ORIGINAL RESEARCH

Open Distal Femur Fractures Treated with Bone Cement Intramedullary Support Combined with Locked Plate Fixation

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ABSTRACT

Objective • The objective of this study was to assess the short-term clinical efficacy of the short-term clinical efficacy of bone cement intramedullary support combined with locked plate fixation in the treatment of such fractures.

Methods • A retrospective study including 21 patients was reviewed at an urban level one trauma center. There were 17 males and 4 females, with a mean age of 33.9 years. Gustilo grade was II (12 cases), III-A (6 cases), III-B (2 cases), and III-C (1 case). Two fractures were AO-OTA type 33A3, 9 cases were type 33C2, and 10 cases were type 33C3. After the first stage debridement and temporary external fixation, all patients received bone cement intramedullary support combined with locked plate fixation through an anterolateral incision at the second stage.. The perioperative complications, need for bone graft, alignment, and radiographic union were recorded. At 1-year follow-up, the range of knee motion was recorded, and functional results were evaluated by the Hospital for Special Surgery (HSS) knee score.

Results • All 21 patients were followed up for 12-36 months, with an average of 18.7 months. 1 case had superficial wound infection, and 2 cases had partial skin edge necrosis of the original open wound. After symptomatic dressing changes, they all healed well. 4 cases had autogenous bone grafting. 18 patients (85.7%) achieved radiographic union, with a mean union time of 6.2 months. Two patients underwent secondary operation 9 months after surgery due to nonunion and finally united after autologous bone grafting. One patient developed a deep infection 8 months after surgery and was successfully treated with Masquelet technique. Finally, bone union was achieved 7 months after surgery. The alignment was good in 17 patients (81.0%). No deep infection or hardware failure occurred during 1-year follow-up. The average range of knee extension and flexion was 5.2 ° and 106.8 °, respectively. The HSS score averaged 83.6.

Conclusions • Bone cement intramedullary support combined with locked plate fixation was an effective treatment modality of open distal femur fractures with high union rate, low complication, adequate alignment and satisfactory functional outcomes. (*Altern Ther Health Med.* [E-pub ahead of print.])

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INTRODUCTION

Distal femur fractures occur in less than 1% of all fractures and in 4-6% of femoral fractures.[1-3] A classic bimodal injury distribution is found in patients. Elderly patients are often caused by low-energy injuries (such as walking falls). In contrast, young patients are mostly caused by high-energy injuries (such as car accidents or falling from buildings).[4] Open distal femur fractures represent a unique subgroup of distal femur fractures, which are often seen in high-energy injuries and are very challenging to treat. They are characterized by fractures involving both supracondylar and intercondylar regions of the distal femur, severe soft tissue injury, wound contamination, high risk of vascular and nerve injury, and traumatic bone loss. Studies have reported a high incidence of nonunion, infection, and hardware failure after such fractures.[5,6]

At present, the clinical fixation methods for distal femur fractures are mainly divided into different types of plate fixation or retrograde intramedullary nail fixation.[7] Both biomechanical studies and clinical studies have compared the efficacy of different internal fixation methods for distal femur fractures. Still, the results are not consistent, which may be related to the type of fracture, patient population, bone grafting, and so on.[8-10] Nevertheless, the results of existing studies support that the clinical efficacy of plate combined

with retrograde intramedullary nail fixation is better than that of plate fixation alone, especially for open comminuted distal femur fractures, young patients, or osteoporosis patients.[11,12] However, the disadvantages of plate combined with nail fixation include high technical requirements, increased operation time, additional cost of hardware, and increased articular cartilage injury at the nail entry point.

According to the characteristics of plate combined with retrograde intramedullary nail fixation of distal femur fractures, combined with our successful experience of Masquelet technique in the treatment of chronic osteomyelitis bone defects in limbs,[13] the author put forward the idea of bone cement intramedullary support combined with locked plate fixation in the treatment of such injuries. Compared to plate combined with retrograde intramedullary nail fixation, we believe that this technique can avoid the drawbacks of combined fixation and also achieve good therapeutic effects. For fresh fracture patients, we believe that fracture healing and limb function recovery are basically determined one year after surgery, and there will be almost no significant changes in follow-up later. So this study aimed to evaluate the short-term clinical efficacy of this technique in the treatment of such fractures.

