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Original Article

The effectiveness of intramedullary nailing on the fixation of tibia diaphyseal fractures: Biomechanical point of view

Biyomekanik bakış açısıyla, intramedüller çivilemenin tibia diyafiz kırıklarının fiksasyonu üzerindeki etkinliğinin değerlendirilmesi

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ABSTRACT

Aim: The aim of the study was to exhibit the success rate of nailing on tibia shaft fractures. Biomechanical advantage of the nails was also evaluated and discussed in this study.

Material and Methods: Reamed and static interlocking intramedullary nailing was performed with closed or mini-open reduction in 35 patients (25 males, 10 females; mean age 37.14±13.13 years). 27 fractures were closed and 8 fractures were open fractures. The evaluation in the study was performed according to Johner and Wrush criteria.

Results: The mean follow-up period was 12.5 months (range 5 to 20 months). Union occurred in all patients. Mean union period was 17.02±7.96 weeks. In four cases, a valgus angulation of 2-5 degrees was detected that whom had distal third tibial fractures. In one case, an external rotation more than 10^0 was detected and in another case, grave claudication was shown. In two cases, extremity shortening of 6-10 mm was seen. According to ankle and subtalar mobility; 27 (77.1%) of the patients were recorded as excellent, 7 (20%) good, 1 (2.9%) moderate results. According to Johner and Wrush criteria; 54.3% of the patients were recorded as excellent, 34.3% good, 8.6% moderate and 2.8% bad results.

Conclusion: This study suggests that reamed interlocking intramedullary nailing is an effective method in tibia diaphyseal fractures because of successful functional results, high union and low complication rates. On the biomechanical side, anti-rotation of the fixation area and axial load sharing capacity of nailing has critical demand on fracture healing.

Keywords: Tibia diaphyseal fractures, biomechanics, intramedullary nailing, interlocking screws

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ÖZ

Amaç: Çalışmanın amacı, tibia diyafiz kırıklarında intramedüller çivilemenin başarı oranını değerlendirmektir. Bu çalışmada ayrıca çivilerin biyomekanik avantajları da değerlendirildi ve tartışıldı.

Gereç ve Yöntemler: Kilitli oymalı intramedüller çivileme, 35 hastada (25 erkek, 10 kadın; yaş ortalaması 37,14 ± 13,13) kapalı veya mini açık redüksiyon ile yapıldı. Tibia kırıklarının 27'si kapalı, 8'i açık kırıktı. Tüm hastalara oymalı ve statik kilitlemeli intramedüller çivileme yapıldı. Çalışmada hastalar Johner ve Wrush kriterlerine göre değerlendirildi.

Bulgular: Ortalama takip süresi 12,5 ay (5-20 ay) idi. Hastaların hepsinde kaynama gerçekleşti. Ortalama kaynama süresi 17,02 ± 7,96 hafta idi. Tibia 1/3 distal kırığı olan dört olguda 2-5 derecelik valgus açılanması saptandı. Bir olguda, dış rotasyon 10^{0}'dan fazla tespit edildi ve başka bir olguda da yürümede belirgin aksama tespit edildi. İki olguda, 6-10 mm'lik ekstremite kısalığı tespit edildi. Ayak bileği ve subtalar eklem hareketlerine göre; hastaların 27'si (%77,1) mükemmel, 7'si (%20) iyi, 1'i (%2,9) orta dereceli olarak değerlendirildi. Johner ve Wrush kriterlerine göre; hastaların %54,3'ü mükemmel, %34,3'ü iyi, %8,6'sı orta ve %2,8'i kötü olarak saptandı.

Sonuçlar: Kilitli oymalı intramedüller çivilemenin, tibia diyafiz kırıklarında başarılı fonksiyonel sonuçları, yüksek kaynama oranları ve düşük komplikasyon oranları nedeniyle etkin bir tedavi olduğunu düşünmekteyiz. Biyomekanik açıdan bakacak olursak, fiksasyon alanının anti-rotasyonunun ve çivilemenin aksiyel yük paylaşım kapasitesinin, kırık iyileşmesi üzerinde kritik bir öneme sahip olduğu görülmektedir.

