An evaluation of three-dimensional image-guided technologies in percutaneous pelvic and acetabular lag screw placement

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Abstract
Background: Percutaneous stabilization using three-dimensional (3D) navigation system is a promising treatment for pelvic and acetabular fractures. However, there are still some controversies regarding the use of 3D navigation to treat pelvic and acetabular fractures. The purpose of this study was to compare the Iso-C 3D fluoroscopic navigation, standard fluoroscopy, and two-dimensional (2D) fluoroscopic navigation in placing percutaneous lag screws in pelvic specimens to better understand the merits of 3D navigation techniques.

Methods: Fifty-four instrumentation procedures were performed in this study using six cadaveric pelvic specimens. Three groups were designated for different procedures and tests: group I, standard fluoroscopy; group II, 2D fluoroscopic navigation; and group III, Iso-C 3D fluoroscopic navigation. Nine screws were placed in each pelvis, including four screws placed bilaterally through the ilium into S1 and S2 vertebrae, four screws placed bilaterally through anterior and posterior columns of acetabulum, and one screw placed through the pubic symphysis. 3D fluoroscopic techniques were evaluated to determine the accuracy of screw position, instrumentation time, and fluoroscopic time. The data were statistically analyzed using SPSS 13.0.

Results: The malposition rate was 38.89%, 22.22%, and 0% in standard fluoroscopy, 2D fluoroscopic navigation, and Iso-C 3D fluoroscopic navigation groups, respectively. There was no significant difference between standard fluoroscopy and 2D fluoroscopic navigation. Compared with Iso-C 3D fluoroscopic navigation, there were significant differences (analysis of variance [ANOVA], P < 0.05). The mean instrumentation operating time using Iso-C 3D fluoroscopic navigation technique was 15.4 ± 4.5 min. There were significant differences compared with standard fluoroscopy (31.5 ± 6.2 min) and 2D fluoroscopic navigation (26.3 ± 7.5 min; ANOVA, post hoc Scheffe, P < 0.01). The mean fluoroscopic time of Iso-C 3D fluoroscopic navigation was 66 ± 4.8 min. Compared with standard fluoroscopy (132.8 ± 7.3 min) and 2D fluoroscopic navigation (47.7 ± 5.6 min), there were significant differences (ANOVA, post hoc least significant difference, P < 0.01).

Conclusions: In the present study, we compared Iso-C 3D fluoroscopic navigation, 2D fluoroscopic navigation, and standard fluoroscopy. Iso-C 3D fluoroscopic navigation showed...
a higher accuracy rate in positioning and a shorter instrumentation operating time. The fluoroscopic time was longer in Iso-C3D fluoroscopic navigation than that in standard fluoroscopy, indicating that radiation exposure can be moderately reduced in Iso-C3D fluoroscopic navigation operation, although the fluoroscopic time was the shortest in 2D fluoroscopic navigation.

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1. Introduction

The goal of operative treatment for unstable pelvic ring and acetabular fractures is an anatomic reduction and rigid fixation. Early operative treatment decreases immobilization-associated risks such as thromboembolic events, pneumonia, decubital ulcer, and psychological decompensation. In pelvic and acetabular operations, postoperative complications such as soft tissue irritations and wound infections are approach related [1]. Precise implant positioning with minimal invasiveness is a major requirement to reduce risks of iatrogenic injuries. Percutaneous lag screw stabilization is an attractive option for treatment of slightly dislocated vertical sacral fractures [2–6] or slightly dislocated unstable periacetabular fractures [7–11]. There are some percutaneous lag screw techniques used now, including iliosacral screw, lag screws in anterior or posterior columns of the acetabulum, and lag screw in the pubic symphysis. The lag screws are often placed under the guidance of standard fluoroscopy. Because of the complex three-dimensional (3D) anatomy of the pelvis and the close proximity to neurovascular structures, the percutaneous screw fixation is demanding and requires the surgeon to have detailed anatomic knowledge and extensive surgical experience. In addition, the patient and the operating room team are exposed to high levels of fluoroscopic time. Augmenting visualization of the anatomic site, image-guided computer-assisted surgery (CAS) may be valuable in this special clinical situation [12–18]. Because of complex anatomic circumstances within the pelvis [19,20], the operative access is all but trivial.