MATERIALS AND METHODS

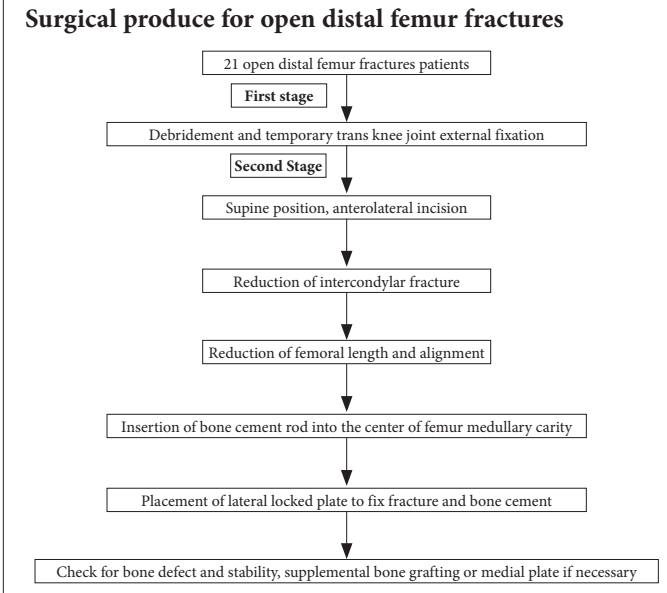
The clinical data of patients with open distal femur fractures admitted to our hospital from July 2013 to July 2019 were retrospectively analyzed, and the inclusion and exclusion criteria were formulated as follows. Inclusion criteria: (1) age 18-60 years old; (2) imaging examination (X-ray, three-dimensional CT) and physical examination confirmed open distal femur fractures; (3) good compliance; (4) fracture for the first time; Exclusion criteria: (1) patients complicated with severe multiple organ injury without surgical treatment; (2) bilateral open distal femur fractures; (3) final fixation with external fixator or amputation; (4) follow-up period less than 1 year, death or lost to follow-up; (5) incomplete case data. According to the above criteria, 21 patients were finally included, including 17 males and 4 females, aged 19-56 years, with an average age of 33.9 years. There were 9 cases on the right side and 12 on the left side. The causes of injury were traffic accidents (14 cases), falling from a building (5 cases), and heavy pounds (2 cases). According to Gustilo grade,[14,] there were 12 type II and 9 type III (6 type III-A, 2 type III-B, and 1 type III-C). According to AO-OTA classification, there were 2 cases of type 33A3, 9 cases of type 33C2, and 10 cases of 33C3. 8 cases were associated with other fractures (3 lumbar vertebrae, 2 tibiae, 2 ankles, 2 calcaneus, 2 distal radius, 1 pelvis, 1 patella, 1 distal humerus and 1 metacarpal), and 5 cases were associated with other organ injuries (4 pulmonary contusions, 2 subarachnoid hemorrhages, 1 spleen rupture, 1 brain contusion and 1 renal contusion). All patients in this study signed the informed consent form to participate in this study, and this study was approved by the ethical review committee of the author's institution's Human Subjects Review Board (Institutional Review Board of General Hospital of Northern Theater Command , No.:Ethnic Review (2022) 147).

Surgery treatment

Under general anesthesia, open wounds were thoroughly debrided in the operating room to remove contaminants, unhealthy tissues, and significantly inactivated free bone fragments. After thorough debridement, bacterial culture samples were collected, and the wound was sutured. Conventionally, the negative pressure drainage was used. The trans knee joint external fixator was used to restore the length of the femur, correct the angular deformity, and stabilize the fracture as far as possible. One patient was complicated with femoral artery rupture, which was repaired by primary suture after debridement. One case was given antibiotic bone cement bead implantation and vacuum sealing drainage because of severe contamination, and the wound was sutured directly after the second debridement on the fifth day after the first debridement. All patients were treated with antibiotics (vancomycin hydrochloride 1000 mg bid) after surgery. Then open reduction and internal fixation were performed after the results of bacterial culture were negative, and the original open wound healing was stable. The average interval between debridement and definitive surgery was 7.6 days.

