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Which of the three different intramedullary nail designs is superior in the treatment of femoral shaft fractures?

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ABSTRACT

Aim: The aim of this study a retrospective comparison was the clinical and radiological results results of patients with femoral shaft fracture made oftreated with three different types of intramedullary nail (IMN).

Material and Method: The study included 54 patients operated on in our clinic because of femoral shaft fracture. The records were retrospectively examined of 18 patients applied with locked IMN (LIMN), 17 with blade expandable IMN (BEIMN), and 19 with talon distalfix IMN (TDIMN). The groups were compared statistically in respect of age, gender, BMI, affected side, operating time (mins), radiation exposure (number of shots), time to union (weeks), visual analog scale (VAS) score, soft tissue problems associated with implant irritation, amount of shortening (mm), coronal, sagittal and torsional angulation (degrees).

Results: The mean VAS score of the TDIMN group was determined to be statistically significantly higher than that of the LIMN and BEIMN groups (p=0.008, p=0.045). The operating times were similar in the BEIN and TDIMN groups (p=0.768) and significantly shorter than in the LIMN group (p<0.001). Radiation exposure was similar in the TDIMN and BEIMN groups (p=0.039), and the number of shots in the LIMN group was significantly higher than in the other two groups (p<0.001). The coronal angulation values were lower in the TDIMN group than in the BEIMN and LIMN groups (p=0.001, p=0.020). The sagittal angulation values were lower in the TDIMN group than in the BEIMN and LIMN groups (p=0.001, p<0.001). No significant difference was determined between the groups in respect of time to union, limb shortness, rotational deformity, and soft tissue problems related to implant irritation (p>0.05).

Conclusion: TDIMN is less resistant to axial loads due to its hook structure design. In fact, this is sometimes seen as a hook break. High VAS scores explain this. The sagittal and coronal angulation of the TDIMN is less, but the time to union, rotational angulation, and shortness development are similar in all three nails. This showed that all three nails did not have a significant advantage over each other in providing fracture stability.

Keywords: Femoral shaft fracture, intramedullary nail, distal hook, locking, blade expandable

INTRODUCTION

Intramedullary nails are most often selected because of the success in stabilisation of long bone fractures (1). Intramedullary nail (IMN) fixation is the standard treatment method for both femoral shaft fractures (FSF) and tibial shaft fractures. Bone union has been reported at the rate of 97% with IMNs applied in femoral fractures (2,3). IMNs are implants with the advantages of being minimally invasive, they can be applied rapidly, provide good fracture fixation, and allow early mobilisation (3). The factors of IMNs determining resistance to various forces are the nail design, whether or not it is grooved, the number, diameter, and placement of locking screws, the distance of the locking screws from the fracture region, and bone quality (1,4,5).

Different designs of IMNs are currently used in the treatment of femoral fractures. Some of these are screw and locking IMN (LIMN), blade-expandable intramedullar nail (BEIMN), and adjustable talon distalfix intramedullar nail (TDIMN) (6-8).

LIMN is currently often used for FSF. Rotational and axial stable fixation is thought to be provided due to the proximal and distal locking screws. However, important points that still have to be overcome are the risk of soft tissue damage, number of fluoroscopy images taken, prolonged operating time, and difficulties in the placement of distal locking screws (4,5). With the use of TDIMN, while fixation is provided in the proximal with

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classic locking screws, fixation in the distal is provided by the attachment of the adjustable hooks to the inner surface of the bone cortex (7). Although distal adjustable hooks seem to eliminate screw application problems in the distal, there can be considered to be a need for further research on the subject of stability. In BEIMN applications, there is no proximal or distal screw, but instead there is a blade and a grooved nail which passes within this blade. The blade expands the nail in the isthmus, proximal and distal diaphysiometaphyseal regions. Compression between the nail in the intramedullar canal and the endosteal region of the bone provides stability in the fracture line. In this design, no screw is applied in the proximal or distal (3,6,8)

To summarise the designs, in LIMN there is both proximal and distal screw locking, in TDIMN there is a locking screw only in the proximal, and in BEIMN there is no locking screw (3-8). These three nail designs show different biomechanical properties and are often used in FSF, so it is necessary to determine the advantages and disadvantages of each in respect of application and healing and to know the superiority of each over the others. The aim of this study was to determine the most stable IMN design, which would provide timely and healthy fracture healing, which can be applied easily, rapidly, and economically, with the least number of fluoroscopy images taken, for use in femoral fractures. The question we seek to answer in our hypothesis is: Can intramedullary nails with different designs used in the treatment of femoral shaft fractures show different healing patterns on fracture healing? Therefore, a retrospective comparison was made of the results of patients applied with LIMN, TDIMN, and BEIMN in our clinic in the treatment of FSF.

MATERIAL AND METHOD

Participant

The study was carried out with the permission of Hitit University Non interventional Clinical Researches Ethics Committee (Date: 28.02.2022, Decision No: 2022-04). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. In this study, patients who were operated by the same surgical team on between January 2014 and December 2020 using 3 different nails: Blade Expandable Nail System (Tianjin Walkman -China), Femoral İnterlocking Nail System (Double Engine-China) and Talon Distal Fix Femoral Nail System (USA). Fractures were classified according to the AO/OTA classification.