CAS systems have been used in orthopedic operations since the early 1990s. The newest development in navigation systems is 3D navigation, which requires a special C-arm that can perform orbital rotation around the object of interest and creates a computed tomography (CT)–like data set, which is used for the navigation. This technology allows the routine application of image-guided screw placement in the operating room. However, there are some controversies for the use of 3D navigation in pelvic and acetabular operations. To elucidate the advantage of 3D navigation, we compared the accuracy, instrumentation time, and fluoroscopic time of Iso-C3D fluoroscopic navigation, standard fluoroscopy, and two-dimensional (2D) fluoroscopic navigation in this study.

2. Material and methods

Fifty-four tests were performed in six cadaveric pelvic specimens (age ranging from 32 to 69 y old; mean, 47 y old). All specimens were randomly separated into three groups: group I, standard fluoroscopy; group II, 2D fluoroscopic navigation; and group III, Iso-C3D fluoroscopic navigation. Before operation, the bone specimen was placed in supine position and fixed on a radiolucent operating table. A piece of operation towel covered the specimen to mimic percutaneous screw placing (Fig. 1).

Sire Mobil Iso-C3D C-arm (Siemens Medical Solutions, Erlangen, Germany), Siemens ISO-C3D interface (Siemens Medical Solutions), and Medtronic StealthStation System (Medtronic Surgical Navigation Technologies, Louisville, CO) were used to assist in placing nine screws (7.3 mm; AO Synthes, West Chester, PA) in each specimen. Four screws were placed bilaterally through the ilium into S1 and S2 vertebrae. Four screws were placed bilaterally through the anterior and posterior columns of the acetabulum. One screw was placed through the pubic symphysis.

2.1. Application of standard fluoroscopy

1. Iliosacral screws: standard lateral, inlet, and outlet fluoroscopic pelvic views were needed to be obtained in this instrumentation. By rotating these views, one guide pin was placed across the ilium into the S1 vertebra, and a separate guidewire was placed into the S2 vertebra. The ideal screw location was considered parallel to the superior S1 vertebral end plate, midway between the S1 superior end plate and the S1 neuroforamen, and midline between the S2 superior end plate and the S2 neuroforamen. Each guidewire was advanced just beyond the sacral midline. This process was repeated for the opposite side after confirmation of the guide pin location. A cannulated drill was then used over each guidewire followed by the placement of each cannulated screw [18].

2. Lag screws of the posterior column of the acetabulum: as we reported before, the screws were placed in the safe anchor path of the posterior column of the acetabulum [21]. Anteroposterior and iliac views were obtained to help placing the screws. One guide pin was placed in the posterior column of the acetabulum. After confirmation of the guide pin location, a cannulated drill was then used over each guidewire followed by the placement of each cannulated screw. This process was repeated for the opposite side [21–23].

3. Lag screws of the anterior column of the acetabulum: the screws were placed according to the report by Ebraheim et al. [24]. Inlet pelvic, outlet pelvic, iliac, and obturator views were obtained. The tip of the guide pin was drilled in the cortex of the iliac body, about two cross fingers above the acetabular cavity. Under image intensifier control, the drill tip was passed into the medial side of the acetabular cavity until it reached the pubic ramus and perforated the anterior cortex at the symphysis pubis. Then, the
A cannulated screw was placed followed by the guide pin. The same process was then repeated for the opposite side.

4. Lag screws of the pubic symphysis: anteroposterior and inlet pelvic views were obtained. The guide pin was placed parallel to pubic symphysis, from one side of pubic tubercle to another side. After the location was confirmed, the screw was placed.

2.2. Application of 2D fluoroscopic navigation

The StealthStation with FluoroNav combined an optical tracking camera with the images from C-arm. FluoroNav, coupled with intraoperative fluoroscopic imaging, was allowed for real-time navigation in multiple planes and reduced the length of radiation exposure, while providing anatomic information to the surgeon. In this application, the reference frame was secured to a cancellous pin that was screwed into the posterior iliac spine. Before performing the surgical procedure, each specimen was automatically registered using a C-arm target while obtaining fluoroscopic images.

1. Iliosacral screws: standard lateral, inlet, and outlet fluoroscopic pelvic views.
2. Lag screws of the posterior column of the acetabulum: anteroposterior and iliac views.
3. Lag screws of the anterior column of the acetabulum: inlet pelvic, outlet pelvic, iliac, and obturator views.
4. Lag screws of the pubic symphysis: anteroposterior and inlet pelvic views.

