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Preliminary Study of the Treatment Strategy for Retaining Traumatic Foreign Bodies Involving the Carotid Artery

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Purpose: Craniomaxillofacial trauma is usually accompanied by indwelling foreign bodies, and some of those are close to the carotid artery, which increases the risks and difficulties of surgical treatment. The introduction of interventional radiology combined with image-guided surgical navigation may be a good solution for precise surgery to remove foreign bodies.

Patients and Methods: Four patients were included in the study. All patients underwent digital subtraction angiography and enhanced computed tomography before surgery. The patients were divided into 3 categories (A, B, and C) according to the presence of carotid artery damage and its positional relationship with the foreign body, and 3 corresponding treatment strategies were developed. Treatments were completed using interventional radiology and surgical navigation systems.

Results: All foreign bodies were completely removed, except for 1 remaining in the jugular foramen in a patient. The prognosis of all patients was good, and no systemic complications occurred.

Conclusion: The combined interventional radiology and surgical navigation method proposed in this study is an effective method to improve the accuracy and safety of foreign body removal surgery.

Key Words: Carotid artery, craniomaxillofacial, foreign body, interventional radiology, surgical navigation

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Craniomaxillofacial trauma caused by car accidents and collisions is often accompanied by indwelling foreign bodies. Some foreign bodies are close to or even penetrate the carotid artery. They may cause infection and inflammation and even endanger the life of the patient. It is necessary to accurately determine the state of the blood vessels and their positional relationship with the foreign body before surgery and to formulate a complete surgical plan. It is also necessary to precisely perform surgery while monitoring blood vessel damage during the operation. Otherwise, the risks and difficulty of the operation will be increased. Interventional radiology, including digital subtraction angiography (DSA) and interventional vascular embolization, is a common method used to assess the direction and state of blood vessels and prevent and treat bleeding diseases.[1] In our previous reports,[2,3] a surgical navigation system was shown to help surgeons more accurately locate and remove foreign bodies. Therefore, we used interventional radiology combined with surgical navigation to remove traumatic foreign bodies of the head and neck that involved the carotid artery. We classified the relationship between the foreign body and the carotid artery and examined treatment strategies and procedures.

PATIENTS AND METHODS

Patients

Four patients with foreign bodies located near the carotid arteries and veins after trauma were admitted to the Department of Oral and Craniomaxillofacial Surgery, Ninth People's Hospital, Shanghai Jiao Tong University School of Medicine from 2010 to 2020 (Table 1, Supplemental Digital Content 1, http://links.lww.com/SCS/E242). This study was approved by Medical Ethics Committee of Shanghai Ninth People's Hospital, College of Stomatology, Shanghai Jiao Tong University School of Medicine.

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FIGURE 1. Digital subtraction angiography (A) and CT (B) showed no obvious defects in the arteries of the neck, and the closest distance to the carotid artery was 9.46 mm (blue indicates the foreign body, and red indicates the carotid artery). CT indicates computed tomography.

METHODS

Classification of the Positional Relationship Between the Foreign Body and Carotid Artery

All patients underwent preoperative enhanced computed tomography (CT) (slice thickness, 0.625 mm; LightSpeed 16; GE Healthcare, Chalfont St Giles, Buckinghamshire, UK) and DSA examinations. Patients were divided into 3 categories according to the positional relationship between the foreign body and the carotid artery. Type A: the blood vessels of the head and neck were not damaged, and the distance between the foreign body and the carotid artery was greater than 5 mm, including case 1 and case 2. Type B: there was no obvious damage to the blood vessels of the head and neck, and the foreign body was close to the carotid artery (closest distance <5 mm or even directly touching the surface of the blood vessel wall), including case 3. Type C: the foreign body had damaged the carotid artery, including case 4. We chose different treatment strategies for various types of foreign bodies.

Surgical Procedure

Type A: there was no damage to the blood vessel, and the closest distance between the foreign body and the carotid artery was >5 mm.

In case 2, the patient was accidentally pierced by a steel strip while working, which penetrated the front of the right ear to the left submandibular area. Digital subtraction angiography and CT of the neck (Fig. 1) showed that the foreign body did not cause vascular damage, and the closest distance to the carotid artery was 9.46 mm. Based on the above findings, we chose to remove the foreign object using a surgical navigation system.