The patients included were those with AO 32A1, AO 32A2, and AO 32A3 type femoral shaft fractures who had been operated on with the correct technique and at least 2 years of regular follow up. The distribution by fracture subtype of AO 32A1, AO 32A2, and AO 32A3 consisted of 6, 7, 5 patients in the LIMN group, 5, 6, 6 patients in the BEIMN group, and 6, 7, 6 patients in the TDIMN group, respectively. Patients were excluded had an open fracture, pathological fracture, a fracture other than in the femur, a history of femur operation, multiple trauma of other systems, if they were smokers, had diabetes mellitus, any chronic systemic disease, or did not have complete radiological imaging or demographic data.

Experimental Approach

All of the 2-way femoral radiographs taken at 4-6 week intervals for union were evaluated chronologically. Presence of callus in at least 3 cortices was evaluated as radiological fracture healing (9, 10). Sagittal and coronal angulations were measured simultaneously by an experienced radiologist and orthopedist on leg length radiographs during patient follow-up. When fracture healing was detected, radiological measurements were assessed to decide if there is an angular deformity. For torsional evaluation, the whole femur was scanned with CT and axial scans of the femoral neck and femoral condyles were evaluated by drawing the first line along the posterior border of the femoral condyles and the second line through the femoral neck. Two vertical lines were drawn with respect to these lines respectively and the angle between them is referred as femoral torsion. The difference between the angle of the fractured leg and uninjured leg was compared to identify the angle of deformity in the fractured leg.

A record was made of operating time (mins), number of fluoroscopy images taken and time to fracture healing (weeks). The radiological images were examined of the patients with regular records at the end of follow up in respect of the mean amount of shortening in the fractured femur, the amount of angulation in the sagittal and coronal planes, and the development of rotational deformity (**Figure 1**). The visual analog scale (VAS) score at the end of one year postoperatively was taken as the criteria for functional results. The body mass index (BMI) data of the patients were evaluated. Differences between the groups were evaluated by comparing the available data.

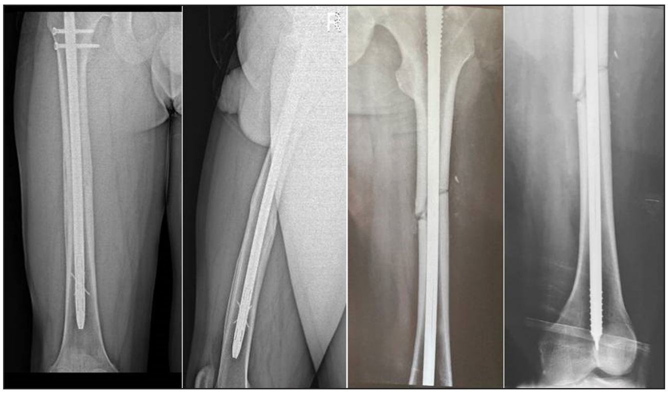

Figure 1. X-ray images of patients in the TDIMN and BEIMN groups

Procedures

Closed reduction of the fracture was obtained with a reduction device after entry to the intramedullar canal and femoral nail applications were made from the fossa priformis or the trochanteric region. A guidewire was advanced IMN within the reduction device. Sufficient reaming was obtained with reamers advanced over the guidewire in the intramedullar canal. When the fracture was reduced, final fixation was provided by the nail (2, 4).

In the first group, the LIMNs applied within the canal at 1mm smaller diameter than the diameter of the last reamer, were determined to be fixed with interlocking screws in the proximal (n:2) and distal (n:2). In the second group, the BEIMN diameter was determined to be selected as 1mm smaller than the diameter of the last reamer. The nail was adjusted to be facing the anterolateral of the femur that would provide compression of the blade groove. The length of the nails was selected to be of an appropriate length equivalent to the metaphysiodiaphyseal junction of the proximal and distal areas, which would provide expansion with the blade, and after the application, that the blade ends were in contact with the bone endosteum was determined with fluoroscopy. In the third group, the TDIMN diameter was determined to be 1mm smaller than the diameter of the last reamer. The adjustable distal hooks were attached to the bone inner cortex and by applying maximum torque, the hook opening was confirmed under fluoroscopy (**Figure 2**). To provide stronger fixation, the hooks were placed in the distal diaphyseal region without passing to the metaphyseal region. Fixation was provided with 2 locking screws in the proximal and 6 adjustable/retractable hooks of 38 mm diameter in the distal.

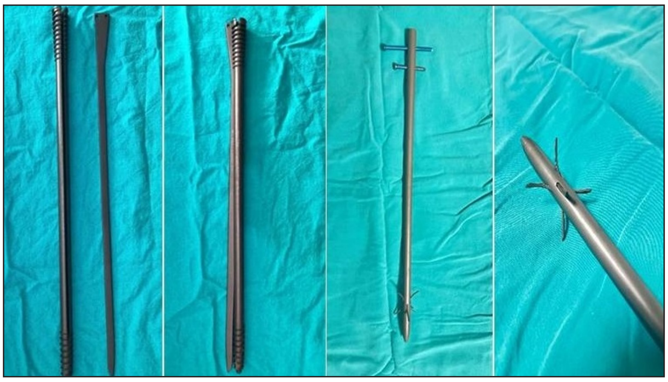

Figure 2. Images of the BEIMN and the adjustable TDIMN length and diameter measurements drawing

It was recorded that the nailing was performed in all the patients in the lateral decubitus position with the patient lying laterally and the affected side uppermost. Closed reduction was applied after traction of all the fractures. The applications were made with a lateral approach in the proximal femur. Under fluoroscopy guidance, the distal screws were applied free in LIMN applications, and in LIMN and TDIMN applications, the proximal screws were applied over the system guide.