The intended path and length of each screw was determined using FluoroNav (Fig. 2). Guide pins were inserted along the intended path, followed by drilling. Then, the cannulated screws were placed. Intraoperative images were not taken because navigation was performed using the images obtained before the surgical procedures started.

2.3. Application of Iso-C$^{3D}$ fluoroscopic navigation

The StealthStation with Iso-C$^{3D}$ was performed using intraoperative 3D data set acquisition and automatic registration of that data set. 3D fluoroscopic C-arm was capable of generating an isotropic 3D data set. These data were sent to other devices via Digital Imaging and Communications in Medicine transfer. The system used a patient reference frame and C-arm target to relate instrumentation to the patient’s anatomy. In this application, the reference frame was secured to a cancellous pin that was screwed into the iliac crest. The specimens were scanned using the 190° rotational scanner (Sire Mobil Iso-C$^{3D}$) for registration. The StealthStation was used to insert the screws based on the reference images. The lengths of screws were measured in the system. Guide pins were placed along a chosen path, followed by drilling, and then the cannulated screws were placed (Fig. 3). Images were not taken during the operation.

2.4. Evaluation of operation efficacy

2.4.1. Accuracy of screw position

After instrumentation, all screws were observed in pelvic specimens. High-resolution CT and x-ray were used to evaluate the position of screws (Figs. 4 and 5). The accuracy of screw position was considered entirely within the cortical margins of pelvis. Perforations that could cause serious complications were assessed in this study.

Perforations were graded according to prior established classification methods used to evaluate optimal pedicle screw placement [25–27]: grade 0, no perforation; grade 1, perforation <2 mm; grade 2, perforation between 2 and 4 mm; and grade 3, perforation >4 mm. The grades 1, 2, and 3 were defined as malposition.

2.4.2. Instrumentation and fluoroscopic time

Mean instrumentation time ($T_s$, the time of placing screw) was calculated by dividing the sum of each screw-placing time by 18, and fluoroscopic time ($T_{flu}$) of every screw was calculated by dividing the sum of each fluoroscopic time by 18.

2.5. Statistical analysis

Statistical analysis was performed using statistical software SPSS 13.0 (SPSS Inc, Chicago, IL). All the data were expressed as mean ± standard deviation. Malposition rate of screws was evaluated by using chi-square test, and the differences between groups were analyzed using analysis of variance with
3. Result

3.1. Screw position and malposition rate

In the standard fluoroscopy group, the malposition rate was 38.89% in all 18 screws. For the iliosacral screws, three had identified perforation, with one in spinal canal, one in sacral foramen, and one in pelvic cavity. Two anterior column lag screws had identical perforation, with one in acetabulum and one in pelvic cavity. In lag screws of pubic symphysis, two had identical perforation, with one in pelvic cavity and one in obturator foramen. In the 2D fluoroscopic navigation group, the malposition rate was 22.22%. There were four screws with identified perforation. In Iso-C3D fluoroscopic navigation group, there was no screw with identified perforation. There was no significant difference between standard fluoroscopy and 2D fluoroscopic navigation. Compared with the Iso-C3D fluoroscopic navigation, there were significant differences (P < 0.01, Tables 1 and 2).

3.2. Instrumentation and fluoroscopic time

The mean instrumentation time of Iso-C3D fluoroscopic navigation was 15.4 ± 4.5 min. Compared with standard fluoroscopy (31.5 ± 6.2 min, P < 0.01) and 2D fluoroscopic navigation (26.3 ± 7.5 min, P < 0.01), there were significant differences. The mean fluoroscopic time of Iso-C3D fluoroscopic navigation was 66 ± 4.8 min. Compared with standard fluoroscopy (132.8 ± 7.3 min, P < 0.01) and 2D fluoroscopic navigation (47.7 ± 5.6 min, P < 0.01), there were significant differences (Table 2; Figs. 6 and 7).

4. Discussion

Large skin incisions and extensive tissue dissection are required in conventional pelvic and acetabular operations. To obtain a clear view field of the operation site, tendons must be cut with muscles retracted or reflected. Osteotomies are also performed to create better visibility. It is necessary to find less invasive procedures that can enable the surgeon to achieve the same goals as used in conventional open reduction and internal fixation for pelvic fracture. Percutaneous stabilization is a major requirement in surgical treatment of pelvic and acetabular fractures to reduce risks of iatrogenic injuries.