Anahtar kelimeler: Tibia diyafiz kırıkları, biyomekanik, intramedüller çivileme, kilitleme vidaları

Introduction

Tibia fractures are among the most common fractures in traumatology [1]. They constitute approximately 10% of long bone fractures [2]. Due to its anatomic position, they are the most common seen long bone fractures [3]. Conservative treatment with plaster, external fixation, osteosynthesis with plate screw and intramedullary nailing are frequently used in the treatment of tibia diaphysis fractures [4,5]. Superiority of one of the treatment options is not definitely defined. Each technique has its advantages depending on various factors. Choosing a treatment option that is not appropriate for the peculiarities of the patient and the fracture may lead to very heavy iatrogenic complications and prolong the treatment duration [6].

Interlocking intramedullary nailing is the most efficient methodology in tibia shaft fractures in order to protect patients from joint stiffness and mobilize and activate them as soon as possible [1]. When inserted in closed intervention, reamed interlocking intramedullary nailing has been more frequently preferred over other surgery methods due to the bone union ensured by the fractured hematoma, the low complication rate and the reliable stabilization it does provide [7].

A general knowledge on nail biomechanics and biology is required for providing a better understanding of the intramedullary nail. Implants share torsional, bending and compressive loads with the osseous structure that surrounds it and are inserted to the bone not close to the fracture site.

Material and Methods

Our study comprised 35 patients who were treated by reamed interlocking intramedullary nailing methodology after the year 2005 and were regularly followed. Reamed interlocking intramedullary nailing was performed with closed or mini-open reduction in 35 patients (25 males, 10 females; mean age 37.14±13.13 years) (Table 1). Static locking was applied to all fractures. The fractures were categorized according to the AO classification [8]. According to this classification our patients were grouped as Group A:22 patients (77.1%), Group B:11 patients (22.9%) and Group C: 2 patients (5.5%). 8 open and 27 closed fractures were identified. When divided according to the Gustilo-Anderson classification [9] the open fractures were 5 patients for Type 1 and 3 patients for Type 2 (Table 2).

Average time of patients before being admitted to surgery was 4.68±1.89 days. Postoperative mobilization time after surgery was 2days and duration of hospital stay was 8.54±4.40 days (Table 1).

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Table 1: Patients and operative demographics	
Gender, n (%)	
-Male	25 (%71,4)
-Female	10 (%28,6)
Age* (year)	37,14±13,13
Duration of operation* (day)	4,68±1,89
Post-operative mobilization** (day)	2 (1-30)
Hospitalization time* (day)	8,54±4,40
Fracture healing time* (week)	17,02±7,96
*Mean±Standard Deviation **Median (minimum-maximum)	

Table 2: Classification and comparison of fractures	
AO Classification n (%)	35 (%100)
-Group A	22 (%77,1)
- Group B	11 (%22,9)
- Group C	2 (%5,5)
Fracture Type n (%)	35 (%100)
-Open	8 (22,8)
-Closed	27 (%77,2)
Gustilo-Anderson Classification n (%)	8 (%100)
-Type 1	5 (%62,5)
-Type 2	3 (%37,5)

Patients were operated in supine position on the operation table with the help of fluoroscopy. Tourniquet was not applied to the patients who were being inserted intramedullary nailing. According to their general condition, patients received general, epidural or spinal anesthesia.

In the post-surgery period, patients were followed up on a monthly basis. Graphics of antero-posterior as well as sides of the patients were taken. Within the first month, patients were not allowed to load on their broken legs. At the end of the first month, progressive load was given according to the bone union viewed on the graphics. Dynamization was applied on patients who were evaluated to be weak in terms of bone union on the graphics. Fracture healing was present when combining callus tissue had been observed on at least 3 cortexes on double-sided graphics and patients were able to fully load without pain. Results of our study were evaluated according to Johner and Wruhs Criteria [10].

Informed consent was obtained from all patients and the study was approved by the local Ethics Committee.

Results

The mean follow-up period was 12.5 months (range 5 to 20 months) (Figure 1). Union occurred in all patients, except one. Mean union period was 17.02±7.96 weeks. Dynamization was applied to 10 patients (28.5%) due to delay of bone union. In four cases, a valgus angulation of 2-5 degrees was detected who had distal third tibial fractures. In one case, an external rotation of more than 10^0 was detected and in another case, grave claudication was shown. In two cases, extremity shortening of 6-10 mm was seen. According to ankle and subtalar mobility; 27 (77.1%) of the patients were recorded as excellent, 7 (20%) good, 1 (2.9%) moderate results. According to Johner and Wrush criteria; 19 patients (54.3%) were recorded as excellent, 12 patients (34.3%) good, 3 patients (8.6%) moderate and 1patient (2.8%) as bad.

