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The antegrade angle-stable locking intramedullary nail for type-C distal femoral fractures: a thirty four case experience

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Abstract

Introduction This is a retrospective study that provides initial experience and verifies the effectiveness of the newly-designed antegrade interlocking angle-stable intramedullary nail (IAIN) combined with half-threaded cancellous screws in the management of type-C (AO/OTA classification) distal femoral fractures.

Methods During a period of 30 months, 34 patients (mean age 43.1 years) with type-C (AO/OTA classification) fractures of the distal femur were treated with IAIN and half-threaded cancellous screws were reviewed. Peri-operative and post-operative parameters were analyzed.

Results All of the fractures healed in a mean time of 12.6 weeks with no incidences of malunion, nonunion or infection. No secondary failure of fixation occurred. Partial weight bearing was initiated in an average of 7.4 weeks post-operatively, with full weight bearing initiated in 13.8 weeks. All of the patients, except for one, gained full extension. The mean flexion of the knee joint was 110.1°, while the mean Hospital for Special Surgery (HSS) knee score was 85.2.

Conclusion The IAIN and half-threaded cancellous screws provided a reliable fixation that facilitated uncomplicated outcomes and uneventful early mobilization in treating type-C fractures of the distal femur.

Keywords Femoral fracture · Intra-articular · Antegrade · Interlocking intramedullary nail · Angle-stable

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Introduction

Incidences of distal femoral fractures account for 3–6% of all femoral fractures, with the majority of them being comminuted and unstable fractures [1–3]. Until now, type-C distal femoral fractures (usually complex intra-articular femoral fractures, according to AO/OTA classification) have been a challenge, even for experienced orthopaedic surgeons. Nowadays, instead of non-operative methods, operative treatment is the overriding method for type-C distal femoral fractures. Operative treatment includes extramedullary fixation (such as dynamic condylar screws, or and locking compression plates, or LISS, etc.) and intramedullary fixation (such as antegrade or retrograde intramedullary nails) [4–7]. Although fixation with plates and screws is widely preferred in the cases with severe intra-articular femoral fractures and enables early mobilization of the knee joint, this technique requires a larger incision, which leads to excessive soft-tissue disruption, blood loss and operating time. Furthermore, delayed union or non-union and infection may ensue.

Intramedullary nail is now commonly accepted as being an effective implant for diaphyseal fractures. Previously, the poor hold of distal locking configuration was the reason for minimizing the use of intramedullary nailing for joint fractures. However, with the newly designed implants and more locking configuration, the indications for intramedullary nailing have broadened to include intra-articular involvement [8–10]. To the best of our knowledge, few studies have focused on antegrade intramedullary nailing in the treatment of type-C distal femoral fractures. This retrospective study is based on the hypothesis that the newly designed antegrade interlocking angle-stable intramedullary nail (IAIN), which was improved for distal femoral fractures fixation combined with half-threaded cancellous screws, can provide stable fixation of intra-condylar fractures. The distal interlocking configuration combined with half threaded cancellous screws can offer good stability in distal femoral comminuted fractures. Furthermore, this study shows that the combination of IAIN and half threaded cancellous screws can minimize complications and accelerate the fracture union and functional recovery of patients with type-C distal femoral fractures.

The purpose of this study was: (1) to introduce the newly designed intramedullary implant, the IAIN; and (2) to assess the clinical effect of the IAIN used in the management of type-C distal femoral fractures.