There are some percutaneous screws used now, such as the iliosacral screw, lag screw of the anterior and posterior columns of the acetabulum, and lag screw of the pubic symphysis. Sacroiliac dislocations and fracture dislocations are indications for percutaneous iliosacral screw fixation. Fixation is performed after open or closed reduction of the dislocated joint. Once the anatomy is restored, the iliosacral screws can be placed percutaneously. However, this technique can cause complications, including perforation of sacral canal, neuroforamina, and iliac vessels.
In most acetabular fractures, fractures may be reduced and fixed indirectly. The accompanying fracture of the anterior column cannot be reduced under direct view, if the Kocher–Langenbeck approach is used for reduction and fixation of a fracture involving the posterior wall and/or column. An accompanying fracture of the posterior column cannot be or can be only partially reduced and fixed directly if an ilioinguinal approach is used for reduction and fixation of a fracture involving the anterior wall and/or column. Percutaneous placement of additional screws can be added to enhance the stability of the whole construct. The anterior column screw is inserted from the body of iliac bone toward the symphysis pubis. It passes the acetabular cavity on its medial side and runs inside the superior ramus of the pubis. In fact, these are the same screws as the retrograde transpubic screw for stabilization of the anterior pelvic ring but placed in the opposite direction. The posterior column screw is placed above the acetabulum from lateral to medial. It starts at the lateral cortex of iliac body and perforates the inner cortex of the posterior column in the pelvis at different levels, depending on the localization of the fracture line separating the posterior from the anterior column.

Fixation of the anterior pelvis can be performed alone when the posterior pelvic ring is only partially disrupted or it can be used to augment posterior fixation constructs in the case of complete hemipelvic instability. In most situations, the traditional fixation of displaced pubic symphysis using plate and screws requires extensive exposure, which may lead to serious complications. To avoid these complications, the lag screw of pubic symphysis can be used to fix symphysis diastasis injury. The screw is inserted in the junctional zone between pubic tubercle and superior ramus of pubis on either side. The direction is parallel to the superior border of the pubic symphysis.

The standard C-arm fluoroscopy is the most frequent image-guided technique in percutaneous screw fixation. But screw malposition rates with fluoroscopic guidance have been reported to range from 2% to 15% [20,28], with an incidence of neurologic injury between 0.5% and 7.7% [29]. In another study, Gertzbein et al. [26] reported that the rate of
misplacement of iliosacral screws using conventional fluoroscopy was 2%–35%. In the meantime, the instrumentation and radiation exposure time are longer, caused by changing the position and angle of the C-arm.

CAS systems have been used in orthopedic operations for about 20 y. For the lumbar and the thoracolumbar junction, image-guided procedures appear superior to the conventional approach in terms of pedicle screw misplacements [30–33]. Another merit is the reduction of radiation exposure for operating room personnel while using computer-navigated systems, which has been reported for different types of procedures [34–37]. In treating pelvic and acetabular fractures, CAS is still in preliminary stages.

Fig. 4 – The screws were evaluated by x-rays. (A) Anteroposterior view, (B) inlet view, (C) iliac view, and (D) obturator view.

Fig. 5 – The screws were evaluated by 3D CT, and reconstruction was mimicked in the positioning of the screws.
3D fluoroscopy–based navigation combines the advantages of CT and fluoroscopy-based navigation. With axial cut, 2D and 3D reformations in CT-like quality, no matching procedure is necessary because of the inherent registration, and a continuous update is possible as the fluoroscope is in the operation room. Because of the improved image quality compared with 2D fluoroscopy and the intraoperative option of an immediate 3D control, 3D fluoroscopy–based navigation can achieve more accuracy in pelvic and acetabular operations. In this study, standard fluoroscopy, 2D fluoroscopic navigation, and Iso-C3D fluoroscopic navigation were compared in three different ways.

In standard fluoroscopy group, the malposition rate was 38.89%. Compared with 2D fluoroscopic navigation group (22.22%), there was no significant difference. For 2D fluoroscopic navigation, a high quality of the defined fluoroscopy projections is mandatory for safe and precise screw positioning. But if the image quality is insufficient, the navigation procedure may not be performed well, especially in S2 and anterior columns of the acetabulum. In this study, two of four perforations were observed in S2 (one in sacral foramen and one in anterior cortical boundary of the sacrum). In the traditional fluoroscopic group, three iliosacral screws (S2) showed perforation. Ebraheim et al. reported that the pedicle width of S2 was 14.8 ± 1.9 mm (one of two of S1). The height was 17.6 ± 1.9 mm (two of three of S1), indicating that the S2 screw is not easy to place [23]. On the other hand, one anterior column of the acetabulum screw was perforated at the acetabulum by 2D fluoroscopic navigation, and two screws were observed to have perforation (one in acetabulum and one in medial wall of anterior column). All these screws were perforated around iliopectineal tubercle, which was the narrow area in anterior column of the acetabulum. In Iso-C3D fluoroscopic navigation group, there was no screw perforation observed. Thus, the accuracy of screw was the highest using Iso-C3D fluoroscopic navigation.

