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FULL PAPER

Clinical application of surface projection in the localization of metal foreign bodies using computed tomography scan

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Objective: To analyse the clinical efficacy of surface projection in the localization and removal of metal foreign bodies using CT scan.

Methods: Total 795 cases with 1008 metal foreign bodies were treated at our hospital in 2012. Pre-operative surface projection was performed to localize foreign bodies in patients under the guidance of CT scan. The removal path from the skin surface to foreign body and puncture site were then determined. Finally, the foreign bodies were extracted using proper foreign body forceps which were chosen according to the size, depth and position of the foreign bodies in different parts of the human body. The incision length, operative time and intraoperative blood loss were recorded. Additionally, outpatient follow-up was scheduled post-operatively for 1 week.

Results: The accurate localization rate under the guidance of CT scan was 100%, and 1008 pieces of metal foreign bodies were all successfully removed with a removal rate of

100%. The mean incision length was 0.4 ± 0.1 cm, the mean operative time was 4.1 ± 2.0 min and the intraoperative blood loss was 1.1 ± 0.5 ml. These results showed minimal invasiveness, shorter operative time and minimal blood loss, respectively. Additionally, the results of outpatient follow-up showed that the wound healed spontaneously. Moreover, there were no significant bleeding, incision infections or complications.

Conclusion: Surface projection may be an accurate and effective method for the pre-operative localization and extraction of metal foreign bodies.

Advances in knowledge: (1) Surface projection was applied for localization of metal foreign bodies in our study. (2) The accurate localization rate of surface projection under the guidance of CT scan was 100%. (3) All foreign bodies were successfully removed with a removal rate of 100%. (4) Surface projection technique has advantages in the removal of foreign bodies.

INTRODUCTION

Foreign bodies embedded in the soft tissues are a common cause of medical consultation and mainly consist of metal, plastic, wooden or glass shards.¹ They are often overlooked and can cause severe inflammatory, allergic and infectious complications in patients.^{2,3} Long-term retention of these has also led to the onset of tumours.⁴ Therefore, foreign bodies that remain within the body are harmful and should be extracted.

The foreign bodies are shown to be non-palpable, small-sized, freely moving and difficult to access in the soft tissues and, importantly, always have close anatomical relationship with vital structures, such as blood vessels and nerves; surgical removal is thus invasive and difficult.⁵ Moreover, the search for foreign bodies intraoperatively has been confirmed to be time consuming and frustrating.⁵ Thus, technological advances for removal of foreign bodies have attracted more and more attention. Magnets have been applied for removal of a metallic foreign body,⁶⁻⁸ and a snared magnet is an

attractive solution for endoscopic removal of a long sharp metallic foreign body.⁹ In addition, various imaging modalities, such as plain radiographs, MR images, ultrasound and CT have been used to detect and localize these metallic foreign bodies.¹⁰⁻¹³ The clinical accuracy and the ease of detecting foreign bodies have been effectively promoted in image-guided removal of foreign bodies.¹⁰ Despite all these technological advances, successful removal of foreign bodies remains costly and challenging.

CT has ideally thought to be suited for the detection of foreign bodies owing to its cross-sectional nature and excellent contrast resolution.¹⁴ Furthermore, CT has also proved to be a superior approach in the visualization and imaging of metallic orbital foreign bodies.¹⁵ Our hospital began to conduct research on the removal of foreign bodies in soft tissues in the early 1980s and recently established a novel method for determining the surface projection of foreign bodies with the aid of CT scan. Under the guidance of CT scan, the surface projection of the foreign body on

Figure 1. Illustration of the surface projection of the spot-like foreign body in the lower leg. A and B are two ends of the marking line on the skin; C is the foreign body; D is the projection of the foreign body on the proximal skin; E corresponds to D on the CT cross-sectional image passing through A; DE is perpendicular to this cross-section.

the skin is calculated and drawn, and then the surgeon can determine the localization of the foreign body. The position, shape and size of the foreign bodies are also characterized before surgery. The aim of our study was to verify the practicality of CT-guided surface projection for foreign body removal devised from our relevant experience and to demonstrate its advantages in the removal of foreign bodies.

METHODS AND MATERIALS

Clinical data

In 2012, total 1008 metal foreign bodies in 795 patients (548 males and 247 females) were removed at our hospital, and the average age of these patients was 34 ± 6 years (age range, 1–91 years).

Canister shots at one site or several foreign bodies in one patient were counted as one case. This study was performed in line with the ethical standards and was approved by the local ethical committee. Moreover, informed consent of each patient enrolled in this study had been provided.

Medical history and pre-operative localization

Medical history was elicited from each patient, including injury process, types of foreign bodies and piercing direction. The wound site and the activities of the injured region were then determined. If the wound was fresh, the wound site could be used to determine whether the foreign body was palpable. Notably, the degree of original contamination was not concerned because puncture procedure was not restricted by the original contamination.

The localization of the foreign body was detected by anteroposterior and lateral X-ray views. The marker line indicating the position of the foreign bodies was then attached to the skin surface.

