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Mini Review

Segmental fractures of the long bones and healing problems

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Abstract

Healing problems of segmental fractures of long bones are some of the most common complications. The purpose of this study is to review the incidence and pathogenesis of healing problems of segmental fractures of long bones. This is a simple literature review using the Pubmed database. Papers were searched with the use of the following keywords: ("segmental fractures") AND ("femur" OR "femoral" OR "tibia" OR "tibial" OR "humerus" OR "humeral" OR "forearm" OR "radius" OR "ulna). Moreover, the reference lists of the included papers were scanned for additional studies. Prospective or retrospective evaluating union rate and healing problems after the management of segmental fractures in long bones (femur, tibia, humerus, forearm) were included in this review. The search retrieved a total of 118 papers. After application of exclusion criteria, 30 studies were left in the present review. Successful healing of segmental fractures of long bones depends on the initial condition of the fracture, and surrounding soft tissues, since these high energy injuries may compromise the bone fragments blood supply. The rate of non-union is higher in open and severely comminuted fractures. Intramedullary nailing of segmental fractures of long bones seems to be the surgical option with the least healing problems.

Keywords: Long bones, Malunion, Non-union, Segmental fractures

Introduction

Segmental fractures of long bones are diaphyseal fractures, with two clearly distinct fracture lines and an intermediate free bone fragment[1]. They are high-energy injuries, usually caused by motor vehicle accidents and falls from heights. They may be open fractures, often accompanied by extensive soft tissue injuries around the fracture site, but also by other concomitant injuries (other fractures, craniocerebral injuries, chest or abdominal injuries)[2,3]. Segmental fractures of long bones mostly occur in young men between 21 and 40 years old. Most often these injuries concern the right upper and lower extremities, mainly the tibia, the femur, the forearm and the humerus.

Most common complications of segmental fractures of long bones are healing problems (delayed union, malunion, non-union), shortening, infection, pulmonary embolism, neurological deficits, compartment syndrome, bone loss, painful gait, and adjacent joint stiffness. These potential complications increase the rate of re-operations. Particularly, healing problems and infection are related to the blood support of the intermediate bony fragment and the extent of the soft tissue damage around the fracture[1,4-7].

Segmental fractures of long bones have a significant impact on various aspects of the patient's life. In some cases the fracture does not allow the patient to work and has financial consequences. Trauma limits the patient's normal social life and functionality. The burden of long bone fractures affects society through the loss of productivity, the direct and indirect costs of treatment, and the additional contribution to morbidity and mortality. The management and treatment of segmental fractures of long bones burdens health systems significantly due to