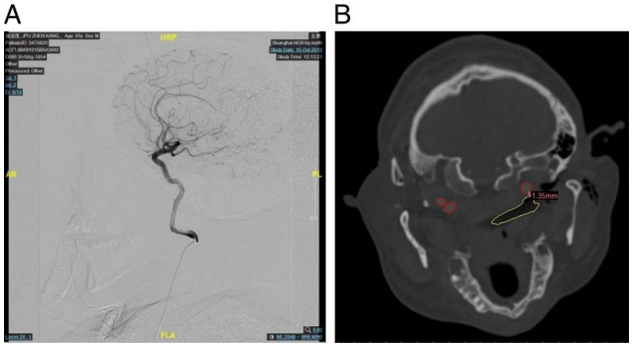

FIGURE 2. Digital subtraction angiography (A) and CT (B) showed no obvious defects in the arteries of the neck, and the closest distance to the carotid artery was 1.35 mm (yellow indicates the foreign body, and red indicates the carotid artery). CT indicates computed tomography.

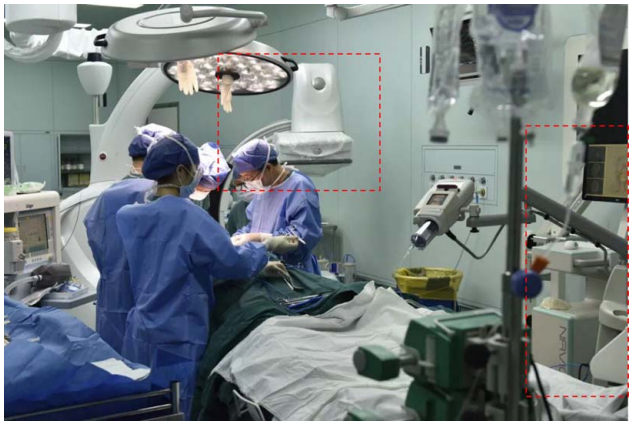

FIGURE 3. Digitally integrated operating room (A indicates the surgical navigation system, B indicates the interventional radiography machine).

Type B: the closest distance of the foreign body to the carotid artery was <5 mm.

A 65-year-old male patient fell while riding a battery-powered bike, and a tree branch pierced the right cheek to the back wall of the pharynx. Enhanced CT (Fig. 2B) showed that the closest distance between the branch and the carotid artery was 1.35 mm. Preoperative DSA (Fig. 2A) showed no obvious vascular damage.

The operation was performed in a digitally integrated operating room equipped with an interventional radiography machine and a surgical navigation system (Fig. 3). After anesthesia, a surgeon from the Interventional Radiography Department approached the carotid artery through a femoral artery catheter that was used to monitor vascular injury and prepare for embolization of the injured blood vessel at any time. Using the surgical navigation system, a surgeon from the Oral Craniofacial Department approached the foreign body, peeled off the surrounding soft tissue, and completely removed the foreign body through the original wound in the right cheek. Then, the Interventional Radiography Department surgeon performed angiography of the left internal carotid artery, which showed that the internal carotid artery wall was smooth and undamaged, and the indwelling catheter in the femoral artery was removed.

Type C: foreign body that damaged the carotid artery.

In some cases, when a patient visits a doctor, although no obvious symptoms are present, the examination will find that a foreign body has caused damage to the maxillofacial and neck

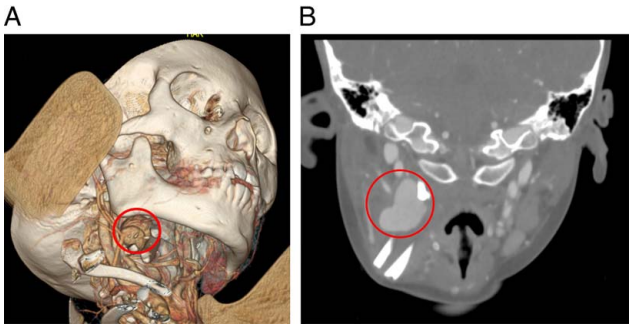

FIGURE 4. (A, B) Enhanced CT of case 4, with pseudoaneurysms indicated by a red circle. CT indicates computed tomography.