Statistical Analysis

Statistical analysis of the data was conducted with the SPSS (SPSS Inc., Chicago, IL, USA) package program. The normal distribution of the data was tested with the Shapiro-Wilks test. Descriptive statistics for categorical variables were presented with frequency and percentage (%). Descriptive statistics of normally distributed continuous data were reported as mean±standard deviation (SD) and median (min-max) of non-normally distributed data. Comparison of continuous data between more than two independent research groups was performed with One-Way ANOVA for normally distributed data and Kruskal Wallis test for non-normally distributed data. Following the statistically significant ANOVA test, Tukey post-hoc pairwise comparison tests were used to determine between which groups the difference was. Following the statistically significant Kruskal Wallis test, Dunn-Bonferroni post-hoc pairwise comparison tests were used to determine between which groups the difference was. Comparisons of proportion between research groups were performed with either the Chi-square test or Fisher's exact test, depending on the sample size in the crosstab cells. The statistical significance level was evaluated as $p<0.05$.

RESULTS

The data of a total of 54 patients were analyzed. The groups were composed as 18 (33.3%) in the LIMN group, 17 (31.5%) in BEIMN, and 19 (35.2%) in TDIMN. The operated side was the left side in 27 (50%) patients, and the right side in 27 (50%) patients. The mean age of the patients was 35.29±10.47 years (range, 17-55 years) and the mean VAS score was 1.87±1.40 (range, 0-6). Soft tissue problems associated with implant irritation were seen in 5 (9.3%) patients.

The statistical findings of the comparisons between the groups in respect of age, gender, BMI, affected side, operating time, number of fluoroscopy images taken, time to fracture healing, VAS score, soft tissue problems associated with implant irritation, amount of shortening, coronal, sagittal, and torsional angulation, are shown in **Table 1**.

No statistically significant difference was determined between the groups in respect of age, gender, BMI, and affected side ($p=0.346$, $p=0.810$, $p=0.915$, $p=0.686$, respectively).

Table 1. Comparison of gender, side, age, VAS score, operation time, number of fluoroscopy images taken, time to fracture healing, shortening amount, coronal angulation, sagittal angulation, rotational angulation, and implant irritation variables among research groups

	LIMN (1) (n=18)	BEIMN (2) (n=17)	TDIMN (3) (n=19)	r (54)	p	Post-hoc p
Gender (F/M)	10/8	9/8	12/7	0.421	0.810[a]	-
Side (R/L)	10/8	9/8	8/11	0.755	0.686[a]	-
Implant irritation (Yes/No)	3/15	0/17	2/17	2.840	0.304[b]	-
	mean±SD (min-max)	**mean±SD (min-max)**	**mean±SD (min-max)**	**F (2,53)**		
Age	36.33±9.97 (19-54)	32.24± 8.04 (19-44)	37.05±12.59 (17-89)	5.755	0.346[c]	-
BMI	21.83±1.86 (18-25)	22.12±2.06 (18-25)	22.05±2.35 (19-27)	0.089	0.915[c]	-
Number of fluoroscopy images taken	93.11±7.17 (80-103)	51.59±7.77 (39-65)	45.21±7.79 (33-58)	213,105	**<0.001**[c]	**1-2:<0.001** **1-3:<0.001** **2-3:0.039**
Operation time (minutes)	77.89±9.44 (66-94)	46.06±4.99 (35-51)	43.05±8.03(33-65)	111.771	**<0.001**[c]	**1-2:<0.001** **1-3:<0.001** 2-3:0.768
	median (min-max)	**median (min-max)**	**median (min-max)**	**Z(2)**		
Time to fracture healing (weeks)	20 (18-52)	22 (20-30)	20 (16-28)		0.061[d]	-
Shortening amount (mm)	2 (0-3)	3 (1-4)	2 (0-16)	2.830	0.243[d]	-
Visual Analog Scale Score	1 (0-2)	1 (0-2)	3 (0-6)	10.394	**0.006**[d]	1-2:1.000 **1-3:0.008** **2-3:0.045**
Coronal angulation (degrees)	3 (2-4)	3 (2-4)	2 (0-6)	13.362	**0.001**[d]	1-2:1.000 **1-3:0.020** **2-3:0.001**
Sagittal angulation (degrees)	4 (2-5)	3 (2-5)	1 (0-6)	20.090	**<0.001**[d]	1-2:1.000 **1-3:<0.001** **2-3:0.001**
Rotational angulation (degrees)	3 (2-4)	3 (2-5)	3 (2-5)	5.295	0.071[d]	-

[a]Pearson Chi-Square test with frequencies, [b]Fisher exact test with frequencies, [c]One Way ANOVA test with mean±standard deviation, [d]Kruskal Wallis test with median (min-max), F: Female, M: Male, R: Right, L: Left, LIMN: Locked intramedullary nail, BEIMN: Blade expandable intramedullary nail, TDIN: Disafix talon intramedullary nail

The VAS scores showed a statistically significant difference between the groups (Z(2)=10.394; p=0.006). According to the post-hoc multiple comparisons, the VAS scores of the TDIMN group were statistically significantly higher than those of the LIMN and BEIMN groups (p=0.008, p=0.045). There was no significant difference between the VAS scores of the LIMN and BEIN groups.