Figure 1. A: Before surgery, **B:** After surgey first month, **C:** After surgey 4th month, **D:** After surgey 6th month

In the postoperative term, superficial infection was observed in two patients on the incision line of the knee region. The infection was treated with appropriate antibiotics. The anterior knee pain complaint of one patient was mitigated by extracting the intramedullary nailing after bone union. Vascular damage, neurologic deficit, compartment syndrome, osteomyelitis, deep venous thrombosis, breaking of screws or lock screws was not observed.

Discussion

Conservative treatment with plaster, external fixation, osteosynthesis with plate screw and intramedullary nailing are frequently used in the treatment of tibia diaphysis fractures [4,5]. Superiority of one of the treatment options is not definitely defined. Each technique has its advantages depending on various factors. Carefully choosing the treatment option, restoration of the structural stability and keeping mechanical axes of the tibia body within acceptable limits are the criteria for a successful treatment. Acceptable reduction with morbidity at the minimum may be achieved with a different treatment option for each patient [11].

Conservative treatment methodologies applied in the treatment of tibia shaft fractures are easily applicable and cost efficient. Complications deriving from surgery are not observed in these methodologies. However, it is also mentioned in literature that in patients who underwent conservative treatment, complications like joint stiffness due to long immobilization, difficult scar caring due to open fractures, angulation of extremities, rotation, shortening and delay in bone union are frequently seen [12].

Many surgical treatment options have been developed in order to eliminate the disadvantages of conservative methods. Plate-screw, which is one of these options, has been used for long years. Complications like leading to high infections specifically in open fractures even if anatomic and rigid internal identification has been obtained, not achieving high bone union due to soft tissue and periost injury, not enabling early mobilizations and breaking of plates have led to the development of alternative surgical methodologies [13].

Subcutaneous and locking plates have been promising in alleviating these complications and have been specifically found significant for fractures close to the joint surface [14]. External fixators that are one of the methods used for tibia shaft fracture have been successfully used for Type 3 open fractures as they allow for minimal soft tissue damage, preserve blood flow at the fracture line, accelerates bone union by allowing dynamization, enabling early mobilization by ensuring rigid fixation. Adaptation problem between patients and devices, pin site infections, high rates of malunion and reoperation as well as high neurovascular injury risk restrict the usage of external fixators [15].

Reamed interlocking intramedullary nailing has been preferred more frequently due to high union rates because of preserving hematoma when applied closed, enabling early loading, ensuring reliable stabilization and presenting low rates of complication [7].

Material properties, cross-sectional shape, anterior bow and the diameter are intrinsic specificities that affect the nail biomechanics. Fixation of biomechanics is also affected by extrinsic variables like medullary canal reaming, fracture stability and applying locking bolts. Torsion, compression and tension are the load types on an IM nail. The presence of a longitudinal slot of nails has a greater effect on torsional stability [16]. In order to enable the inserting of larger nails on closed diaphyseal long-bone fractures, canal diameters with IM reamers were expanded. Factors like nail size, number of locking screws or bolts, distance of the locking screw or bolt from the fracture area are among the factors effecting stability. Torsional friction in the medullary cavity is increased by fluting of the nail.

Reamed nails can be statically or dynamically inserted according to the type of fracture. Screws used in reamed nailing increase stability by resisting to axial and rotational forces [17]. Using fully grooved single screw is generally sufficient for distal locking. However, using 2 screws is advised for distal fractures. The valgus and varus are thereby specifically protected from rotation. We preferred static nailing for all patients on whom intramedullary nailing was inserted. Nailing was generally done with 1 screw at the proximal and 2 screws at the distal. Nailing with one screw at the distal and proximal was done at some cases which we evaluated as sufficient.

Translation and rotation at the fracture site are restricted by interlocking screws inserted proximal and distal to the fracture line. Toggling of the bone is enabled by minor movements occurring between the nail and screw. Nail bending rigidity and nail fit are affected by the diameter of the nail. An appropriate nail is important to maintain fracture reduction and assist the minimization of movement between nail and bone.

Reamed intramedullary nailing was used for all patients. Average healing time was 17.02±7.96 weeks. No difference with respect to healing time was found when compared with other studies in literature [11]. Bone healing time of 3 patients was 20 weeks and more. These patients had additional orthopedic pathologies in addition to tibia fractures. Dynamization was needed for all of these patients. It was remarkable that these patients stayed the longest in hospital of the entire group in the study.