Surface projection

Surface projection of each foreign body in each patient was performed with the aid of a CT scan (GE LightSpeed Plus® CT Scanner; General Electric Medical Systems, Milwaukee, WI). The optimal puncture site for foreign body removal was determined and marked at the corresponding position of the skin. Data acquisition of operative region was obtained using plain CT scan. A separate description of surface projection for spot- and strip-like foreign bodies was as follows.

Localization of spot-like foreign bodies

The two ends of the marker line on the skin were assumed as A and B (Figure 1), the foreign body was designated as C, and the optimal site on the skin surface was designated as the puncture site D which had the shortest distance to C and should avoid the essential tissues and organs. The line connecting D and C was the puncture path for foreign body removal (Figure 2a), which should be perpendicular to the skin. The position of D was marked on the CT display screen, and point A was visualized by

Figure 2. CT cross-sectional image passing through the spot-like foreign body C (a) and marker A (b). D is the puncture site on the skin that is nearest to C. An alternative puncture site is selected if there is a need to avoid the essential organs. The distance between C and D, as measured on the image, is 0.87 cm. ED is perpendicular to CT in the cross-sectional image. The distance between E and A, as measured on the image, is 2.71 cm.

scanning the CT display screen repeatedly. Meanwhile, the new point E corresponded to D (Figure 2b). DE was perpendicular to EA, and triangle DEA was a right-angled triangle (Figure 1). The lengths of DE and EA were measured, and the distance between A and D was calculated by the following formula: $AD = \sqrt{DE^2 + EA^2}$. The length of BD was calculated by the same method. The marker lines on the skin were drawn using a compass according to the calculated lengths of AD and BD. Then, the accurate position of D on the skin was determined (Figure 3). Point D was the projection of the foreign body (C) on the skin surface, providing a reference for the puncture site. The distance between D and C was also marked. The post-operative localization of DC and marker line AB on skin are shown in Figure 3.

Localization of the strip-like foreign body

For the long-strip foreign body, the end which is easy to clamp by forceps was marked as C1, while the other end was C2. The projection of C1 is D1 (Figure 4). C1 and D1 were marked on the CT display screen, and the length of C1D1 was calculated. Then, the marker line was attached to the skin at the corresponding place (Figure 5a). The same methods as the spot-like foreign body were also used for the determination of D1, D2 and the calculation of the length of C1D1 and C2D2, as well as the application of the marker line AB. The marker line C2D2 was parallel with C1D1 and was considered as the projection of C1C2 on the skin (Figure 5b), which facilitated the surgeon to choose the appropriate the incision position. The marker line AB and a dotted line D1D2 on the skin are displayed in Figure 6.

If the foreign body was sheet- or block-like, multipoint marking to outline the contour of the foreign body was performed depending on its shape and size.

Removal of metal foreign body using foreign body forceps

The foreign bodies were removed after relevant preparations and the determination of optimal puncture path. The local anaesthesia

Figure 3. Post-operative photograph after removal of the spot-like foreign body in the lower leg. AB is the marking line and D is the incision.

Figure 4. Illustration of the surface projection of the fractured needle in the hips. AB is the marking line on the skin surface; C1C2 is the fractured needle; D1D2 is the projection of the fractured needle on the skin surface.

needle was penetrated into the skin vertically according to the markers. This technique could reach the foreign bodies and eliminate the intraoperative fluoroscopy localization, thus reducing both the operative time and X-ray exposure. If vital blood vessels, nerves and scars needed to be avoided or if the original wound was chosen as the puncture site (projected to the wound), point D under CT-guided surface projection was selected as the puncture site to reach point C (the foreign body). According to the size, depth and position of the foreign bodies in different parts of the human body, proper foreign body forceps were chosen. The foreign bodies were then extracted. In addition, outpatient follow-up was scheduled 1 week post-operatively.

RESULTS

General information of the cases

All foreign bodies were successfully removed. Of all the patients, steel sheet, steel slag, iron dust, steel wire and iron wire were found in 363 patients, round-shaped objects, such as shotgun pellets and steel balls, were identified in 165 patients, strip-like objects, such as acupuncture needles, suture needles, sewing needles and barbed wire, were discovered in 84 patients and aluminium and tin products were found in 63 patients. For the remaining 120 patients, the foreign bodies were porcelain enamel and fragments of lead glass.

The removal velocity of foreign bodies was unequal (average time of 5 min) due to the different size, position and depth of the foreign bodies.

The size of the metal foreign body was represented by its length. The length was ≤ 5 mm in 493 patients (62%), 6–10 mm in 183 patients (23%), 11–20 mm in 103 patients (13%) and > 20 mm in 16 patients (2%).

The foreign bodies were localized in the hands, feet, upper limbs, lower limbs, head and neck, chest and abdomen and hips in 249, 53, 154, 89, 117, 77 and 56 patients, respectively. Notably, some metallic fragments which traversed the peritoneum or pleura were also removed successfully.

Figure 5. CT cross-sectional image passing through C1 (a) and C2 (b) which are, respectively, the tail and tip of the fractured needle in the hips, and the marker. The length of C1D1, as measured on the CT image, is 2.14 cm. D2 was selected to enable C2D2 to be parallel with the marker. The length of C2D2, as measured on the CT image, is 5.48 cm. L, left.

