoma	Adenoid cystic carcinoma	4	Adenoid cystic carcinoma
4	70	M	Parapharyngeal space	Adenogenous carcinoma	Poorly differentiated adenocarcinoma	4	Poorly differentiated adenocarcinoma
5	78	M	Lateral skull base	Epithelial neoplasm	Epithelial-myoepithelial carcinoma	3	Epithelial-myoepithelial carcinoma
6	52	M	Parapharyngeal space	Adenogenous neoplasm	Pleomorphic adenoma	3	Pleomorphic adenoma
7	57	F	Parapharyngeal space	Adenogenous neoplasm	Pleomorphic adenoma	5	Pleomorphic adenoma
8	53	F	Parapharyngeal space	Mucoepidermoid carcinoma	Mucoepidermoid carcinoma	4	Moderately differentiated mucoepidermoid carcinoma
9	47	F	Lateral skull base	Osteogenic tumour	Tendon sheath giant cell tumour	4	Tendon sheath giant cell tumour
10	25	F	Lateral skull base	Chondrogenic tumour	Chondrogenic tumour	4	Chondroma
11	51	M	Lateral skull base	Chronic inflammation of muscle tissue	Chronic inflammation of muscle tissue with fibrosis and ossification	5	Myositis ossificans
12	33	F	Parapharyngeal space	Pleomorphic adenoma	Pleomorphic adenoma	3	Pleomorphic adenoma
13	43	F	Parapharyngeal space	Adenogenous tumour	Acinic cell carcinoma	4	Acinic cell carcinoma
14	50	F	Lateral skull base	Fibrous tissues	Fibrous tissues and dilated lymph vessels, likely to be lymphatic malformation	5	Mixed vascular lymphatic malformation
15	48	M	Lateral skull base	Fibrogenesis	Fibrolipoma	3	Fibrolipoma
16	60	F	Pterygopalatine fossa	Chronic inflammation of fibrous tissue	Chronic inflammation of muscle and fibrous tissues	5	Poorly differentiated mucoepidermoid carcinoma
17	60	F	Parapharyngeal space	Neurogenic tumour	Schwannoma	3	Schwannoma
18	62	F	Parapharyngeal space	Pleomorphic adenoma	Pleomorphic adenoma	3	Pleomorphic adenoma
19	62	F	Lateral skull base	Poorly differentiated malignant tumour	Adenogenic carcinoma	5	Non-specific adenocarcinoma
20	36	M	Lateral skull base	Neurogenic tumour	Schwannoma	3	Schwannoma

F, female; M, male.

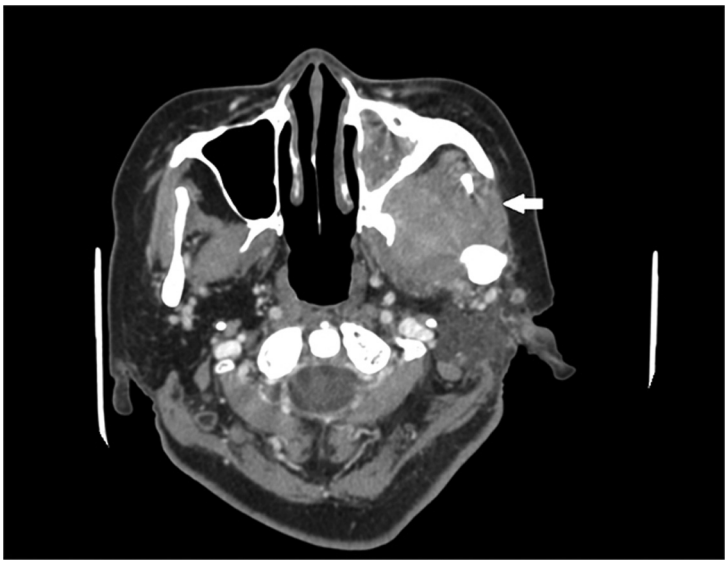

Fig. 5. CT of a 60-year-old female (case 16) with a left pterygopalatine fossa and maxillary sinus lesion. The pre-procedural enhanced CT showed a diffuse lesion (arrow). The biopsy showed chronic inflammation of muscle and fibrous tissues. A poorly differentiated mucoepidermoid carcinoma was diagnosed by surgical resection.

optimal for head and neck tumours because of its inherent disadvantages. Incisional biopsy is considered the last resort for patients in whom other methods have failed repeatedly or those warranting resection at the time of obtaining diagnostic specimens[8]. Fine-needle aspiration (FNA) is an effective technique for diagnosis that avoids an open wound and is commonly used in the clinical setting for head and neck lesions, especially for the diagnosis of malignant tumours[5,6]. However, it depends highly on the cytopathologist's experience, because only cells are harvested for evaluation. As such, FNA has a high false-negative rate and is not definitive for the final diagnosis[6,9].