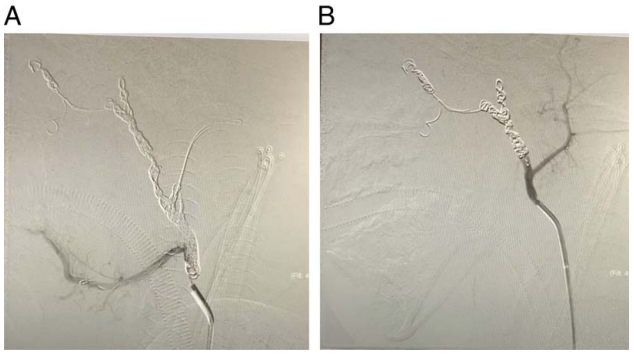

FIGURE 5. (A, B) Intraoperative DSA image of embolization of the right internal mandibular artery and right external carotid artery and its injured branch vessels, leaving only the blood supply of the lingual artery. DSA indicates digital subtraction angiography.

blood vessels, as in case 4. A 6-year-old boy was in a car accident on his way to school, and a glass strip pierced his right maxillofacial area. Enhanced CT showed several pseudoaneurysms in the right carotid artery (Fig. 4), which we concluded were caused by the glass cutting the carotid artery and its branches.

During the surgical removal of foreign bodies, pseudoaneurysms may rupture and cause heavy bleeding and may even endanger the patient's life. Therefore, after consultation with a physician from the Interventional Radiology Department, we decided to perform superselective vascular embolization first. Under DSA monitoring, a microcatheter was introduced to embolize the right internal mandibular artery and right external carotid artery and its injured branch vessels, leaving only the blood supply of the lingual artery (Fig. 5).

We segmented and reconstructed the foreign bodies using enhanced CT imaging after embolization. One of the foreign bodies had impacted the jugular foramen at the base of the skull (Fig. 6).

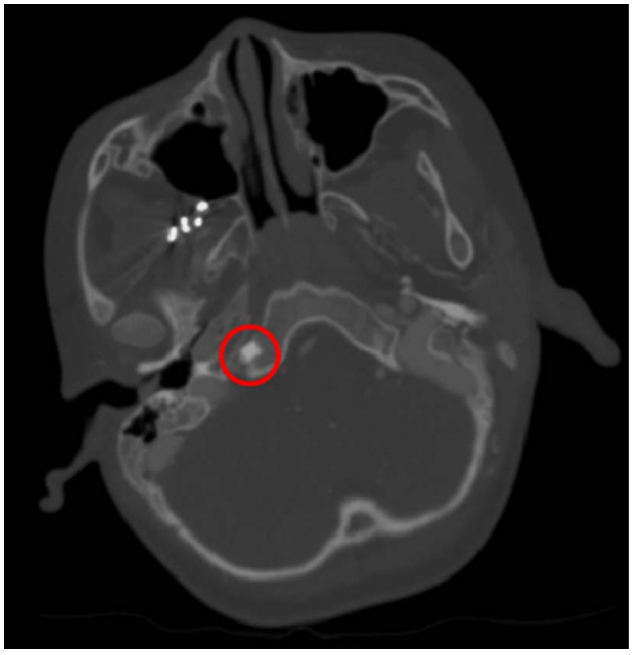

FIGURE 6. The foreign bodies had impacted in the jugular foramen (red circle).

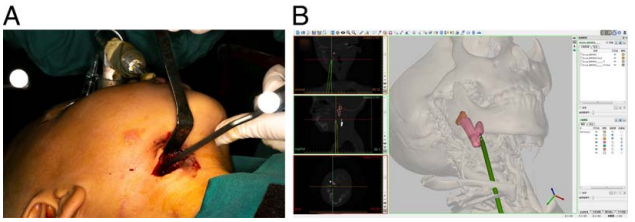

FIGURE 7. (A) Removal of foreign bodies with using a surgical navigation system. (B) Corresponding surgical navigation interface.

After consultation with a neurosurgeon, we realized that the forcible removal of this foreign body may cause intracranial connected to extracranial, a craniotomy was necessary for repair, which would cause a large amount of damage; therefore, we decided temporarily not to remove the foreign body. The remaining 6 glass strips were successfully removed using DSA monitoring and surgical navigation (Fig. 7).

RESULTS

The foreign bodies were safely removed from all patients (Fig. 8). No carotid artery injury occurred during the operations. Moreover, the wounds in the surgical area healed well. After 3 months of follow-up, no obvious bleeding or infection was observed.