Definitive surgical stabilization was performed uniformly. The patient was placed in the supine position with a sterile bump under the knee joint. The external fixator was removed. An anterolateral incision of approximately 10-15 cm was made through the distal femur. According to the severity of the intercondylar fracture, the articular surface was reduced first and then fixed with multiple 3.5 mm lag screws. It should be noted that the area of locked plate screws was reserved. Then the supracondylar fracture was reduced. A variety of techniques alone or in combination could be used to reduce fractures, such as traction, sterile bumps, Steinmann pins, and bone pry. The length of the distal femur was restored by reducing the main broken bone fragments in the non-bone defect area.

The reduction of length and alignment of the distal femur was checked by fluoroscopy. After confirming that the reduction was satisfactory, the position of the bone cement rod to be placed was marked, and its length and proximal diameter were measured. Bone cement rods with appropriate length and diameter were made. The bone cement rod was inserted into the center of the medullary cavity of the distal femur through the fracture end to ensure that the distal and proximal ends of the bone cement rod were in good contact with the bone cortex and were firmly inserted. After fluoroscopy confirmed that the femoral shortening and angulation deformity were corrected satisfactorily, fractures were temporarily fixed by Kirschner wires. The lateral locked plate was inserted into the lateral femur from the distal end to the proximal end. After radiographically confirming that the proximal end of the plate was located in the center of the diaphysis, a Kirschner wire was inserted into the proximal end of the plate through the screw hole sleeve to fix the plate. A cortical bone screw was screwed into the common hole of the plate as a lag screw, and the plate was attached to the femur, and then the distal and proximal locking screws were



driven one by one. It was important to note that at least one of the proximal or distal locking screws could be used to fix the fracture through the bone cement rod to enhance its stability. According to the area of bone defect and stability of fractures, bone graft was selected for the former, and extra medial plate fixation was selected for the latter. In this group, 4 patients received autologous bone grafts. The iliac bone was harvested and made into "matchstick" bone strips for grafting. Three patients were treated with extra locked plate fixation through a small medial incision. Negative pressure drainage was routinely placed.

Postoperative management

Antibiotics (cefuroxime sodium 1.5 g bid) were routinely administered for 3 days postoperatively, and the drainage was withdrawn 2-4 days after surgery. No patients were additionally protected with orthoses or splints. Patients were instructed to perform continuous passive motion exercises. The sutures were removed 2 weeks after surgery. Active knee flexion and extension activities were performed 3-6 weeks after operation, and weight-bearing was avoided within 6 weeks after surgery. Weight-bearing was gradually increased according to the patient's reexamination results.

Follow-up and evaluation

The patients were followed up at 1 week, 6 weeks, 3 months, 6 months, 9 months, and 1 year after surgery. Anteroposterior lateral X-ray of the distal femur were taken to assess union and limb alignment, and complications (superficial or deep infection, hardware failure, vascular and nerve injury, etc.) were recorded by the same doctor (Dr Xie). When it was difficult to judge union by X-ray, a three-dimensional CT examination was used. Fracture union was defined as continuous callus formation on 3 of the 4 cortical surfaces. A good alignment was defined as a femoral varus or valgus deformity of no more than 5°. The range of flexion and extension of the affected knee joint was recorded at 1 year follow-up. Hospital for Special Surgery (HSS) knee function score[15] was used to objectively evaluate knee function, which includes pain (30 points), function (22 points), range of motion (18 points), muscle strength (10 points), flexion deformity (10 points), stability (10 points) and subtractive items. The full score is 100 points, which is divided into four grades: excellent (above 85 points), good (70-84 points), fair (60-69 points) and poor (below 59 points).

Statistical method

Statistical analysis was performed by SPSS25.0 software, descriptive analysis of general and disease-related data; [case (%)] was used to represent the count data, chi-square test; normal distribution was expressed as mean±standard deviation, t test, a=0.05 as the test level, $P < .05$ was considered statistically significant.

