Three-dimensionally-navigated cross-cannulated screw fixation for traumatic pubic symphysis diastasis: an anatomical study

Guangchao SUN¹, Chengguo YIN², Zhiyong LIU³, Lubo WANG³, Weidong MU³

¹Departments of Traumatic Orthopaedics, Shandong Provincial Hospital Affiliated to Shandong University, Jinan, Shandong, China
²Department of Orthopaedics, Affiliated Hospital of Binzhou Medical University, Binzhou, Shandong, China
³Hand Surgery, The Third People Hospital of Jinan, Jinan, Shandong, China

Objective: The aim of this study was to design and optimize the secure corridor of cross-cannulated screw implantation in pubic symphysis through Orbic 3D (Siemens Medical Solutions, Erlangen, Germany) computerized navigation and to provide an anatomic basis through the study of regional anatomy.

Methods: Fifteen embalmed adult cadavers (8 males, 7 females) were used in this study. All pelvic specimens were placed in the supine position on a radiolucent carbon fiber table. The ideal angle of screw placement, appropriate screw diameter, and perfect attachment point were determined by the computerized navigation system. According to the above data, cross-cannulated screws 6.5 mm in diameter were implanted by the guide pins. Based on detailed local dissection, the entry-exit points of double screws were exposed in the pelvis. The distances were measured between the entry-exit points and the major structures. Radiographs and computed tomography (CT) scans of the pelvis were performed to reassess the position of screws.

Results: The trajectory of the first screw originated from the trailing edge of the pubic tubercula to the anterior-lower corner of the contralateral pubic tubercula. The second screw was directed from the base of the pubic tubercula to the junctional zone between the pubic tubercula and inferior ramus of the pubis of the opposite side of the body. Both screws maintained a safe distance from the surrounding major structures. All screw corridors were found intact without any damage under X-ray and CT images.

Conclusion: The Orbic 3D computer navigation system is a reliable and new method of achieving a secure corridor for screw implantation in the pubic symphysis.

Keywords: Computer navigation; lag screw; pubic symphysis diastasis; regional anatomy.
The rate of pelvic fractures with pubic symphysis diastasis is as high as 24%.[1–3] The current gold standard is an open or closed reduction and internal fixation,[4–6] In most situations, traditional fixation of the displaced pubic symphysis using plate and screws requires extensive exposure, which may lead to complications such as blood loss[7] and wound healing problems, as well as neural or vascular injury.[8] Thus, there is a need to investigate less-invasive alternatives.

In an attempt to overcome the complications of extensile surgical approaches, percutaneous lag screw fixation has been advocated for the treatment of pubic symphysis injury.[9–11] More recently, single-cannulated screw techniques have been applied to clinical stabilization of the pubic symphysis[10] and have been reported as biomechanically more stable than plate fixation. Cano-Luis et al.[12] reported that there was no difference between the intact pelvises and the pelvises fixed with cross screws in terms of the biomechanical stability.

However, due to the complex three-dimensional (3D) anatomy of the pelvis, the security of a cross screw corridor is still debated. In order to achieve a secure corridor, regional anatomical measurement was performed through trial and error in pelvic specimens. Generally, multiple attempts were required in the present study to successfully insert the cannulated screw into the pubic symphysis, which has the potential to destroy the bony corridor and increase the difficulty of the experiment.

Navigation techniques have been introduced to increase the precision of screw placement. Orbic 3D (Siemens Medical Solutions, Erlangen, Germany) computer navigation for the placement of percutaneous screws across acetabular fractures with no or minimal displacement has aroused great interest,[13–16] but no experimental cadaveric studies have been reported in the literature.

The goal of the present study was to design and optimize the secure corridor of cross screws in pubic symphysis through Orbic 3D computer navigation and anatomic observation. A new method was evaluated to achieve a secure corridor in our study.

Materials and methods
Fifteen embalmed adult cadavers (8 males, 7 females) were used in this study. Mean age of death was 65 years (range: 53–85 years). Mean weight was 66 kg (range: 62–90 kg). All cadavers were obtained from the Anatomy Program at the Medical College of Shandong University. Under X-ray examination, all cadavers had normal bodies without congenital monstrosity, tuberculosis, rheumatism, etc. All cadavers were truncated from the L5 and one-third of the proximal thigh, and the middle parts were retained as the pelvic specimens.