Materials and methods

Introduction of IAIN

The IAIN system is composed of the main nail with seven threaded locking holes, tip cap, fully-threaded cancellous locking screws that have to go through the locking holes of the main nail, forming an angle stable structure in the distal end, and half-threaded cancellous screws, which do not go through the locking holes and can be applied freely based on the comminution of the fracture. The main nail's radius of curvature is 125 cm [11], the diameter of the proximal part is 14 mm, and from the shaft to the distal end is 9–13 mm (Fig. 1). Its length ranges from 320 mm to 440 mm. The proximal three holes allow screws to fix from lateral to medial, inferolateral to superiomedial (forming a 135°angle with the main nail, which is suitable for the neck-shaft angle) and inferiomedial to superiolateral directions. There are four holes in the distal part (there is a groove to ensure the position of the main nail, which looks like a fifth hole). The first and fourth holes are parallel to each other and vertical to the Whiteside's line. The other two holes have a 30°angle with the first hole. The fully-threaded cancellous locking screws are designed in a fusiform manner, having a 4.5-mm diameter in the middle, a 3.0-mm diameter at both ends and a 5-mm diameter of the thread. The half-threaded cancellous screws are applied to both fix the fragments and improve the strength of the whole system. The main nail is anatomically fit into the femoral cavity and can be inserted easily into the medullary canal, sometimes without reaming. Above all, the IAIN can be used in all kinds of femoral fractures, apart from posterior condylar fractures and avulsion fractures (Fig. 2).

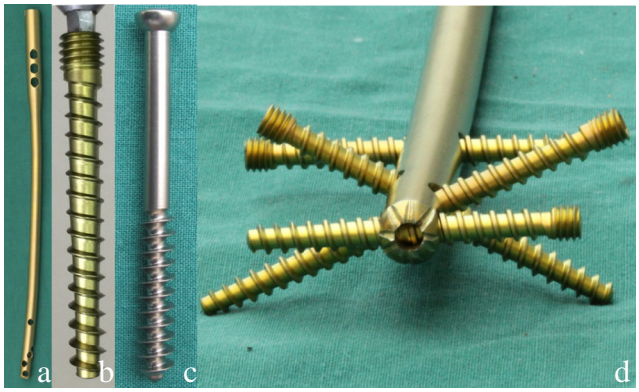

Fig. 1 (a) The main nail, (b) fully-threaded cancellous locking screw, (c) half-threaded cancellous screw and (d) distal part with fully-threaded cancellous locking screws

Patients

Inclusion and exclusion criteria

With approval of the Institutional Review Board and in accordance with the Declaration of Helsinki in ethical standards, this retrospective study of patients who met the following inclusion criteria was performed: (1) age between 30 and 60 at the time of injury, (2) type-C distal femoral fractures (AO/OTA classification), (3) treated with IAIN, and (4) available follow-up records of at least 12 months post-operatively. Exclusion criteria were as follows: (1) severe cognitive dysfunction which may have hindered post-operative rehabilitation, (2) history of previous knee surgery on either side, (3) pathologic fracture, (4) concomitant fractures of other areas, (5) absence of independent walking capability prior to trauma.

The records of 25 men and 9 women aged 32 to 60 (mean age 43.1 years) years old, who had undergone IAIN surgery between February 2014 and June 2016 for type-C distal femoral fractures were reviewed. The causes of injury included motor vehicle accidents ($n = 28$) and simple falls ($n = 6$). Thirty-two patients had closed fractures and two had open fractures (grade II, according to the Gustilo Anderson classification) [12]. Twenty-seven left-sided and seven right-sided femurs were involved. Pre-operative X-ray and CT scan were performed on all the patients. According to the AO/OTA classification for type-C distal femoral fractures [13], they were classified as C1 ($n = 19$), C2 ($n = 11$) and C3 ($n = 4$). For the

Fig. 2 Peri-operative and post-operative views of case no.11 (type-C3 femoral fracture). (a, b) Pre-operative antero-posterior and medio-lateral X-ray. (c, d) Pre-operative antero-posterior and medio-lateral CT reconstruction. (e, f) Three months' post-operative antero-posterior and medio-lateral X-ray. (g, h) One week after the removal of IAIN

patients with open grade II fractures, the nailing procedure was postponed for 14 days after thorough debridement.