RESULTS

All patients were followed up for 12-36 months, with an average of 18.7 months. Superficial infection occurred in 1 case of lateral femoral incision, partial necrosis of the original open wound of the distal femur in 2 cases, and fat liquefaction of the iliac incision in 1 case. After symptomatic dressing changes, they all healed well. Bone union was achieved in 18 patients (85.7%) 3-9 months after surgery, with an average union time of 6.2 months. Two patients were diagnosed as nonunion because of no callus formation at 9 months after surgery and received autologous bone grafts in the second operation, both of which finally united at 6 months after surgery. One patient developed a deep infection 8 months after surgery, which was treated with the Masquelet technique and eventually got union at 7 months after surgery. Seventeen patients (81. 0%) had good femoral alignment confirmed by postoperative X-ray. 4 cases (19.0%) had varus deformity of the distal femur, with a mean varus angle of 8.6°. No deep infection or hardware failure occurred during the follow-up period. At 1 year follow-up, the average range of knee extension and flexion was 5.2 ° and 106.8 °. The average HSS score was 83.6. According to the HSS knee score, 7 cases were excellent, 11 cases were good, and 3 cases were fair. Twelve patients (57.1%) returned to their original work. Recovery of limb function: 10 good, 8 good, and 3 bad (see Table 1). A typical case is shown in Figure 1.

DISCUSSION

Unlike closed distal femur fractures, open distal femur fractures represent a unique subgroup of distal femur fractures. The former mostly occurs in elderly female patients with osteoporosis, and the cause of injury is commonly low-energy; the latter mostly occurs in young people with high-energy injuries.[7] There are limited reports on the incidence of open distal femur fractures. Pietu, et al.[16] reported that the incidence of open distal femur fractures accounted for 17.5% of distal femur fractures, mainly in young men, and most of them were AO-OTA type C fractures. Open distal femur fractures are characterized by severe soft tissue injury, wound

Table 1. Results of 21patients treated with bone cement intramedullary support combined with locked plate fixation

Case n	Age	Gender	Class	Gustilo	Other injuries	Complications	Bone graft	Medial plate	Bone union	Union time (m)	Malalignment	Length shortening	Knee extension (°)	Knee flexion (°)	HSS	Return to original work
1	19	M	33C2	III-B	Subarachnoid hemorrhages, femoral artery rupture	Superficial incision infection	No	No	Yes	8	No	No	3	110	excellent	No
2	22	M	33C3	II			No	No	Yes	4	No	No	5	100	good	No
3	35	F	33C3	III-B		Partial necrosis of wound	Yes	No	Yes	6	No	No	6	97	good	No
4	52	M	33C2	II	Calcaneus		No	Yes	Yes	4	No	No	8	95	fair	No
5	45	M	33C2	II			No	No	Yes	5	No	No	9	115	excellent	Yes
6	37	M	33C3	II			No	No	Yes	6	No	No	2	105	good	No
7	50	F	33C3	III-C	Lumbar vertebrae, pelvis, tibiae, ankle, pulmonary contusions, subarachnoid, hemorrhages, spleen rupture, renal contusion	Partial necrosis of wound	Yes	No	Yes	9	No	No	0	120	excellent	Yes
8	41	M	33A3	II			No	No	Yes	7	No	No	2	104	good	Yes
9	26	M	33C2	III-A			No	Yes	No		Varus (7.5°)	No	14	99	fair	No
10	33	M	33C3	III-A	Lumbar vertebrae, calcaneus, distal radius, pulmonary contusions, brain contusion	Superficial incision infection	Yes	No	Yes	7	Varus (10.0°)	No	6	135	excellent	No
11	34	M	33C3	III-A	Patella		No	No	No		No	No	8	107	good	Yes
12	20	M	33A3	II			No	No	Yes	5	No	No	5	120	excellent	Yes
13	29	M	33C3	II	Distal radius, ankle, pulmonary contusions		No	No	No		No	No	9	96	fair	No
14	37	F	33C2	III-A	Tibiae, metacarpal		Yes	No	Yes	5	No	No	9	107	good	Yes
15	39	M	33C2	II			No	No	Yes	8	No	No	7	100	good	Yes
16	57	M	33C3	III-A	Distal humerus		No	Yes	Yes	9	Varus (9.5°)	No	2	98	good	No
17	22	M	33C3	II			No	No	Yes	5	No	No	3	107	excellent	Yes
18	23	M	33C2	II			No	No	Yes	4	No	No	0	103	good	Yes
19	31	F	33C2	II			No	No	Yes	5	No	No	1	130	excellent	Yes
20	39	M	33C3	II	Lumbar vertebrae, pulmonary contusions		No	No	Yes	7	No	No	5	100	good	Yes
21	21	M	33C2	III-A			No	No	Yes	8	Varus (7.5°)	No	6	96	good	No