More stress is put on the locking stress when the fracture is closer to the distal locking screws and the nail receives less cortical contact [18]. To reverse the condition, the fracture gains rotational stability when the distal locking screw is far from the fracture area. This is in relation to the nail friction in the medullary cavity [19]. Stability is insignificantly affected by oblique or transverse orientation of distal screws in distal-third tibia fractures [20]. Fracture biomechanics is affected by the location of the distal locking screws. Blocking screws are helpful in the alignment of femur and tibia non diaphyseal fractures. Metaphyseal fragments demand inserting multiple locking screws. The placement of blocking screws can facilitate the alignment of non-diaphyseal fractures of the femur and tibia. The primary stability of fixed fracture can be improved by blocking screws [21].

Dynamization procedure should ensure the bridging between the fracture ends by organizing cyclical micro movements at the fracture line and ensuring continuous compression at the callus tissue [22]. Richardson et al. [23] came to the conclusion that dynamization is most effective in the postoperative week 6. Alho et al. [24] found that dynamization accelerated bone healing. But too early dynamization is leading to shortening and misalignment of the fracture. Therefore, they advised that dynamization should not be performed before postoperative month 4 [24]. We thought that dynamization is required when healing is delayed. In our study, dynamization was not performed as a routine. However, dynamization was applied to 10 (28.5%) patients by whom we evaluated that healing was delayed. Duration for dynamization was minimum 3 months and maximum 10 months. Average dynamization time was identified as 4.8 months.

Frontal knee pain is one of the problems faced after intramedullary nailing. Frontal knee pain has been researched in several studies. Cases of patellar tendon split approach have been seen more frequently than in the parapatellar approach. Only one patient in our study experienced frontal knee pain. It was though that this pain was caused by the irritation of the patellar tendon through the intramedullary nail. Intramedullary nail was removed after bone healing and complaints decreased significantly.

Apart from the discussion on whether intramedullary nailing should be done, it is more important to decide whether the nailing should be reamed or unreamed. The aim of reaming is increasing the adaptation between the screw and the medullar canal as well as increasing stability by inserting larger screws. Contact area is increased by 38% by a 1mm reamer in cases of same size of reamer and nail [25]. More rigidity in bending and torsion is ensured by inserting nails with a larger diameter. Reamed nails ensure more stable biomechanical fixation stability compared to unreamed nails [26].

Moreover, it was found that the debrises emerging from reaming have osteogenic character [27]. It has to be known that the size of the screw used in intramedullary nailing of tibia shaft fractures should be large enough to resist loading and opposite forces resulting from joint movements. As the size of the screw grows, so does the structural stability and flexion rigidity [25]. Bone healing may change according to the coherence between the geometric specificities of the screw and the bone and the screw-bone contact surface affecting the stabilization of the fracture [28]. This shows that large screws as much as possible should be used to increase stability.

Blachut et. al [29] conducted a randomized and prospective study comprising 136 closed tibia fractures. Reamed interlocking intramedullary nailing was inserted to 73 patients and unreamed interlocking intramedullary nailing was inserted to 63 patients. Bone healing rate of 96% was obtained for reamed nailing and 89% for unreamed nailing. 2 broken screws were seen in the reamed cases and 10 for the unreamed. The result of the study revealed that an even worse healing was experienced in unreamed nailing as well as delay in the bone healing although blood building was disrupted at the minimum. No disadvantage was identified in reamed nailing compared to unreamed nailing with respect to complications and reamed nailing was advised [29]. Keating et al. [30] compared the application of reamed and unreamed intramedullary nailing in open tibia fractures and found no significant difference in terms of bone union time, malunion, infection and broken material. Similar results have been obtained in both treatment methodologies [30]. The reamed technique was used for all our patients in our study and implant insufficiency was not observed in any one. We think that this is correlated with the engagement of larger and more solid screws after the reaming intervention.

Conclusion

In conclusion, material properties, diameter, cross-sectional shape, anterior bow, and the presence of locking screws affect the biomechanical characteristics of the nail [31]. Titanium alloy and 316L stainless-steel are the two most frequently used materials for the IM nails. Although the stainless-steel nails have 25% more torsional rigidity than did the titanium alloy version. [32]. Torsional rigidity and the amount of contact within the medullary canal are affected by the cross-sectional shape of the nail. As a result, reamed interlocking intramedullary nailing is recommended in tibia diaphysis fractures due to low complication rates, quick bone union and better functional results.

Declaration of conflict of interest

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