The depth of foreign bodies was inhomogeneous due to their different positions. Some were localized on the surface of the skin (<1 mm) and some were localized on hips (up to 12 cm).

Treatment effect

The accurate localization rate under the guidance of CT scan was 100%. The removal rate was 100%. The mean incision length was 0.4 ± 0.1 cm, the mean operative time was 4.1 ± 2.0 min and the intraoperative blood loss was 1.1 ± 0.5 ml. The symptoms of all cases achieved remission post-operatively.

Outpatient follow-up analysis

Outpatient follow-up was scheduled post-operatively for 1 week to observe the clinical outcomes. The results showed that the wounds healed well, and there were no significant bleeding, incision infections and complications after foreign body removal.

Figure 6. Pre-operative localization of the fractured needle in the hips and the position of the incision. AB is the marking line on the surface; D1D2 is the projection of the fractured needle on the skin surface; D1 is the position of the incision, D2 is the point nearest to the foreign body.

DISCUSSION

Three-dimensional (3D) imaging has been used for better understanding of the anatomy.¹⁶ 3D stereotactic surface projection is widely applied as a diagnostic approach in various diseases.^{17–20} However, this approach is rarely used in the precise localization of foreign bodies currently. In our experience, great progresses had been made in the field of 3D imaging and drawing with respect to the calculation of surface projection, localization of foreign bodies and determination of puncture site. Our experience revealed that a CT image-guided approach could be used to determinate pre-operative surface projection of the metal foreign body. Moreover, surface projection under the guidance of CT scan could accurately localize foreign bodies, and their removal rate was 100%.

In a previous clinical study, exact localization of the foreign body was prerequisite for successful surgical removal.²¹ Plain X-ray scan only displays two-dimensional images and cannot generate a 3D profile of the foreign body;²² thus, it is sometimes of limited value in the localization of the foreign bodies.²³ A case report²⁴ has confirmed fluoroscopy-guided removal of a metallic foreign body. However, because of the risks associated with tracheotomy, this fluoroscopic technique is not considered to be an ideal alternative to surgically remove a foreign body from the trachea of a cat.²⁵ MRI is also demonstrated to be an effective way to localize foreign bodies, but it has risks of causing fatal damage due to its strong magnetic field.²⁶ The hand-held metal detector is easy, inexpensive and free of radiation, but it fails to reliably detect very small metallic foreign bodies.²⁷ Therefore, these approaches for the localization and the removal of foreign bodies still need improvement.

In contrast to previous imaging techniques, we employed CT scans to calculate the projection of foreign bodies on the skin surface. CT is routinely used for imaging of the foreign body, and the size and shape of the foreign body can be reproduced accurately.^{28,29} CT-guided localization of foreign bodies in soft tissues has been shown to be reliable.³⁰ In the present study, after several experiments on the materials, threads of gauze detectable with X-ray were finally chosen as marker material, which was universally available and could achieve clear imaging without metal artefacts. We attached marker lines on the skin to indicate the position of the foreign body; afterwards, the surface

projection of the foreign body was calculated by CT scan. The position, shape and size of the foreign body were then determined by surface projection, as well as the removal path which should avoid vital organs and be as short as possible. With the use of 3D imaging and drawing, the errors in manual measurement could be significantly reduced, and the accuracy of calculations was much improved. Based on the accurate localization rate of surface projection (100%) and the removal rate of foreign bodies (100%), we speculated that, with easy-to-use markings of the surface projection under the guidance of CT scan, foreign bodies could be accurately localized.

Furthermore, the results showed minimal invasiveness, shorter operative time and fewer complications. Additionally, the wounds healed well, suggesting that our approach also had the advantage of minimal blood loss, no suturing, spontaneous healing of the wound and less severe post-operative pain. Taken together, our clinical results suggested that surface projection under the guidance of CT scan might be a good approach for foreign body removal with obvious advantages. Notably, ultrasonography is recently considered to be an easier and faster technique for the localization of foreign bodies.³¹ There are

many advantages of ultrasonography. Ultrasonography is reported to have many advantages, such as the sensitivity for detection of foreign bodies is up to 95%;³² however, it is shown to be unsuitable for those located deep and inside the air-filled cavities.²⁶ Moreover, ultrasonography examination needs contact with the surgical procedure field directly and has a risk of contamination.²⁴ Ultrasonography is reported to localize superficial foreign bodies more effectively than CT, but CT is a more effective technique for the visualization of foreign bodies in air than ultrasonography.³³ It can therefore be hypothesized that it may be an effective technique for foreign body removal via accompanying CT with ultrasonography. Further studies may be applied to verify our hypothesis. Moreover, progress in medical treatment and the development of individualized services will greatly promote the application of surface projections for the localization of foreign bodies.

CONCLUSION

In summary, the results of our study are encouraging and reveal that surface projection under the guidance of CT scans may be an accurate and effective approach for the pre-operative localization and extraction of metal foreign bodies.

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