Statistically significant differences were determined between the groups in respect of operating time (F(2,53)=111.77; p<0.001), number of fluoroscopy images taken (F(2,53)=213,105; p<0.001), angulation in the coronal plane (Z(2)=13.362; p=0.001), and sagittal angulation (Z(2) =20.090; p<0.001). According to the post-hoc multiple comparisons, the operating time of the LIMN group was statistically significantly longer than that of the TDIMN and BEIMN groups (p<0.001, p<0.001). There was no significant difference between the operating times of the TDIMN and BEIMN groups.

In respect of number of fluoroscopy images taken was significantly higher in the LIMN group than in the BEIMN and TDIMN groups (p<0.001, p<0.001). The number of fluoroscopy images taken in the BEIMN group was significantly higher than in the TDIMN group (p=0.039). The coronal angulation values of the TDIMN group were determined to be statistically significantly lower than those of the LIMN and BEIMN groups (p=0.020, p=0.001). The sagittal angulation values of the TDIMN group were determined to be statistically significantly lower than those of the LIMN and BEIMN groups (p<0.001, p=0.001).

No significant difference was determined between the groups in respect of time to fracture healing, limb shortness, rotational deformity, and soft tissue damage related to implant irritation (p=0.061, Z(2)=2.830; p=0.243, Z(2)=5.295; p=0.071, r(54)= 2.840; p=0.304, respectively). The operating times, number of fluoroscopy images taken, and time to bone union of the three groups are shown as a boxplot in **Figure 3**.

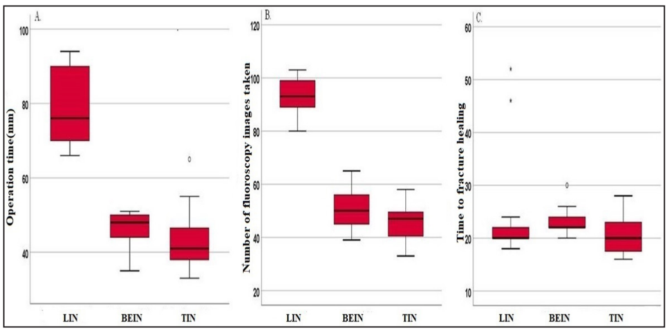

Figure 3. Boxplot of the distribution of operation time (minutes), number of fluoroscopy images taken and time to fracture healing among research groups

DISCUSSION

In this study, we compared the clinical and radiological results of our applications of three different designs of intramedullary nails, which are commonly used in femoral shaft fractures. The most important findings of our study are shorter operation times and less need for fluoroscopy in TDIMN and BEIMNs. TDIMN sagittal and coronal angulation was less common, but this had no effect on clinical improvement. The time to fracture healing, rotational angulation and shortening development were similar in all three nails. As a result, we determined that three different nails used in femur fractures did not have a significant clinical and radiological advantage over each other in ensuring fracture stability.

The primary aim of fracture treatment is to provide the optimum mechanical and biological environment for every stage of fracture healing (11, 12). It can be considered that the results of clinical studies of IMNs with different biomechanical properties will be of guidance to orthopaedic surgeons, as different nail designs may lead to different complications or may affect the fracture healing. Mechanical stimulation in the fracture region is necessary for bone repair. The stability of the fixation system and the movement formed as a result of functional loading are important for bone union (13,14).

The best means of stimulating callus development allows movements such as compression that support healing and prevents movements that could impair healing such as curving, rotational angulation, and tranlational shift (13,15,16). Axial and rotational stability in other nails is not as good as in IMNs. Delayed fracture healing and non-union associated with this property have been reported in many publications (3,7,17,18). Non-union rates have been reported as 10.5% in middle-aged patients with a closed femoral shaft fracture treated with closed reduction and LIMN (15). Shorter time to fracture healing have been reported in expandable nails compared to locking nails, but there are higher rates of non-union (22.6%) and revision surgery (16.1%) (3). Fracture stability is an important determinant of rapid union (12) and this is related to nail design. In studies that have compared the adjustable hook nail with conventional locking nails used in femoral and tibial fractures, these have been reported to delay bone union, but as expected the operating and fluoroscopy usage times were shorter (7,18).