All pelvic specimens were placed in the supine position on a radiolucent carbon fiber table (Hobo, China). On the iliac crest, an arc incision was performed in order to place the 2 fiducial screws with reflective array in the iliac crest for registration. All pelvic specimens were scanned by a SIREMOBIL Orbic-C3D arm (Siemens Medical Solutions, Erlangen, Germany). Through the 190° rotational scanner of the Orbic-C3D arm, the 3D image data of pelvic specimens in multiple planes were obtained. All acquired images were transferred to the Stealthstation Treatment Guidance Platform System (Medtronic Sofamor Danek, Broomfield, CO, USA). Accurate coronal, transverse, and sagittal images of the pubic symphysis were procured. The accuracy of the image was checked using a tool navigator. The tool navigator was used along with 3D fluoroscopic real-time images to determine the entry point and direction of the screw, resulting in low radiation exposure for the patient and surgeon, compared to traditional methods.

For implantation of the first screw, a 2-cm transverse incision, which was palpable on the skin surface of the pubic symphysis, was made in both sides of the pubic tubercles. A navigation probe was placed in the junctional zone between the pubic tubercle and superior ramus of pubis of either side (Figure 1a). By means of adjusting the navigator probe, the optimal position and direction were obtained in the computerized navigation system. The attachment point of the navigator probe in the pubic tubercle was the entry point of the first screw, and the direction of the screw was determined. The appropriate screw diameter was calculated through the Medtronic system. According to these data, a guide pin (2.0 mm diameter K-wire) was inserted into the symphysis pubis through the navigation system. For implantation of the second screw, a navigation probe was placed in the other side of the tuberculum pubicum (Figure 1b). In order to avoid the first screw corridor, the second screw formed an inclination angle with the hemline of the upper edge of the pubic symphysis. The ideal angle, appropriate screw diameters, and perfect attachment point for screw placement were determined by the computerized navigation system and the Medtronic system. Through the guide pins, double cross-cannulated screws (6.5 mm diameter) were implanted. Radiographs and computed tomography (CT) scan of the pelvis were performed postoperatively to reassess the length and position of cross screws (Figures 2a, b).

All dissection procedures were performed through a midline vertical incision and a Pfannenstiel incision.
The pelvic skin and subcutaneous soft tissues were removed, so as to expose the anterior muscle of the both thighs (one-third of the proximal thigh). The intact arteriae iliaca externa, vena iliaca externa, femoral nerve, and blood vessels were exposed completely in both sides. The distances were measured respectively from the entry-exit points of screw placement to the medial aspect of the major structures in both sides of all 15 specimens with vernier calipers (range: 0 150 mm, precision 0.01 mm).

The 3-aspect anteroposterior thicknesses of the pubic symphysis was measured. The angles of guide pins to the horizontal plane and coronal plane were measured by a universal angle measuring device (range: 0 320°, precision 2').

All measurements were taken twice and recorded by vernier calipers and a universal angle measuring device with the pelvis in supine position. All statistical analyses were performed using SPSS software (version 19.0,
SPSS Inc., Chicago, IL, USA) and were described by mean and standard deviation (Mean±SD). Comparing the angles of cross screw placement between female and male, the independent-samples t-test was used, and p value <0.05 was considered to be statistically significant.

### Results

In the sagittal plane, the articular surfaces of the pubic bones are oval in shape. The thinnest aspect lies in the lower extremity of the symphysis pubis. All data are presented in Table 1.

The trajectory of the first screw originated from the trailing edge of the pubic tubercula to the anterior-lower corner of the contralateral pubic tubercula. The trajectory of the second screw was from the base of the pubic tubercula to the junctional zone between the pubic tubercula and inferior ramus of the pubis in the opposite side of the body. All data are presented in Table 2.

Mean length of the 2 screws were 7.0±4.2 cm (the first screw) and 7.1±3.8 cm (the second screw), and there was no difference between male and female. Mean distances between entry-exit points and the major anatomical structures are depicted in Table 3. Among them, the nearest anatomical structure to the entry point was the spermatic cord (fallopian arch in the female). According to these data, the minimum distance was over 9 mm from the entry-exit points to the major anatomical structures. All screw corridors were intact without any damage under X-ray and CT images (Figures 3a, b).