Figure 1. A 52-year-old male patient with right open distal femur fracture caused by a traffic accident. The gross image showed a Gustilo type II fracture (A). Preoperative three-dimensional CT showed that fracture involved supracondylar and intercondylar of the distal femur, which was classificated as AO-OTA type 33C2 (B). Preoperative X-ray showed that the external fixator was fixed after debridement, but femoral shortening and angulation deformity could also be seen (C, D). According to the degree of shortening and compression of the distal femur, the bone cement rod with appropriate length and diameter was made and inserted into the center of the medullary cavity of the distal femur throught fracture end (E, F). At 1 week after surgery, X-ray showed that the fracture reduction was good and the support of bone cement rod was satisfactory (G, H) . One year after surgery, X-ray showed that the fracture united completely, the alignment was good, and no hardware failure occured (I, J). One year after surgery, the range of knee extension and flexion was 0° and 130° (K, L)

contamination, high incidence of AO-OTA type C fractures, bone loss or defect, and often combined with other injuries, even with life-threatening important organ injuries. Therefore, the treatment is completely different from that of closed distal femur fractures. Two-stage treatment is a widely accepted strategy for such injuries. In the first stage, the principle of damage control surgery is followed, especially for patients with combined injuries; the fracture is temporarily stabilized after thorough debridement, which creates conditions for stabilizing the patient's vital signs, soft tissue recovery, and infection control. In the second stage, open reduction and internal fixation of fracture is performed.[17]

There is no recognized gold standard for the fixation of open distal femur fractures. Many clinical studies have reported the results of different internal fixation methods for the treatment of closed distal femur fractures. However, the clinical reports of open distal femur

fractures are limited. Barei, et al.[5] reported the clinical results of 36 open distal femur fractures treated with lateral locked plate fixation, of which 34 cases (94.4%) achieved primary bone union, 2 cases of nonunion also finally achieved bone union after plate revision and bone grafting. 35 cases (97.2%) had good femoral alignment. No infection occurred in their study. Blatter et al.[18] reported that 25 cases of comminuted distal femur fractures were treated with one-stage femoral shortening fixation, two-thirds of which were open fractures. 24 cases achieved primary bone union, with an average union time of 14 weeks. The bone grafting rate was only 25%. One-third of the patients had symptomatic leg length discrepancy, with an average shortening of 2.6 cm. These patients were all well managed with an orthosis or a heel lift following the union of their fractures. Abdel-Aleem et al.[19] reported that 22 patients with Gustilo type III fractures were treated with an external fixator, all of which were AO-OTA type C fractures. All patients achieved bone union at 7 months after surgery, and then the external fixator was removed. There were no malalignments. Deep infection occurred in only 2 cases. The mean range of knee extension and flexion was 0 ° and 107.59 ° at 44 months after surgery.

Similarly, Kumar et al.[20] reported satisfactory clinical results in the treatment of Gustilo type III fractures with external fixators. Nevertheless, the use of an external fixator as the ultimate fixation for open distal femur fractures is subject to deliberation. Considering that most open distal femur fractures are AO-OTA type C fractures, and nearly half of them are type C3 fractures, it is difficult to reduce the comminuted femoral articular surface with external fixators anatomically, and whether it will accelerate the progression of knee osteoarthritis in the later stage is still a matter of concern. Prolonged external fixation to achieve bone union invariably results in knee stiffness. Yet, studies by Abdel-Aleem et al.[19] and Kumar et al.[20] both reported that patients achieved a good range of motion in knee flexion and extension at the last follow-up. This may be due to the fact that the surgeon did not use the trans-knee joint external fixation and encouraged the patients to exercise the knee joint early. However, early functional exercise may cause the risk of external fixator pins loosening and fracture displacement. In the study of Abdel-Aleem, et al.,[19] 8 patients (36.4%) had external fixator pin tract infection, which was also a problem that cannot be ignored, especially for the external fixation pin used to fix the distal femoral intercondylar fracture. Once the pin tract infection happens, it is likely to cause intra-articular infection.