DISCUSSION

When car accidents, falls, and impacts produce open wounds in the maxillofacial region, penetration of foreign bodies often occurs. Some foreign bodies are located close to important organs and carotid artery, which may cause heavy bleeding, airway obstruction, and suffocation. Residues of some organic materials, graphite, or other colored materials (such as lead) may cause permanent skin pigmentation, granulomas, and infections or inflammation, and these foreign bodies should be removed in a timely manner.[4–6]

The blood vessels of the head and neck have various anatomical variations and complex branch anastomoses.[7] Understanding the structure and orientation of these vessels is essential for the safe and effective removal of foreign bodies in the head and neck. Previous reports[8] in the literature have demonstrated that the use of enhanced CT to image the head, blood vessels, and foreign bodies before surgery is a feasible method to help determine the location of foreign bodies and vascular damage before surgery. However, enhanced CT is not sufficiently accurate to detect minor vascular damage and smaller vascular branch directions, and it does not have the ability to reflect intraoperative bleeding and intraoperative interventions in real time. Vascular interventional radiology is a discipline that integrates imaging diagnosis and clinical treat-

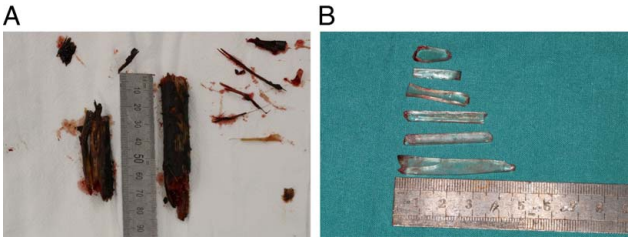

FIGURE 8. (A) Branches removed by surgery in case 3. (B) Glass strips removed by surgery in case 4.

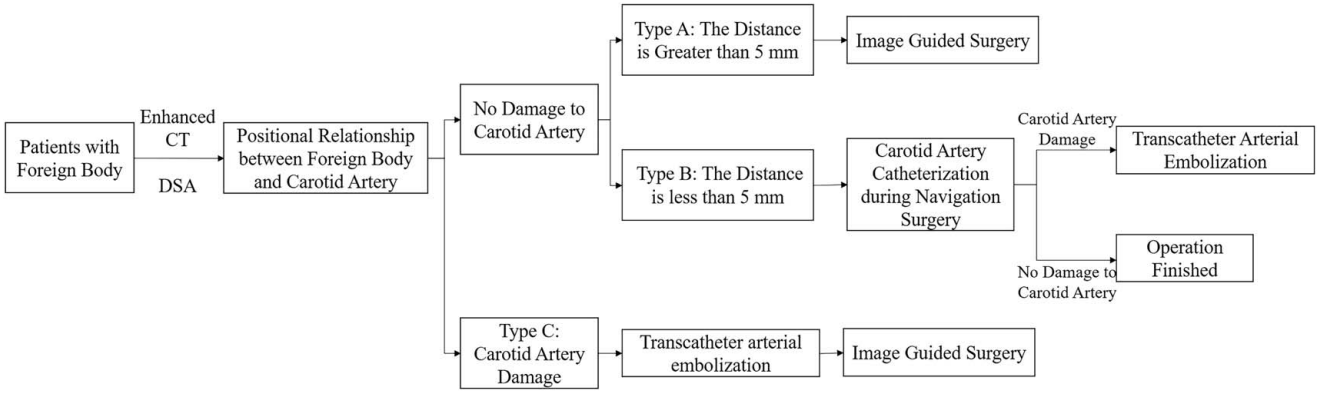

FIGURE 9. Treatment classification and process.

ment, including diagnostic angiography, drug perfusion, vascular embolization, and other treatment techniques.[9] Digital subtraction angiography can be used to visualize the state of blood vessels in the head and neck, the flow direction and the proximity of foreign bodies to other structures.[10,11] Interventional vascular embolization is one of the most commonly used methods for the treatment of bleeding diseases.[12] Therefore, we chose to use vascular interventional radiology for the diagnosis and treatment of patients injured by foreign bodies.

Computer-assisted surgical navigation technology has been widely used to locate and remove foreign bodies during maxillofacial surgery. Our research team used surgical navigation to complete 34 deep maxillofacial foreign body removal operations.[2] Lee and Zaid[13] successfully avoided the inferior alveolar nerve using a surgical navigation system, and a foreign body in the pterygomandibular space was removed. The above reports all demonstrated that surgical navigation systems can help surgeons determine the position of a foreign body in a complex anatomical environment during the operation, determine the best surgical approach, and increase the safety and efficiency of the operation. Therefore, the introduction of a surgical navigation system under the premise of adequate vascular assessment and intraoperative vascular protection can reduce the operation time; improve the accuracy of the operation; and decrease the invasiveness of the operation.

In this study, we classified patients according to the relationship between the carotid artery and the foreign body and adopted different treatment strategies.