Surgical technique

An appropriate main nail's diameter was selected according to the femoral medullary canal and the length was measured from the tip of the greater trochanter to the centre of the patella from the pre-operative X-ray of the unaffected femur. The patients were fully supine on a radiolucent table under general or spinal anaesthetic. A mat was placed under the affected limb's hip, which was elevated about 25° from a coronal plane to a horizontal plane. A prophylactic antibiotic was administered half an hour prior to the operation. Closed reduction can be obtained through longitudinal traction, external manipulation manoeuvres and using large reduction forceps (or pelvic clamp) percutanously for C1 and C2 fractures. To achieve reduction of a complex C3 fracture, a 6~9 cm anterolateral or anteromedial skin incision was employed. Condylar fractures can be temporarily fixed by using reduction forceps and Kirschner wires. Then, half-threaded cancellous screws were inserted to fix the condylar fragments from a medial-lateral or oblique direction based on the comminution of the fracture. After using half-threaded cancellous screws, the intra-articular fractures became extra-articular fractures and attention was then diverted to the supracondylar fractures. A skin incision of about 2 cm was performed proximal to the greater trochanter. After palpating the tip of the greater trochanter, an awl was used to make an entry portal for the main nail. The proximal 10 cm of the femur was slightly reamed to provide enough space for the proximal part of the nail and the rest of the medullary canal can sometimes not be reamed. Then, the nail was mounted on a targeting device and inserted into the canal by hand using light pressure. Two fully-threaded cancellous locking screws which were vertical to the Whiteside's line were twisted into the distal part of the main nail after adjusting the alignment and rotation of the lower extremity. The other two fully-threaded cancellous locking screws were then twisted into the distal part. Then the main nail was pushed to the distal end to regain the length of the leg. Usually two fully-threaded cancellous locking screws were inserted in the proximal part from a medial-lateral direction. The position of the

nail and the length of the screws were confirmed by a C-arm in the anteroposterior and lateral planes. Allograft was applied on C3 patients according to the defect of the fracture site.

Post-operatively, a 6° valgus angle flexion-extension brace was used for one~ten months for type C3 patients. The suction drains were removed within 48 hours. All of the patients were asked to exercise their quadriceps from day two. Active and passive range-of-motion exercises of the knee joint began on day three under pain free conditions. The 1~4 one-four weeks limitation of motion depends on the severity of the fracture. All of the patients commenced partial weight bearing using crutches at least four weeks after their operation. Full weight bearing was allowed after enough callus was noted on their X-ray. The patients were assessed using the knee-rating scale of the Hospital for Special Surgery (HSS) [14], which includes pain, function, range of motion, muscle strength, flexion deformity, instability and so on. The full point value is 100. Scores ≥85 are excellent, 70–84 are good, 60–69 are fair and <60 are poor.

Results

The mean operating time was 1.5 (range 1–2.1) hours. Both the C1 and C2 fractures were reduced by the closed technique, whereas a 6~9 cm incision was performed on the C3 fractures. All C3 patients had bone grafting based on the defects of the fractures. The 34 patients in this study were followed up regularly for an average of 20.5 (range 16–30) months and no patients were lost to follow-up. All of the fractures healed (enough formation of bridging callus around the fracture site) uneventfully without complications, such as loss of reduction, infection, malunion and malalignment, and the mean bony union time was 12.6 (range 10–18) weeks. Except for one patient, who lacked full extension of his knee (−10°), all of the patients had full knee extension, while their flexion varied from 80° to 130° (mean 110.1°). The final follow-up indicated, according to the HSS knee-rating scale, that 20 patients rated excellent, 14 patients rated good, 0 patients rated fair and poor. Two patients had less than 4° of valgus angle of lower extremity alignment, ten had 4~6°and two had over 6°. The patients' characteristics and functional outcomes are described in Table 1.