In a study by Başaran et al. (6), the time to fracture healing in tibia shaft fractures was found to be longer with BEIN nail design compared to LIMN, but non-union did not develop in any patient. Full union was obtained in all the patients in the BEIMN group in the current study. In contrast to expectations, because of delayed union in 2 patients in the LIMN group, which is thought to be of more stable design, dynamisation was applied in the 16th week, and then full bone union was seen in the follow up. In the TDIMN group, there was a need for revision surgery because of non-union in 4 patients. In this TDIMN group, nonunion and revision surgery were performed with a rate of 21.05%. Delayed union was 11.1% in the LIMN group. Similar to the literature, the reflection of this in all cases consisting of 54 patients was found to be 3.7% for delyed union and 7.4% for nonunion. When the times to bone union were examined, the times were similar in the BEIMN, TDIMN, and LIMN groups. It was thought that in the TDIMN group, there could have been more rapid union because of the dynamic structure of the distal hook allowing axial loading and micromovement. In some patients of the current study TDIMN group, translational shift in the fracture line was determined and breaks associated with overloading in the hooks providing distal retention. This was evaluated as a sign that the hook design could not sufficiently withstand axial and translational loading. This condition originating from the structure of the hook providing distal retention could be responsible for the development of non-union related to stability failure in the TDIMN group. We think that the higher VAS scores in the TDIMN group are an indication that fracture healing is adversely affected. The delayed union seen in the LIMN group can be attributed to the reduced micro-movement in the fracture line associated with strong fixation, because problem-free union was obtained with nail dynamisation. It is striking that there were no union problems in the BEIMN group and the biomechanical compatibility between the bone and fixation material was seen to be more balanced.

It is known that just as the radiation-related risk of cancer is increased as a result of exposure to high doses, it may also develop with an accumulation over years of low doses such as in medical imaging (19). Radiation exposure associated with C-arm fluoroscopy used in operations increases the risk of lung and colon cancer in both males and females (20). Ionised radiation increases the risk of malignancy in the orthopaedic surgical team (21), and it has been reported that the cancer risk of orthopaedic surgeons is 5-fold higher than that of the general population (22). This risk is though to be related to the total ionised radiation from fluoroscopy used in all operations (20). It should therefore be a basic aim to minimise the lifetime cumulative radiation exposure of surgeons and the associated risks that can develop (23). Appropriate fluoroscopy safety precautions must be followed such as wearing suitable protective equipment, reducing the duration of fluoroscopy, and keeping the greatest distance from the radiation source (23, 24). Following the standard safety precautions will enable the surgical team to be exposed to the minimum level of radiation and be within permissible limits (24, 25). To increase awareness of the dangers of radiation, it is important that surgeons, nurses, and technicians have information related to this (26). While this is the situation, there is a need for the development of surgical methods that will minimise the use and effects of radiation to be developed and become more widespread with accessible technologies. The minimising of radiation effects can be considered to be the second most important point after stability in the design of IMNs. By forming an electromagnetic field, nail designs with distal locking significantly reduce the duration of exposure to ionised radiation (27), suggesting that this could be a good alternative in the treatment of long bone diaphyseal fractures (28).

The operating time and fluoroscopy time have been found to be shorter in simple femoral shaft fractures treated with expandable nails compared to locking nails (3). In the treatment of long bone fractures applied with TDIMN, shorter operating and fluoroscopy times have been obtained (7, 18). Similarly, in both tibia and femur fractures applied with BEIMN, a shorter operating time and less use of fluoroscopy have been reported (8, 29). The number of scopy shots can be an indirect indicator of the radiation dose received. Because each scope chute emits radiation to the environment and we think that this is correlated with radiation exposure (30, 31).

When the numbers of fluoroscopy shots were examined in the current study, there was seen to be an increase in the order of TDIMN, BEIMN, and LIMN. The mean operating time was similar in the BEIMN and TDIMN groups, and this was shorter than in the LIMN group. The ease of application of the TDIMN and BEIMN nail designs reduced the operating time and the need for fluoroscopy. Distal locking screw fixation in the LIMN design was determined to have prolonged the operating time because of the freehand technique of application without an external guide and increased the duration of fluoroscopy to be able to confirm the appropriate distal screw placement.

Translational and rotational forces in the fracture line prevent fracture healing (1, 32, 33). Femoral malrotation has been reported in 20-30% of cases after IMN. While rotational angulation differences of <10° are accepted as normal variations, a difference of 10-14° shows a potential deformity, and ≥15° is accepted as a clinically and functionally significant real rotational deformity (34-36). A rasping procedure causing reduced rotational resistance of the bone prepares the ground for the development of rotational deformity (37), but that alone may not be effective as appropriate rasping and the placement of a nail of appropriate diameter will increase retention to the medullar canal.

Despite rasping applied to all three nail groups in the current study, that the rates of rotational deformity were similar in the groups supports this view. Rotational malalignment of the femur is stated as a difference in femoral anteversion between the healthy and injured legs. This can be determined clinically or with radiological measurements (38-40). Measurements were taken in this way in the current study and the results obtained were consistent with literature, with the highest rotational angulation of 5°. In previous biomechanical studies conducted with some expandable nail designs (41, 42), these were found to be insufficient in respect of rotational loading compared to locking nails. In contrast, there are also studies showing that resistance to rotational loading is similar to that of classic nails and resistance to compressive loading is weak (43). Bekmezci et al. (8) recommended that therefore, non-locking nails should not be used in multi-fragmented fractures and metaphyseal region fractures.