### Discussion

Percutaneous lag screw fixation under computerized navigation has become a popular technique to stabilize traumatic pubic symphysis diastasis.[9–10] Intramedullary

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<th>Table 1. Mean thicknesses of tubercula pubicum, middle aspect and lower extremity of pubic symphysis (mm, Mean±SD).</th>
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<tr>
<td><strong>Aspect</strong></td>
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<td><strong>Mean±SD</strong></td>
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<td>Tubercula pubicum</td>
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<td>Middle aspect of pubic symphysis</td>
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<td>Lower extremity of pubic symphysis</td>
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SD: Standard deviation.

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<th>Table 2. Mean angles of screw placement to horizontal and coronal plane (°, Mean±SD).</th>
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<td><strong>Screw</strong></td>
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<td><strong>Male</strong></td>
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<td><strong>Mean±SD</strong></td>
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<tr>
<td>First screw</td>
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<td>Second screw</td>
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SD: Standard deviation.

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<th>Table 3. Mean distances between entry-exit points and major anatomical structures (mm, Mean±SD).</th>
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<td><strong>Structure</strong></td>
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<tr>
<td><strong>First screw</strong></td>
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<td><strong>Mean±SD</strong></td>
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<tr>
<td>Femoral nerve</td>
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<td>Femoral artery</td>
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<td>Femoral vein</td>
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<tr>
<td>Spermatic cord</td>
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<td>Fallopian arch</td>
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<tr>
<td>Moties rotoral</td>
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<tr>
<td>Obturator artery</td>
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<td>Obturator vein</td>
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<tr>
<td>Obturator nerve</td>
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<tr>
<td>Urethra</td>
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Note: “—” shows the relevant data were not measured due to gender differences. SD: Standard deviation.
nailing decreases the amount of stress carried by the implant, resulting in a lower failure rate in long bone fractures,[9] and its biomechanical stability is similar to that of an intact pelvis.[17] Fixation with lag screw can maintain extrusion to the fracture, aiding fracture healing and early functional exercise.[18]

As a new technique, both single screw and double screws can clinically be used for pubic symphysis diastasis. One single screw was only biomechanically sufficient to provide stability in APC-2 and LC injuries (B1, B2 types in AO-OTA classification).[10] A biomechanical experiment verified that single-screw fixation was biomechanically more stable than plate fixation.[18] However, the effective lever arm of single-screw fixation was short, resulting in high pressure generated by the screw in the upper part of the pubic symphysis and weak pressure in the lower part. Therefore, 1 single screw was unable to resist the vertical rotating force of the pubic symphysis.[12] According to Varga et al.,[19] it is necessary to seek greater stability in the lower symphysis, which translates into less sacroiliac mobility.

Double-screw techniques are more effective in stabilizing pubic symphysis diastasis. With regard to these techniques, the direction and location of screws are 2 key points in achieving a secure corridor. Cano-Luis et al.[12] concluded that the optimal entry point for cross lag screw fixation in the pubic symphysis was located at 1 side of the pubic tubercle and the exit point was located 1 cm inside the obturator foramen rim in the contralateral pubic body. The optimal angle was 45° between the vertical axis of screw placement and horizontal plane of the upper border of the pubic symphysis. Ma et al.[20] reported 2 internal fixations for pubic symphysis diastasis, including parallel-screw fixation and cross-screw fixation. Although these studies described entry point and direction of the screw, there was no report about the relationships between entry-exit points and the surrounding major anatomical structures. An accurate and safe screw corridor is essential to insert screws without penetrating the osseous corridor and damaging the important structures in the pubic symphysis.

To date, many different methods have been adopted for the creation of a secure corridor, including X-ray fluoroscopic views,[21] CT scans,[22] and image-processing software (Mimics, etc).[23] Due to the complex 3D anatomy of the pelvis and the lack of direct visualization, conventional fluoroscopy requires the acquisition of multiple images in different projections to determine the correct point of entry and direction of the screw,[24] leading to a prolonged surgical and radiation time.[25] Even for experienced surgeons, multiple attempts were usually required to insert each cannulated screw into the pubic symphysis. The patient and the operating room team were exposed to extended durations of fluoroscopy. To minimize these drawbacks in our study, Orbi-3D computer navigation was introduced to obtain secure corridors on cadavers. Once 3 fluoroscopic images were acquired, the movement of the tool navigator could be visualized and virtually controlled. This significantly reduces the fluoroscopy time, as well as operating time.

