Closed reduction and fixation with 3 cannulated screws is a widely accepted surgery for the treatment of femoral neck fractures. However, how to obtain optimal screw placement remains unclear. In the current study, the authors designed a guide pin positioning system for femoral neck fracture cannulated screw fixation and examined its application value by comparing it with freehand guide needle positioning and with general guide pin locator positioning provided by equipment manufacturers. The screw reset rate, screw parallelism, triangle area formed by the link line of the entry point of 3 guide pins, and maximum vertical load bearing of the femoral neck after internal fixation were recorded. As expected, the triangle area was largest in the self-designed positioning group, followed by the general positioning group and the freehand positioning group. The difference among the 3 groups was statistically significant ($P<.05$). Anteroposterior and lateral radiographs showed that the screws were more parallel in the self-designed positioning group and general positioning group compared with the freehand positioning group ($P<.05$). The screw reset rate in the self-designed positioning group was significantly lower than that in the general positioning group and the freehand positioning group ($P<.05$). Maximum bearing load among the 3 groups was equivalent, showing no statistically significant difference ($P>.05$). The authors’ self-designed guide pin positioning system has the potential to accurately insert cannulated screws in femoral neck fractures and may reduce bone loss and unnecessary radiation.

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Femoral neck fractures are one of the most common traumatic injuries in elderly patients, and the incidence of these injuries is increasing in the aging population. Closed reduction and fixation with 3 cannulated screws is a widely accepted surgery for the treatment of undisplaced or partially displaced femoral neck fractures. However, Lagerby et al reported that accurate screw positioning was observed in only 56.3% (151 of 268) of patients with femoral neck fractures, which may result in fracture nonunion, delayed union, and avascular necrosis. Therefore, how to obtain optimal screw placement is an issue that needs to be addressed urgently.

Usually, surgeons adopt a traditional, massive, hollow screw guide pin locator provided by manufacturers to guide needle orientation, and then the screw is screwed along the pin. However, these guide pin locators are not radiolucent and adjustable. Thus, the location of the guide hole is difficult to determine, and insertion deviation may occur. This subsequently needs to be adjusted by repeated radiography, fluoroscopy, and needle positioning, leading to increased radiation exposure and delayed operative time, as well as increased local bleeding and trauma. These drawbacks make many surgeons abandon the traditional locator and use freehanded guide pin positioning, in which surgeons and patients are completely exposed under fluoroscopy to obtain satisfactory fixation of 3 screws, further increasing radiation and prolonging operative time.

Infrared tracking navigation and positioning systems have been developed that are based on preoperative fluoroscopy and data correction intraoperatively to simulate the location of the instrument on a computer. In the surgical treatment of femoral neck fractures, real-time observation of the virtual image of the angle and distribution of the femoral neck screws in the anteroposterior and lateral positions improves the accuracy of screw fixation, resulting in less radiation exposure, fewer reoperations, and significantly fewer overall complications. However, the adoption of this infrared tracking navigation and positioning system is challenging because of the high difficulty and cost to develop a technique. A majority of secondary- and tertiary-level hospitals in China cannot afford the instruments due to the high purchase and maintenance costs.

For the current study, the authors designed a radiolucent cannulated screw guide pin positioning system with precise adjustment functioning used for femoral neck fractures. Conducting a cannulated screw guide pin positioning test using a composite femoral neck fracture model in vitro, the hypothesis was that the insertion point and direction of the guide needle would be quickly and precisely located intraoperatively, ultimately reducing surgical trauma, operative time, and radiation exposure to medical staff and patients.

**Materials and Methods**

**Design of the Novel Guide Pin Locator**

The novel guide pin locator is made of stainless steel and consists of a positioning unit and connection apparatus. The positioning portion comprises a trigeminal handle with a slide slot and 3 positioning hollow guide rods fixed on it. The 3 positioning guide rods are distributed in an inverted triangle shape, are mutually parallel, and can slide in the slide slot and be locked to control the spacing among the 3 guide rods. The top 2 guide rods have a fixed length, whereas the bottom one has a flexible sliding length and can be arbitrarily regulated and locked to adjust the angle of the top plane, making the rods parallel with the axis of the femur neck after attaching to the lateral cortex of the proximal femur. Connected to the positioning unit is a lockable triaxial connecting device that can control the height and front and rear positions of the positioning unit, as well as the direction of the alignment rod by 3 axial adjustments. The triaxial connection device is ultimately fixed to the middle and upper end of the femur backbone by a Steinmann pin (Figure 1).