Compared with open biopsy and FNA, CNB results in less trauma without a postoperative scar and obtains more sufficient materials for immunohistochemical staining, which helps in determining the clinical treatment; this is particularly useful for patients who have undergone previous surgery and irradiation with severe fibrosis or a granulomatous response[2,3]. Nevertheless, some physicians are still reluctant to perform CNB in consideration of the possible complications, mainly tumour seeding[2]. Tumour seeding theoretically occurs when the malignant cells are disseminated along the needle tract. However, the co-axial technique, as used in the present study, can isolate the specimen from the needle tract by keeping the sample enclosed within the inner needle notch when the cannula is withdrawn, thereby reducing the risk of tumour seeding[10]. The key point of this technique is to push the needle forward to the boundary between the tumour and adjacent tissues, within the normal tissues. With the real-time navigation-guided system, the needle tip can be guided precisely to the shooting point within the normal tissues under 3D visualization as designed preoperatively, avoiding any stabbing into the mass harbouring the abnormality.

Fortunately, reports of tumour seeding after CNB in the head and neck region are rare[10]. Ferreira et al.[5] evaluated a total of 36 patients who underwent CNB for the diagnosis of tumours in the head and neck region over a period of 3 years, and this complication was not observed in any patient. Novoa et al.[2] reported only one case concerning the dissemination of tumour cells after reviewing 1291 CNB in the head and neck region. In fact, the identification of true tumour seeding and local recurrence during follow-up after a previous needle biopsy is difficult when this happens in the organ parenchyma[10].

It is generally believed that tumour seeding is related to the needle diameter, the nature of the tumour, and the anatomical site biopsied[2,10,11]. 18/20-gauge needles are suitable for head and neck tumour needle biopsy, providing acceptable pathological information and resulting in few complications[6,12]. Although the larger-sized needle theoretically increases the possibility of procedure-related complications, there is no evidence that tumour seeding is more common with larger needles[13]. However, for patients whose lesions are clinically suspected to be benign neoplasms, mainly pleomorphic adenoma, biopsies should be performed with an 18-gauge needle. Salivary tumour seeding in patients who have undergone CNB with an 18-gauge needle has never been reported[6], but a longer follow-up is still needed in view of the fact that this may occur up to 20 years following salivary biopsy[14]. Although it does not affect the prognosis as long as the disseminated tumour cells can be removed surgically or destroyed by chemoradiotherapy[2], the risk should be minimized. Excision of the needle tract is often performed at the time of surgery, but this is not routinely required[14–16].

The bleeding risk is another significant complication[2]. A major disadvantage of the side-cutting needle is that the stylet may protrude outside the target to accommodate the specimen notch in the optimal position for small lesions, which will increase the risk of endangering the adjacent structures, particularly when the lesions are very close to the major neck vessels[7]. Walker et al.[16] reported the case of a patient with an oral haemorrhage at 3 months post biopsy, caused by internal maxillary artery pseudoaneurysm formation after CT-guided biopsy in the masticator space. In the present study, the safety of the shooting distance was well managed both in the preoperative design and in the performance of the intraoperative navigation. Owing to the 1.5 or 2.5 cm protrusion distance, the needle biopsy of tumours with a diameter below 1.5 cm is prohibited.

The needle approach is another important factor. The subzygomatic approach is suitable for the biopsy of lesions in the infratemporal fossa and in the masticator, parapharyngeal, and retropharyngeal spaces[17]. Although it carries the risk of injury to the pterygoid venous plexus, this related injury has not been reported[17]. There are also other needle approaches such as the retromandibular approach, with the risk of injury to the external carotid artery, retromandibular vein, and facial nerves[3]. The selection of the needle approach is based on the location of the lesion and individual anatomical relationships[17]. However, what makes navigation-guided CNB different is that the use of enhanced CT scanning combined with/without MRI is very helpful in planning a safer trajectory, as the bony structures, soft tissues, and major vessels are precisely segmented. In the present study, the surgeon could more confidently identify the vessels with the use of the intraoperative real-time image navigation, thereby avoiding vessel injury. As a result, no major bleeding requiring hospital admission occurred after CNB in this study.