Discussion

In the past, type-C distal femoral fractures were treated with operative methods based on the concept of open reduction and internal fixation. Therefore, plates and screws became the standard method of treatment for these fractures, as recommended by the AO/ASIF. Several studies have demonstrated that predictably good results could be expected for most patients with distal femur fractures treated with locked plating [15–17]. The complications of plates and screws (like large incision, nonunion, infection, implant failure, etc.) were gradually exposed through clinical use, and intramedullary nails were applied more often. Intramedullary nails can both offer biological fixation and enhance biomechanical properties [18, 19]. Unlike lateral locking plates, an intramedullary nail is axis fixed and, thus, becomes a load-sharing device and can enable the limb to bear more axial load than shearing load, which will boost the healing of the bone [20]. However, there remains no final conclusion in determining whether to select an antergrade nail or a retrograde nail for type-C fractures, as there are few studies comparing the two techniques. Kulkarni et al. reported either good or excellent results in 27 of their 30 patients with type-A and type-C1 distal femoral fractures treated with antergrade interlocking nailing [21]. In a prospective randomized trial, Tornetta et al. found no differences in operation time, blood loss, technical complications, size of nail or reamer or transfusion between these two techniques [22]. Salem et al. indicated that neither treatment method had a proven advantage over the other, with regards to limb geometry or functional outcome, while proper operative indication, intra-operative control and the surgeon's experience seemed to be more important than the nailing technique [23]. Nevertheless, for retrograde nails, removing them requires opening the knee joint a second time, which can be associated with stiffness, pain and infection of the knee joint [24, 25]. Post-operative knee pain is common following retrograde nails treatment, with a well-established cause being nail protrusion from the intercondylar notch [26].

The IAIN involves multi-directional locking options in different planes, which surpasses most of the retrograde nails. The tight fit between the locking screws and the main nail of this system has a locking function that enhances the fixation stability of the fracture fragments. Usually, the mechanical conditions at the fracture site, such as interfragmentary movements and gap size, have a major influence on the bone-healing. In a study of the displaced osteotomy model in sheep tibiae, Kaspar et al. found that, regardless if there was three-dimensional stiffness in vitro, a regaining of almost normal weight-bearing, gait patterns of the treated hind limb, interfragmentary movements, bridged callus, as seen from the radiographics, or homogeneous and complete bridging of the osteotomy gap from the histomorphometric analysis, the angle stable tibial nail that had a locking function indicated a more superior result than the standard tibial nail [27]. Therefore, the application of multi-directional distal interlocking holes and fully-threaded cancellous locking screws make the IAIN an angle stable structure that has the ability to minimize the interfragmentary movements and gap size, laying a solid biomechanical boundary condition for the bone to heal. The half-threaded cancellous screws can be used freely to fix the bone fragments. The fully-threaded cancellous locking screws and half-threaded cancellous screws have

Table 1 Characteristics and results of 34 patients

Case	Age	Sex	AO classification	Cause of injury	Operation time(hours)	Radiographic union (weeks)	PWB initiation (weeks)	FWB accomplishment (weeks)	Follow up period (months)	HSS knee score	ROM (flexion at final follow up)
1	32	M	C1	Fall	1.2	10	6	10	16	90	120
2	51	M	C2	MVA	2.1	14	8	16	18	80	110
3	36	F	C2	Fall	1.5	11	6	12	20	83	110
4	40	M	C1	MVA	2	10	6	10	18	93	130
5	52	M	C3	MVA	1.8	18	10	18	24	72	80
6	45	M	C3	Fall	2	16	10	16	26	75	85
7	60	M	C1	MVA	1.2	11	6	12	16	88	110
8	51	F	C2	Fall	1.1	15	6	14	18	80	120
9	42	M	C3	MVA	2	17	10	18	24	80	90
10	38	M	C2	Fall	1.5	13	8	14	20	84	100
11	49	M	C3	MVA	1.9	13	8	12	18	75	80
12	45	M	C1	MVA	1.6	10	4	10	16	95	130
13	47	F	C1	Fall	1.3	15	8	15	16	89	120
14	44	M	C1	MVA	1.6	13	6	14	16	80	100
15	35	M	C1	MVA	1.1	11	6	10	18	87	110
16	39	F	C1	MVA	1.1	12	7	11	20	90	120
17	40	M	C2	MVA	1.3	14	9	13	19	85	110
18	38	F	C1	MVA	1.6	10	8	12	21	91	120
19	39	M	C1	MVA	1.7	12	6	10	22	89	130
20	32	M	C1	MVA	1	10	6	10	24	88	120
21	49	M	C2	MVA	2.1	14	8	12	26	92	120
22	41	F	C1	MVA	1.9	11	8	13	21	93	110
23	35	M	C1	MVA	1	13	7	14	16	89	130
24	36	F	C1	MVA	1.6	11	6	12	18	90	100
25	58	M	C2	MVA	1.5	15	8	11	22	87	110
26	50	M	C1	MVA	1.2	11	6	14	19	70	100
27	43	F	C2	MVA	1.1	15	8	14	24	79	105
28	38	M	C1	MVA	1.5	10	10	15	26	84	110
29	45	F	C2	MVA	1.3	14	8	11	30	82	105
30	49	M	C1	MVA	1.2	13	7	12	21	80	115
31	40	M	C1	MVA	1.5	11	7	13	19	89	120
32	34	M	C2	MVA	1.8	16	9	10	23	90	110
33	36	M	C2	MVA	1.9	11	10	13	22	90	130
34	55	M	C1	MVA	1.2	10	6	11	21	88	110
Mean	43.1				1.5	12.6	7.4	12.7	20.5	85.2	110.1