**Establishment of the Femoral Neck Fracture Model and Internal Fixation**

Eighteen synthetic left femur specimens (Osborne Technology Co, Ltd, Hangzhou, China) with similar bone structure and mechanical characteristics to human bone were randomly divided into 3 groups (n=6) to undergo freehand guide pin positioning (freehand positioning group), general guide pin locator positioning (general positioning group) (Figure 2), or the authors’ self-designed guide pin locator positioning (self-designed positioning group). The composite femur specimens were fixed in a bench vice to simulate intraoperative conditions. Three guide pins were first inserted with the 3 different positioning methods under C-arm machine monitoring. The entry points of 3 guide pins were distributed in an inverted triangle shape and the 3 guide pins were kept parallel to each other as much as possible in the process of inserting the needle, followed by withdrawal of the guide pin. The femoral neck fracture model was established by a wire saw osteotomy in the middle.
of the femoral neck perpendicular to the femoral neck axis. Then 3 guide pins were inserted again along the original holes, and 7.3-mm cannulated screws with the appropriate length according to the measured depth of the guide pin were screwed into the femoral neck along the guide pin. The top of the screw was located 5 to 10 mm beneath the femoral head surface, and the distal thread of all screws exceeded the fracture fragments.

**Gross Observation, Radiological Detection, and Mechanical Testing of Specimens**

A cross-section of the femoral neck was photographed when the femoral neck fracture model was established ([Figure 3](#)), then Image-Pro Plus version 5.0 software (Media Cybernetics, Silver Spring, Maryland) was used to measure the area of the triangle constituted by the link line of the entry points of the 3 guide pins divided by the cross-sectional area of the femoral neck (triangle area ratio). After completion of cannulated screw fixation by the 3 different guide needle positioning methods, the screw reset rate (defined as times of guide needle entry or numbers of fixing screws) was recorded. Using anteroposterior and lateral radiographs taken with a C-arm machine ([Figure 4](#)), the angle (\(\Theta\)) between the screw and femoral shaft axis was measured using Image-Pro Plus version 5.0 software, and the average value of the differences in angle (\(\Theta\)) between the 3 screws and the femoral shaft axis was calculated to show screw parallelism. The formula used was: 

\[
\Theta = \frac{([\Theta_1 - \Theta_2] + [\Theta_1 - \Theta_3] + [\Theta_2 - \Theta_3])}{3}.
\]

**Biomechanical** performance (vertical stress and maximum load bearing) was tested in all models using a materials testing machine (Zwick/Roell, Ulm, Germany). Each specimen was given a 1-way, progressive, vertical stress load (at 5 mm/min constant load) until the specimen bearing failed and the bone fractured. To protect the composite femur from mechanical deformation and displacement under pressurized conditions, the distal femoral shaft of the specimens was amputated and the proximal femur was fixed onto a materials testing machine by a specimen fixture device designed by the authors ([Figure 5](#)).
Statistical Analysis

SPSS version 16.0 statistical software (SPSS Inc, Chicago, Illinois) was used for data analysis. Measurement data were expressed as the mean±SD, and comparisons among the 3 different positioning techniques were performed with 1-way analysis of variance with post hoc least significant difference test. A P value less than .05 was considered statistically significant.

RESULTS

As shown in the Table, the triangle area ratio was the largest in the self-designed positioning group, followed by the general positioning group and the freehand positioning group; the difference among the 3 groups was statistically significant (P<.05). The screws were more parallel in the self-designed positioning group and general positioning group compared with the freehand positioning group (P<.05), with no statistical difference between the first 2 groups (P>.05). The screw reset rate in the self-designed positioning group was significantly lower than that in the general positioning group and the freehand positioning group (P<.05), with no statistical difference between the latter 2 groups (P>.05). Maximum bearing load among the 3 groups was equivalent, with no significant difference (P>.05).