To achieve a definitive diagnosis, it is important to evaluate the tumour boundary with surrounding tissues[14]. Although a part of the boundary may be included in the ultrasound-guided core biopsy, this is not always reliable, which may result in diagnostic failure in some cases[14]. The advantage of the navigation-guided CNB is that the segmented 3D images give the surgeons visual information about the location and size of the lesion and the adjacent structures, while different axial two-dimensional images simultaneously give more detailed information. The surgeon can then select a more direct trajectory or make a flexible path to manipulate the biopsy needle exactly towards the lesion in real time. Furthermore, with the information in the preoperative images, the most representative or sufficiently characteristic specimen can be targeted in advance and harvested for pathological diagnosis. This advantage gives the surgeon a greater opportunity to make a correct final diagnosis.

However, in this study, there was still a mucoepidermoid carcinoma case for which the most representative specimen was not obtained, due to its obscure and diffuse character shown in the pterygopalatine fossa and maxillary sinus. In this particular case, chronic inflammation of the muscle and fibrous tissues simultaneously accompanied the lesion, which may have been due to peri-tumoural reactive changes. The inaccurate needle trajectory and lack of a sufficient characteristic specimen may have been the main factors responsible for this misdiagnosis. Hence an experienced surgeon will play a significantly important role in the planning of the needle trajectory.

Due to the potential problems of intraoperative frozen sections, a definitive diagnosis may not be empirically provided by some pathologists, especially those working outside of specialist units, in the face of a challenging diagnostic area.[14] For this reason, frozen sections cannot usually be used to dictate treatment without the final histology. Unsurprisingly, there was a disparity between intraoperative frozen section and CNB histology in case 5 (epithelial neoplasm vs epithelial-myoepithelial carcinoma) and case 13 (adenogenous tumour vs acinic cell carcinoma) in this study. Nevertheless, intraoperative frozen section was still used as a complementary test to improve the diagnostic accuracy in the case of a non-diagnostic or equivocal CNB in this study.

The application of FNA in head and neck lesions is frequently reported, but only a few published series have evaluated its use for skull base and parapharyngeal lesions. Yousem et al.[8] reported 90% accuracy (18/20) for CT-guided transcutaneous aspirations of parapharyngeal and skull base masses with the help of an 18-gauge needle. There is also a case report presenting three cases in which FNA of deep-seated neck masses close to the mucosal surface of the oropharynx was performed successfully under intraoral ultrasound guidance[18].

Connor and Chaudhary[3] reported the diagnostic accuracy of CT-guided CNB of deep face and skull-base lesions to be 87% (13 of 15) for all samples and 93% (13 of 14) for those with adequate histology. In the present study, the diagnostic accuracy was 90% (18/20) for all patients, without intraoperative radiation exposure. Furthermore, for those patients receiving non-surgical treatment or palliative therapy, navigation-guided CNB has the potential benefit of providing a fast and accurate diagnosis without any surgical intervention, particularly for the verification of primary tumour recurrence.

Nevertheless, navigation-guided needle biopsy has its limitations. Firstly, this technique is not appropriate for superficial and flexible lesions. The pressure applied during the puncture process will make the soft tissues and the lesion drift, thus the navigation images will fail to represent the real anatomical structures on screen. Furthermore, the indication for needle biopsy should be considered carefully in the case of a suspected cystic lesion. In the cystic misdiagnosis case in the present study, the threshold was similar to that for a solid lesion in the preoperative CT images, but no specimen was harvested during needle biopsy. An open surgery biopsy was subsequently performed and this was revealed to be a cystic lesion with thick liquid. In fact, if a cystic lesion is identified by radiological examination, an aspiration needle is needed for cystic fluid examination. As indicated by the two inconsistent cases, it should be emphasized that excisional biopsy cannot be totally replaced in spite of the unique advantages of navigation-guided CNB. Thus, rigorous indication criteria should still be applied.

This study proved the feasibility of navigation-guided core needle biopsy for skull base tumours, although the sample size was limited and more evidence of the advantages and disadvantages is needed, such as tumour recurrence. This evidence should be confirmed in the future before the technique becomes widely accepted and clinical guidelines are developed.

In conclusion, assisted by advanced navigation, core needle biopsy offers a safe, effective, and minimally invasive way for making an accurate diagnosis. It is suggested as one of the important diagnostic tools for skull base and parapharyngeal space lesions, with an easy approach, high yield of specimens, and good patient tolerance.

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Competing interests

The authors have no relevant conflicts of interest to disclose.

Ethical approval

This study was approved by the Institutional Review Board of Peking University School and Hospital of Stomatology (PKUSSIRB-2013039).

Patient consent

Patient consent was obtained.

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