The relatively high rotational angulation in the TDIMN group of the current study and the translational shift determined on the radiographs may explain the rate of 21% non-union determined in this group.

Another problem in IMN is axial instability and this may result in shortness. Most authors advocate that static locking is appropriate for the prevention of rotation and shortening (44). By limiting micro-movement, static locking provides length of the fracture line and rotation is prevented (43). Static locking controls loading, shortening and rotation, but as stress is reduced in the fracture line, bone union is slowed down and osteolysis develops (44). In such a case, first dynamisation may be necessary if the nail design is suitable. There are many studies in literature about the timing of dynamisation. In different studies, the time of dynamisation applied to accelerate fracture union has been shown to vary between 9 and 24 weeks (45-47). With dynamisation, the loading on the bone over the implant stimulates callus formation and increases the hardness of existing callus (48-50). It was observed in the current study TDIMN group that the structure of the distal hook could not sufficiently withstand axial loading and broke, resulting in the development of shortness in the fracture line. As there was high stability against axial loading in the LIMN group, there was less development of shortness. The group where the least shortness developed assiciated with axial loading was the BEIMN group. However, the difference between the three groups was not statistically significant.

Angulation at the rate of 9% in sagittal and coronal planes has been reported in IMN applications in femoral fractures. This rate varies between 10% and 30% in fractures close to the proximal and distal regions in particular, and the rate for femoral shaft fractures is 2% (49).

It is thought that the angular deformities that develop could be due to malreduction, an unstable fracture pattern, or insufficient stability formed with IMN. Although these deformities are more frequent especially in young patients, it is possible to prevent them with correct bone fracture reduction and correct implant placement (52, 53)

No studies could be found in literature that showed a relationship between different nail designs and coronal and sagittal plane angulations following IMNs applied in femoral shaft fractures. Another subject of interest is what effects there could be of sagittal and coronal angulation on fracture healing. In the current study, while the coronal and sagittal angulations were similar in the BEIMN and LIMN groups, the values in the TDIMN group were lower than those of the other two groups. The low coronal and sagittal angulation values in the TDIMN group were thought to be due to the nail design. As the adjustable distal hooks provide more stable fixation, obtaining fixation from the cortical diaphyseal region with more compact bone provides resistance to bowing forces which can develop. In addition, reducing the distance between the fracture line and the distal fixation point of the fracture increases the fracture stability. It is recommended that to increase fracture stability there is a distance of at least 2cm between the fracture region and the screws distal of the nail (4, 31). These angular deformities that developed in all three groups did not have any effect on bone union.

Limitations

The limitations of our study, it can be said that it could not be studied in groups with larger sample sizes, since it was a retrospective study. Another limitation is the inability to perform biomechanical studies. However, time to fracture healing and the development of angular problems in IMNs indirectly give an idea about biomechanical stability. In our study, we assumed that the patients' initial alignment after surgery was anatomically normal. Comparing the clinical and radiological results of three different nail designs that have not been examined in the literature in FSF can be said to be the superior aspect of our study. Due to the small sample size, no comparison of fracture subtypes was made for all three intramedullary nails according to the AO classification. This is one of the limitations of our study.

CONCLUSION

In this study, we compared the results of three different IMN applications in FSFs. Since there is no need for screw locking in TDIMN and BEIMN designs, the need for fluoroscopy is less. Accordingly, the surgical time is shorter in these two groups. Although the sagittal and coronal angulation of the TDIMN is less, time to fracture healing, rotational angulation, and shortening development are similar in all three nails. This showed that all three nails did not have a significant advantage over each other in providing fracture stability. Revision surgery was required as a result of nonunion at a rate of 21.05% in the TDIMN group, and dynamization due to delayed union of 11.1% in the LIMN group. Nonunion or delayed union was not seen in BEIMN group.

ETHICAL DECLARATIONS

Ethics Committee Approval: The study was carried out with the permission of Hitit University Non-interventional Clinical Researches Ethics Committee (Date: 28.02.2022, Decision No: 2022-04).

Informed Consent: Because the study was designed retrospectively, no written informed consent form was obtained from patients.

Referee Evaluation Process: Externally peer-reviewed.