DISCUSSION

When internal fixation of femoral neck fractures is performed, it is common to place the screws or pins according to the 3-point principle: 2 screws (the base) are positioned in the proximal portion of the neck (lateral cortex and femoral head), and 1 screw is placed on the femoral calcar (the tip). This fixation causes these 3 screws to locate in the harder bone of the proximal femur and ensures enlarged neck-width coverage among the 3 screws. Gurusamy et al reported that a greater distance between the screws on lateral radiographs reduced the risk of nonunion. In the current study, the authors measured the triangle area constituted by the link line of the entry point of 3 guide pins to evaluate the distances between the screws. As expected, the triangle area ratio was largest in the self-designed positioning group, followed by the general positioning group and the freehand positioning group, indicating that better fixation may be obtained with the authors’ self-designed cannulated screw guide pin positioning device.

Furthermore, several studies have investigated the mechanical strength changes of different cannulated screw configurations during internal fixation of femoral neck fractures in cadaveric or composite bone. These studies show that a triangular cannulated screw fixation configuration has a high peak load, ultimate load, torsional stiffness, axial stiffness, and axial maximal load; less shortening, varus angulation, and extension displacement; and more energy absorption before failure than other configurations. In the current study, a triangular configuration was formed by 3 different positioning methods; thus, the mechanical differences among the 3 groups was not statistically significant, although the maximum vertical bearing load was observed in the self-designed positioning group, followed by the general positioning group and the freehand positioning group.

Table

Comparative Analysis of 3 Groups by Gross Observation, Radiological Detection, and Mechanical Testing

<table>
<thead>
<tr>
<th>Group</th>
<th>Triangle Area Ratio</th>
<th>Screw Parallelism</th>
<th>Screw Reset Rate</th>
<th>Maximum Bearing Load (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Anteroposterior</td>
<td>Lateral</td>
<td></td>
</tr>
<tr>
<td>Freehand positioning</td>
<td>0.09±0.01</td>
<td>1.47±0.46</td>
<td>2.78±0.47</td>
<td>3.44±1.09</td>
</tr>
<tr>
<td>General positioning</td>
<td>0.10±0.03</td>
<td>0.61±0.84</td>
<td>1.19±0.55</td>
<td>2.67±0.70</td>
</tr>
<tr>
<td>Self-designed position</td>
<td>0.11±0.03</td>
<td>0.48±0.63</td>
<td>0.98±0.60</td>
<td>1.33±0.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>54.79</td>
<td>23.25</td>
<td>19.67</td>
<td>16.58</td>
</tr>
<tr>
<td>p</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
</tbody>
</table>

*aCompared with freehand positioning group, P<.05.
*bCompared with general positioning group, P<.05.
In addition, it is believed that screws are inserted parallel to each other to permit impaction of the head back onto the neck in case bone resorption occurs at the fracture site,\(^1\) which can reduce the incidence of bone nonunion and avascular necrosis compared with crossed Garden screw fixation.\(^1\) As expected, anteroposterior and lateral radiographs verified that screw parallelism was better in the self-designed positioning group and the general positioning group than in the freehand positioning group (\(P<.05\)), although there was no statistically significant difference between them (\(P>.05\)).

In internal fixation of femoral neck fractures, due to the limited bone mass of the femoral neck, repeated needle positioning causes further bone mass damage and loss and thus impacts screw fixation strength. Repeated positioning also increases operative time, blood loss, surgical trauma, and radiation.\(^5\) Therefore, the number of drilling attempts can be considered to be an indicator of not only operator skill level but also guide pin locator quality.\(^7\) In the current study, the authors’ self-designed guide pin locator seemed to overcome the shortcoming of repeated positioning required by other methods, showing a significantly lower screw reset rate in the self-designed positioning group than in the general positioning group and the freehand positioning group (\(P<.05\)).

**CONCLUSION**

The authors’ self-designed guide pin positioning system may provide a precise reference for needle entry and direction compared with traditional guide pin positioning and freehand guide pin positioning, effectively avoiding repeat needle positioning and puncture and reducing bone loss, surgical trauma, bleeding, and unnecessary radiation intraoperatively. However, the system has some limitations. The locator needs to be fixed in the femoral shaft and may cause new trauma and local stress concentration of the femoral shaft, followed by fracture. Also, the possibility exists of rotation of the entire guide pin positioning system due to single Steinmann pin fixation, leading to a shift of position. Finally, the multi-axis adjustment may be cumbersome, so a modified handheld handle fixed locator is necessary.

**REFERENCES**