The first strategy is based on a situation in which the arteries of the head and neck are not damaged and the distance from the carotid artery is >5 mm, which was classified as type A. The selection of a distance of 5 mm is based on the error generated during navigation surgery, which mainly includes technical error, registration error, and operation error.[14] The technical error of optical navigation is usually 0.1 to 0.4 mm.[15] The landmark registration method was used in this study. According to a study by Perwög et al.[16] bone landmarks can be used as reference points to detect the accuracy of navigation applications during surgery, and the average error is <2 mm. The operation error is mainly due to pulling of the soft tissue when the foreign body is removed, which causes partial displacement. Therefore, we referred to Thomas et al's[17] error analysis of tumor navigation surgery. They measured the deviation of the tumor bed during the navigation operation, and the average deviation was ~2.9 mm.[18] Because this study was performed using intracranial tumors, the results were influenced by brain drift, and the relative offset of the soft tissues of the head and neck was small. In summary, we suggest that it is feasible to choose 5 mm as the safety margin of the surgical operation, which means that the process of foreign body removal will cause little blood vessel damage. In addition, foreign objects can be removed using only the navigation routine, and no other operations are required.

The second strategy is based on a situation in which no obvious vascular damage was found in the preoperative examination, but the distance between the foreign body and the carotid artery was <5 mm or the object directly touched the surface of the blood vessel wall, which was classified as type B. When removing foreign bodies, the traction of surgical instruments or foreign bodies may damage carotid artery. In addition, some blood vessels are wrapped in deep soft tissue, and bleeding may not be detected in time during the operation. Even if bleeding is found, it is difficult to accurately locate. Temporary intraoperative angiography will increase the bleeding time and the patient's surgical risk. Severe intraoperative bleeding may even endanger the patient's life. Therefore, before the foreign body is removed, coaxial microcatheter technology is used to advance the catheter to the operation area through a femoral artery approach, and the catheter is used for real-time angiography during the operation or immediate embolization when carotid artery rupture is found, which can improve the safety of the surgery.

The third strategy is based on detection of head and neck vascular damage in preoperative examinations, which is classified as type C. For example, in case 4, the patient's external carotid artery wall was damaged, and a pseudoaneurysm formed. In this case, vascular injury endangered the life of the patient and urgently needed to be treated as a priority. In this case, foreign body removal surgery was performed after interventional treatment. The carotid artery and its branches provide the main blood supply for the intracranial nervous system; therefore, unnecessary vascular embolism should be minimized. Superselective vascular embolization is a method used to embolize tumors and vascular malformations or treat bleeding.[19] Its purpose is usually to increase the concentration of local chemotherapeutics to avoid systemic toxicity. Therefore, it is most commonly used in liver cancer treatment.[20] Vascular embolization is hardly reported to use in the removal of foreign bodies in the head and neck. In case 4, the branches of the patient's external carotid artery, except for the lingual artery, were embolized. Superselective vascular embolization not only avoided vascular rupture during foreign body removal but also preserved the blood supply of other healthy blood vessels.

In summary, we outline the treatment process according to the type of foreign body and proximity to the carotid arteries (Fig. 9). All patients with maxillofacial traumatic foreign bodies underwent DSA examination before surgery and were classified as types A, B, or C according to the examination results. For

types A and C, the foreign body is removed under conventional navigational surgery, and an interventional radiology system is used for preoperative inspection. In type B, an indwelling catheter is placed in the femoral artery and advanced to the carotid artery, the foreign body is removed normally, and then angiography is performed during the operation. If vascular injury is found, vascular embolization is immediately performed; otherwise the catheter is removed, and the operation is completed. The interventional radiology system is used for intraoperative protection and treatment. For type C cases, vascular embolization of the damaged blood vessel is performed first, and routine navigation assistance is performed after the vital signs are stabilized. Then, foreign body removal surgery and intervention for treatment are performed. Combining surgical navigation with interventional radiology systems to remove foreign bodies in the head and neck results in a safer, more accurate, and minimally invasive operation and avoids postoperative complications.

Complex operations, especially those involving multiple disciplines, often require the coordination of multiple surgical instruments. Digital integration of medical equipment and standardized information exchange in the operating room can systematically integrate all information about the patient, that is, the digital integrated operating room.[21] In this study, we used an operating room equipped with both interventional radiology equipment and a surgical navigation system, but it only realized part of the functions of an integrated operating room. To better meet the needs of various types of surgery, surgical equipment must also meet the following requirements: first, comprehensive integration of access to peripheral information (DSA, CT, endoscopy, and ultrasound); second, centralized control of operating room equipment (environmental, video, audio, and medical equipment); and finally information exchange can be performed during the surgical process, which can be used for remote teaching and consultation. This may be an important direction for the development of operating rooms in the future.

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