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REFERENCES

1. Rosa N, Marta M, Vaz M, et al. Recent developments on intramedullary nailing: a biomechanical perspective. Ann N Y Acad Sci 2017; 1408: 20-31.
2. Wood GW. Intramedullary nailing of femoral and tibial shaft fractures. J Orthop Sci 2006; 11: 657-69.
3. Sipahioglu S, Zehir S, Sarikaya B, Isikan UE. Comparision of the expandable nail with locked nail in the treatment of closed diaphyseal fractures of femur. Niger J Clin Pract 2017; 20: 792-8.
4. Pourmokhtari, M. Principles of fixation with ınterlocking nailing. Iranian Journal of Orthopaedic Surgery Summer 2018; 16: 265-72.
5. Bong MR, Kummer FJ, Koval KJ, Egol KA. Intramedullary nailing of the lower extremity: biomechanics and biology. J Am Acad Orthop Surg 2007; 15: 97-106.
6. Basaran T, Calbiyik M, Basaran PÖ, Hassa, E, Ipek D. Blade expandable intramedullary nails for fixation of tibial shaft fractures. Acta Orthop Belg 2019; 85: 472-6.
7. Çamurcu Y, Sofu H, Issın A, Koçkara N, Genç E, Çetinkaya M. Is talon tibial intramedullary nailing clinically superior compared to conventional locked nailing? Jt Dis Relat Surg 2017; 28: 152-7.
8. Bekmezci T, Baca E, Kaynak H, Kocabaş R, Tonbul M, Yalaman O. Early results of treatment with expandable intramedullary nails in femur shaft fractures. Acta Orthop Traumatol Turc 2006;40: 1-5.
9. Whelan DB, Bhandari M, Stephen D, et al. Development of the radiographic unionscore for tibial fractures for the assessmentof tibial fracture healing after intramedullary fixation. J Trauma 2010; 68: 629-32.