M male, *F* female, *MVA* motor vehicle accident, *PWB* partial weight bearing, *FWB* full weight bearing

become the so-called jail-screw that can enhance the strength of the fixation, thus allowing early mobilization and weight bearing of the knee joint [28, 29]. Both early partial and full weight bearing can be achieved with the help of a more stable structure in the distal part of the femur. The patients in this present study had mean partial and full weight bearing for 7.4 and 12.7 weeks, respectively, which is better than in some previous studies [30, 31].

A proper length and diameter of the main nail can improve the results of IAIN treating type-C distal femoral fractures. Any mechanical failure in the antegrade interlocking nails of long bone fractures tends to occur at the superior most distal locking hole or locking screw, and this may substantially jeopardize the treatment results and cause fixation failure [32]. A longer nail and more nail-cortical contact can effectively increase the fixation stability and decrease the strain between the locking screw and locking hole. Proper diameter and special radian help the main nail to have more nail-cortical contact. An unreamed nail effectively reduces the intramedullary pressure and heat during the insertion process, resulting in superior

cortical blood circulation and a lower complication rate, in terms of secondary fracture, fat embolism and infection [33, 34]. It can not only prevent the oriented error caused by the reaming, but also reduce the pressure in the cavity caused by hammering, resulting in reoccurrence of the fracture being prevented. The length selection is important and a preoperative length measuring from the tip of the greater trochanter to the midpoint of the vertical axis of the patella was required. Consequently, the distal end of the nail merely purchased the subchondral bone of the intercondylar notch, behind the femoral trochlea. Indeed, this retrospective study has its limitations, namely, the small number of patients and poor results in C3 patients. More cases should be considered in a future study. Clearly, the IAIN is not suitable for comminuted C3 distal femoral fractures.

Conclusion

In conclusion, our experience in the use of IAIN for the treatment of type-C distal femoral fractures provided a satisfactory clinical effect except for C3 patients. The IAIN and half-threaded cancellous screws provided a reliable fixation that facilitated uncomplicated outcomes and uneventful early mobilization in treating type-C fractures of the distal femur despite its limitations. Therefore, we consider this technique as being a good alternative treatment option for type-C distal femoral fractures.

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Compliance with ethical standards

Competing interests Yongqing Wang decided not to be the first author any more on his own will but continued to be the corresponding author. Zhihui Zhao and Yi Li's contributions are equal to this study. All the authors have agreed that they can be the first author at the same time. On behalf of all the authors, we disclose any financial and personal relationships with other people, or organizations, that could inappropriately influence our work. There are no conflicts of interest among all the authors.

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