How to improve the union rate of open distal femur fractures is the top issue for orthopaedic surgeons. Understanding the risk factors for nonunion of such fractures is essential for perioperative management and early intervention. Some studies have found obesity, open fractures, infection, and the use of stainless steel were independent risk factors for nonunion in patients with distal femur fractures treated with lateral locked plating. Ricci et al.[21]found that open fracture, diabetes, smoking, obesity and short plate fixation are risk factors for the reoperation of distal femur fracture. So far, there are no reports on the risk factors of nonunion of open distal femur fractures. Barei et al.[5] analyzed the factors affecting the union of open distal femur fractures and the need for secondary bone grafting and found that even if some patients had metaphyseal bone defects, as long as the posterior and/or medial femoral fragments existed, lateral locked plate fixation could maintain alignment and decrease the need for secondary bone grafting. In this study, 2 cases of nonunion got no bone graft at the first surgery. One case had the anterior bone defect of the distal femur, and the other had a posterior bone defect. The defective bones were removed during emergency debridement.

Studies support that plate combined with retrograde intramedullary nail fixation is a good choice for open distal femur fractures. However, the disadvantages of this method include high technical requirements, increased operation time, additional cost of hardware, and increased articular cartilage injury. According to the characteristics of this method, combined with our successful experience of Masquelet technique in the treatment of chronic osteomyelitis bone defects in limb, the author put forward the idea of bone cement intramedullary support combined with locked plate fixation in the treatment of such injuries.

In this study, the surgeon inserted the bone cement rod into the central of the distal femoral medullary cavity and additionally fixed it through the locking screw of the plate, expecting it to play a role similar to the retrograde intramedullary nail and to achieve the effect of plate combined with nail fixation.[22] Bäumlein et al.[23]confirmed that a cementable screw of the plate could strengthen the fixation of supracondylar femoral fractures. This also provides theoretical support for the use of bone cement intramedullary support technique. Three patients in this study received extra medial locked plate fixation, all of which had a relatively wider range of medial comminuted fractures or bone defects. Studies have shown that the distal lateral femoral plate acts as a tension band, causing compression of the medial femur.[7] Therefore, when the fracture of the medial distal femur is comminuted, or the bone defect is relatively large, additional support is needed for the medial distal femur.

In this study, the average interval between two operations was 7.2 days, which was much longer than 4 days reported by Barei, et al.[5]. The main consideration was that there was still redness and swelling at the open fracture site at 3-4 days, which was difficult to distinguish from similar symptoms caused by infection, while the former could basically recede at about 1 week. In addition, one week of observation time can create conditions for stabilizing the patient's general situation and restoring soft tissue damage. In this group, only 4 patients with larger bone defects confirmed during the operation were treated with autologous bone grafts. No bone graft was selected for patients with fewer bone defects or with bone fragments still visible despite the large fracture comminution. On the one hand, it is mainly based on the research results of Barei et al.[5], and on the other hand, it is

believed that the intramedullary support of bone cement can play the role of membrane induction and promote the growth of crushed bone fragments.[24]

Limitation

There are certain limitations in the present study. First, it is a retrospective series. Second, the number of cases was relatively small. Third, no control group was considered. Fourth, there was no analysis of the impact that patient baseline indicators may have on bone union. In addition, the profile of bone cement rods may vary from surgeon to surgeon. For closed distal femur fractures, especially for elderly patients with osteoporosis, whether this technique can also play a good clinical effect still needs larger-scale studies to further validate the effectiveness of the bone cement intramedullary support technique, explore its applicability to different fracture types, or investigate long-term outcomes.

CONCLUSION

This study provides a new method for the treatment of open distal femur fractures. The results showed that the treatment of open distal femur fractures with intramedullary support of bone cement combined with locked plate fixation could achieve a high bone union rate, good alignment, and satisfactory knee function with few complications. This technique is convenient for clinical promotion and can effectively improve the prognosis of open distal femur fractures.

COMPETING INTERESTS

The authors declare no competing interests.

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AUTHOR'S CONTRIBUTION

Dapeng Zhou and Hong Yuan contribute equally to this article. Correction of data and preparation of the original draft were performed by Bing Xie and Hong Yuan. Tianyu Han and Dapeng Zhou performed conceptualization, supervision, reviewing, and editing. Xiangyu Ma and Zhengang Ji performed data analysis and interpretation.

ETHICAL COMPLIANCE

The ethics committee of Northern Theater General Hospital approved this study.

CONSENT TO PARTICIPATE

Written informed consent was obtained from all the participants included in our study.

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