10. Litrenta J, Tornetta P, Mehta S, et al. Determination of radiographic healing: an assessment of consistency using RUST and modified RUST in metadiaphyseal fractures. J Orthop Trauma 2015; 29: 516-20.
11. Samiezadeh S, Avval PT, Fawaz Z, Bougherara H. Biomechanical assessment of composite versus metallic intramedullary nailing system in femoral shaft fractures: a finite element study. Clin Biomech 2014; 29: 803-10.
12. Clatworthy MG, Clark DI, Gray DH, Hardy AE. Reamed versus unreamed femoral nails. a randomised prospective trial. J Bone Joint Surg Br 1998; 80: 485-9.
13. Rosa N, Marta M, Vaz M, et al. Intramedullary nailing biomechanics: evolution and challenges. Proc Inst Mech Eng H 2019; 233: 295-308.
14. Letechipia J, Alessi A, Rodrı´guez G, Asbun J. Design and preliminary testing of an active intramedullary nail. Clin Transl Invest 2014; 66: 70-8.
15. Ligier JN. Biomechanics of FIN. In Flexible Intramedullary Nailing in Children: The Nancy University Manual. P. Lascombes, Ed. Berlin: Springer-Verlag; 2009; 19-24.
16. Rosa N, Simoes R, Magalh˜aes FD, Marques AT. From mechanical stimulus to bone formation: a review. Med Eng Phys 2015; 37: 719-28.
17. Wu KJ, Li SH, Yeh KT, et al. The risk factors of nonunion after intramedullary nailing fixation of femur shaft fracture in middle age patients. Medicine 2019; 98: e16559.
18. Yapici F, Gur V, Onac O, et al. For intramedullary nailing of femoral shaft fractures, talon fixation is helpful to cope with the troublesome distal locking, but conventional distal locking with screws offers a more stable construct: Talon femoral nail versus conventional femoral nail. Ulus Travma Acil Cerrahi Derg 2022; 28: 513-22.
19. Rühm W, Laurier D, Wakeford R. Cancer risk following low doses of ionising radiation–Current epidemiological evidence and implications for radiological protection. Muta Res Genet Toxicol Environ Mutagen 2022; 873: 503436.
20. Robatjazi M, Dareyni A, Baghani HR, Hosseinzade M, Akbarzadeh R, Mehrpoyan M. Investigation of radiation dose around C-arm fluoroscopy and relevant cancer risk to operating room staff. Radiat Environ Biophys 2022; 61:301-7.
21. Chou LB, Cox CA, Tung JJ, Harris AH, Brooks-Terrell D, Sieh W. Prevalence of cancer in female orthopaedic surgeons in the United States. J Bone Joint Surg Am 2010; 92:240-4.
22. Barry TP. Radiation exposure to an orthopedic surgeon. Clin Orthop Relat Res 1984; 182:160-4.
23. Daryoush JR, Lancaster AJ, Frandsen JJ, Gililland JM. Occupational Hazards to the Joint Replacement Surgeon: Radiation Exposure. J Arthroplasty 2022; 37:1464-9.
24. Tandale SR, Gavali Y, Naik S, et al. Radiation exposure among anesthetist, orthopedic surgeon, and scrub nurse in orthopedic operation theater complex. Med J DY Patil Vidyapeeth 2022; 15: 857-61.
25. González-Cisneros AC, Briceño-González AM. Exposure of radioactive emanations, during surgery in orthopedics and traumatology. Orthotips AMOT 2022; 18: 25-8.
26. Hadelsberg UP, Harel R. Hazards of ionizing radiation and its impact on spine surgery. World Neurosurg 2016; 92: 353-9.
27. Moreschini O, Petrucci V, Cannata, R. Insertion of distal locking screws of tibial intramedullary nails: a comparison between the free-hand technique and the SURESHOT™ Distal Targeting System. Injury 2014; 45: 405-7.
28. Zhu Y, Chang H, Yu Y, Chen W, Liu S, Zhang Y. Meta-analysis suggests that the electromagnetic technique is better than the free-hand method for the distal locking during intramedullary nailing procedures. Int Orthop 2017; 41:1041-8.
29. Bekmezci T, Baca E, Kocabas R, Kaynak H, Tonbul, M. Early results of treatment with expandable intramedullary nails in tibia shaft fractures. Acta Orthop Traumatol Turc 2005; 39:421-4.
30. Magee LC, Karkenny AJ, Nguyen JC, et al. Does surgical experience decrease radiation exposure in the operating room? J Pediatr Orthop 2021; 41: 389-94.
31. Xu W, Christopher AN, Hu S, Steinberg DR, Bozentka DJ, Lin IC. Investigating patient-level radiation exposure in hand and wrist fracture surgery. Ann Plast Surg 2022; 88: 309-13.
32. Steiner M, Claes L, Ignatius A, Simon U, Wehner T. Disadvantages of interfragmentary shear on fracture healing-mechanical insights through numerical simulation. J Orthop Res 2014; 32: 865-72.
33. Penzkofer R, Maier M, Nolte A, et al. Influence of intramedullary nail diameter and locking mode on the stability of tibial shaft fracture fixation. Arch Orthop Trauma Surg 2009; 129: 525-31.
34. Jaarsma RL, Van Kampen A. Rotational malalignment after fractures of the femur. J Bone Joint Surg Br 2004; 86: 1100-4.
35. Brouwer KJ, Molenaar JC, van Linge B. Rotational deformities after femoral shaft fractures in childhood: a retrospective study 27-32 years after the accident. Acta Orthop Scand 1981; 52: 81-9.
36. Bråten M, Terjesen T, Rossvoll I. Femoral anteversion in normal adults: ultrasound measurements in 50 men and 50 women. Acta Orthop Scand 1992; 63: 29-32.
37. Schmitz N, Gehweiler D, Wähnert D, et al. Influence of the Reamer-Irrigator-Aspirator diameter on femoral bone strength and amount of harvested bone graft–a biomechanical cadaveric study. Injury 2020; 51: 2846-50.
38. Sennerich T, Sutter P, Ritter G, Zapf S. Computerized tomography follow-up of the antetorsion angle after femoral shaft fractures in the adult. Der Unfallchirurg 1992; 95: 301-5.
39. Strecker W, Franzreb M, Pfeiffer T, Pokar S, Wikström M, Kinzl L. Computerized tomography measurement of torsion angle of the lower extremities. Der Unfallchirurg 1994; 97: 609-13.
40. Wissing H, Spira, G. Determination of rotational defects of the femur by computer tomographic determination of the antetorsion angle of the femoral neck. Unfallchirurgie 1986; 12: 1-11.
41. Ivanov D, Barabash A, Barabash Y. Expandable intramedullary nail: review of biomechanical studies. Russian Open Medical Journal 2016; 5: e0206.
42. Özkaya M, Demir T. Numerical evaluation of the mechanical properties of a novel expandable intramedullary nailing: A new alternative to standard interlocking nailing. Injury 2021; 52: 3239-52.
43. Plenert T, Garlichs G, Nolte I, et al. Biomechanical comparison of a new expandable intramedullary nail and conventional intramedullary nails for femoral osteosynthesis in dogs. PLoS ONE 2020; 15: e0231823.
44. Akar B, Balioğlu MB. Clinical results of closed intramedullary nailing in femoral diaphysis fractures. Ann Clin Anal Med 2022: 1-5.
45. Jiang M, Li C, Yi C, Tang S. Early intramedullary nailing of femoral shaft fracture on outcomes in patients with severe chest injury. A meta analysis. Sci Rep 2016; 6: 30566
46. Brumback RJ, Virkus WW. Intramedullary nailing of the femur: reamed versus nonreamed. J Am Acad Orthop Surg 2000; 8: 83-90.
47. Vicenti G, Bizzoca D, Carrozzo M, et al. The ideal timing for nail dynamization in femoral shaft delayed union and non-union. Int Orthop 2019; 43: 217-22.
48. Angadi DS, Stepherd DET, Vadivelu R. Rigid intramedullary nail fixation of femoral fracturesin adolescents: what evidence in is available? J Orthopaed Traumatol 2014; 15: 147-53.
49. Gabarre S, Alberada J, Gracia L, Puertolas S, Ibarz E, Herrera A. Influenza of gap size, screw configuration, and nail materials in the stability of anterograde reamed intramedullary nail in femoral transverse fractures. Injury 2017; 48: 40-6.

50. Hamahashi K, Uchiyama Y, Kobayashi Y, Ebihara G, Ukai T, Watanabe M. Clinical outcomes of intramedullary nailing of femoral shaft fractures with third fragments: a retrospective analysis of risk factors for delayed union. Trauma Surg Acute Care Open 2019; 4: e-000203.
51. Ricci WM, Bellabarba C, Lewis R, et al. Angular malalignment after intramedullary nailing of femoral shaft fractures. J Orthop Trauma 2001; 15: 90-5
52. Guerado E, Bertrand ML. Malalignment in intramedullary nailing. How to achieve and to maintain correct reduction? Injury 2017; 48: 30-4.
53. Rothberg DL, Holt DC, Horwitz DS, Kubiak EN. Tibial nailing with the knee semi-extended: review of techni ques and indications: AAOS exhibit selection. JBJS 2013; 95: e116.