According to a preliminary clinical study, ISO-C 3D computer navigation significantly increased the accuracy
of screw placement when applied to many orthopedic surgical operations, such as spinal procedures, foot, and ankle surgeries. A number of experimental studies using both cadaveric and artificial pelvic models also revealed the potential of 3D computer navigation systems in minimizing the risk of screw perforation.

In our study, the ideal angle and position of screws were determined by means of adjusting the navigation probe, and the appropriate screw diameter was calculated through the Medtronic system. Using these data, it was easy to determine the position of the guide pin and screw within the real time coronal, transverse, and sagittal images of the pubic symphysis intraoperatively. Moreover, the entry point of the screw could be determined by the extended line of the planned screw, which made it easier to incise the wound properly. Therefore, it was more efficient and simpler than traditional methods to achieve optimal corridors.

In accordance with the pelvic biomechanical theory, the closer to parallel to the superior border of the pubic symphysis the first screw was, the higher the biomechanical efficiency. The first screw was inclined forward to maintain sufficient margin to the second screw, which was inserted to the lower part of the pubic symphysis. The 2 screws created a reciprocal chiasma and strengthened each other to resist the symphyseal vertical rotation load. Our results indicated that both screws were inserted to the full depth of the pubic symphysis on either side and that the screw threads went beyond the contralateral cortex to produce compression.

According to the regional anatomical study, the spermatic cord or fallopian arch was the closest anatomical structure to the entry point of the 2 screws, which had increased susceptibility to injury during the operation. Our results indicated that the mean distance was more than 9 mm from the spermatic cord or fallopian arch to the entry point. In addition, the spermatic cord or fallopian arch was directly visualized through the transverse incision, through which it could be pulled forward to avoid damage. Thus, the entry points of both screws maintained safe distances from the surrounding anatomical structures. The exit point of the first screw was at the anterior-lower corner of the tubercula pubicum on the contralateral side. According to anatomical measurement, the mean distance between the exit point and the femoral canal contents (including femoral nerve, artery, vein) was over 30 mm in both males and females. Meanwhile, the direction of screw implantation deviated from the corona mortis. Therefore, with regard to the exit point of the first screw, there was a sufficient security buffer area to avoid damage to the surrounding major anatomical structures during the screw placement process. Regarding the second screw, the distance between the exit point and the obturator vein was 24.2±2.4 mm in males and 19.7±1.7 mm in females. The obturator artery was further from the exit point of the screw. The direction of the second screw insertion was angled slightly forward. Therefore, the exit point of the second screw was not deep in the obturator, and injury could be avoided to the canalis obturatorius contents (including obturator nerve, artery, vein). By detailed anatomic observation, the results revealed both screws penetrated the far cortex and the exit points, and maintained a safe distance from the surrounding major anatomical structures. Meanwhile, the 2 screws were arranged in a reciprocal chiasma and could produce an effective compression to pubic symphysis.

Radiographs and CT scans of all pelvises were performed after screw implantation to reassess the position of the screw. Our study indicated that all bony corridors were completed without any damage to the cortex. Due to computerized navigation technique, the angles and positions of screw implantation were accurate. Orbic 3D computer navigation was a safe and reliable method to obtain secure screw corridors on cadavers. Even without the aid of computerized navigation, the screw implantation process can be conducted through radiographic verification and CT scans, according to the data of our study.

There are some limitations to this study. Due to atrophy and desiccation of the embalmed cadavers, the anatomical situations affected the measurement accuracy. In future studies, different diameter screws should be implanted to further confirm the technique’s effectiveness and validity in the treatment of pelvic ring fractures using cross screws. More biomechanical studies and further clinical studies are needed to facilitate a better comparison of cross screws to traditional plate systems.

Conclusion
The Orbic 3D computer navigation system is a reliable new method of achieving secure corridor for screw implantation. The secure corridors of cross screw implantation in the symphysis pubis are reliable and safe. The percutaneous cross screws are safe and effective alternatives to conventional fixations for pubic symphysis diastasis.

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Conflicts of Interest: No conflicts declared.
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