Using Iso-C3D fluoroscopic navigation, images were of CT-like quality and with no matching procedure in instrumentation. The location, angle, and length of screws were confirmed at one time. The mean instrumentation time (15.4 ± 4.5 min) was shorter than that in the other two methods (P < 0.01). Compared with standard fluoroscopy, 2D fluoroscopic navigation could show three different images at the same time, and there was no need to move C-arm in operation. The mean instrumentation time in the 2D fluoroscopic navigation group was shorter than that in the standard fluoroscopy group (P < 0.01).

In this study, the mean fluoroscopic time of the Iso-C3D fluoroscopic navigation group was longer than that in the 2D fluoroscopic navigation group (P < 0.01). Using Iso-C3D

Table 1 – The details of malposition screws of each group.

<table>
<thead>
<tr>
<th>Perforation</th>
<th>Iso-C3D fluoroscopic navigation</th>
<th>2D fluoroscopic navigation</th>
<th>Standard fluoroscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iliosacral screws</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sacral foramen</td>
<td>—</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sacral spinal canal</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Superior or inferior sacral vertebral</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>End plate</td>
<td>Anterior cortical boundary of sacrum</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Lag screws of posterior column of acetabulum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetabulum</td>
<td>Acetabulum</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Posterior wall of posterior column</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Medial wall of posterior column</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Lag screws of anterior column of acetabulum</td>
<td></td>
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<td></td>
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<tr>
<td>Acetabulum</td>
<td>—</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Medial wall of anterior column</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Anterior wall of anterior column</td>
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<tr>
<td>Lag screws of pubic symphysis</td>
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<tr>
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<td>—</td>
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<tr>
<td>Anterior wall of pubic symphysis</td>
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<td>—</td>
</tr>
<tr>
<td>Superior wall of pubic symphysis</td>
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<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Obturator foramen</td>
<td>—</td>
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<td>1</td>
</tr>
<tr>
<td>Amount</td>
<td>0</td>
<td>4</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 2 – Instrumentation time, fluoroscopic time, and malposition rate in the three groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Instrumentation time (min)</th>
<th>Fluoroscopic time (s)</th>
<th>Malposition rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard fluoroscopy</td>
<td>31.5 ± 6.2</td>
<td>132.8 ± 7.3</td>
<td>38.89</td>
</tr>
<tr>
<td>2D fluoroscopic navigation</td>
<td>26.3 ± 7.5*</td>
<td>47.7 ± 5.6*</td>
<td>22.22</td>
</tr>
<tr>
<td>Iso-C3D fluoroscopic navigation</td>
<td>15.4 ± 4.5*</td>
<td>66 ± 4.8*</td>
<td>0*</td>
</tr>
</tbody>
</table>

* Compared with standard fluoroscopy group, P < 0.01.
† Compared with Iso-C3D fluoroscopic navigation, P < 0.05.
‡ Compared with 2D fluoroscopic navigation, P < 0.05.
fluoroscopic navigation, the C-arm was needed to scan the specimen automatically in 190° and acquire 256 images. But during the operation, there was no need to expose to radiation. In the 2D fluoroscopic navigation group, there were several images that needed to be acquired before operation. So, the mean fluoroscopic time was shorter than that in the other two groups.

5. Conclusions

In the present study, we compared Iso-C3D fluoroscopic navigation, 2D fluoroscopic navigation, and standard fluoroscopy to aid in placing percutaneous lag screws. Iso-C3D fluoroscopic navigation showed the advantages of higher precision and shorter instrumentation time. Although the fluoroscopic time is longer than that in 2D fluoroscopic navigation, radiation exposure can be decreased during the operation. Concordant with clinical scenarios, Iso-C3D fluoroscopic navigation has shown advantages; hence, clinically, it may better avoid complications, thus decreasing length of stay and hospitalization expenses.

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References