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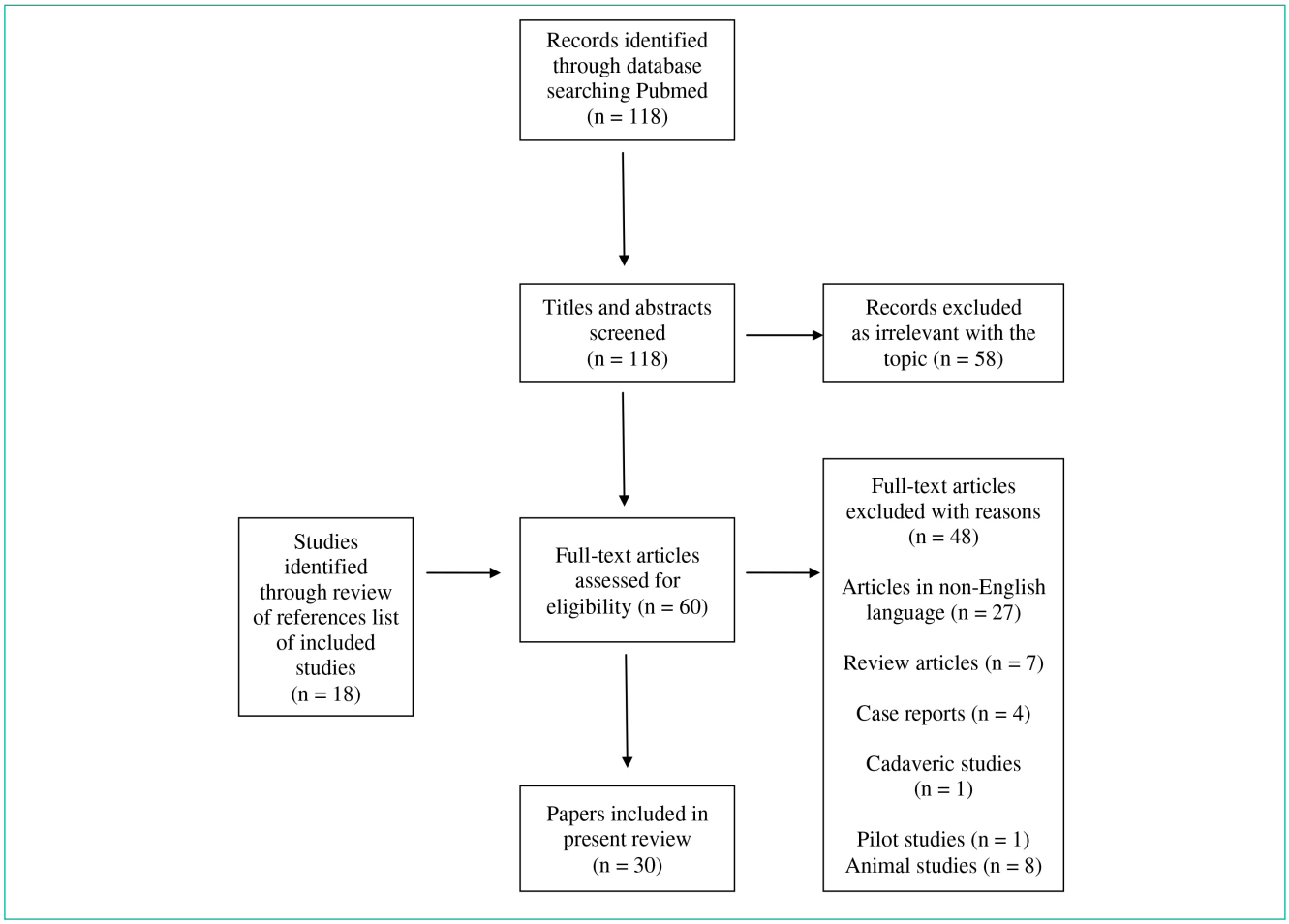

Figure 1. Study Flowchart.

surgical cost, possible re-admission to the hospital and the physical rehabilitation of patients[1,2].

Fractures take several weeks to several months to heal, depending on the extent of the lesion, the age of the patient, the type and site of the fracture, and the general state of health of the patient. The assessment of fracture healing is based on a series of x-rays taken at at least two levels. Successful union is defined as the presence of a mature bridging callus in all cortices in both the anteroposterior and lateral radiographs, combined by painless full loading of the limb. Fracture healing may sustain a significant delay (delayed union) or even complete cessation (non-union) at some intermediate stage.

Delayed union is defined as the failure to achieve healing within 6 months of the initial injury. Delayed union is clinically manifested by increased local temperature, slight swelling, and painful movements in the site of the fracture. The fracture line is visible in X-rays and both bony limbs show relative osteoporosis. Delayed union can evolve either to successful union or non-union. Non-union is defined as a remaining fracture line for 9 months after the initial injury without evidence of progression in the last 3 months. It is clinically manifested by the appearance of painless movements in the site of the fracture[1]. Malunion is defined as the anterior or posterior angulation more than 5° or the varus / valgus deformity more than 5° [6].

Materials and Methods

This is a simple literature review using the PubMed internet database. Papers were searched with the use of the following keywords: ("segmental fractures") AND ("femur" OR "femoral" OR "tibia" OR "tibial" OR "humerus" OR "humeral" OR "forearm" OR "radius" OR "ulna"). Moreover, the reference lists of the included papers were scanned for additional studies. Prospective or retrospective evaluating union rate and healing problems after the management of segmental fractures in long bones (femur, tibia, humerus, forearm) were included in this review. Study protocols, case reports, systematic reviews, meta-analyses, studies in other than English language and non-human studies were excluded.

Results

The search retrieved a total of 118 papers. After screening of titles and abstracts, 58 articles were rejected as irrelevant with the topic. Of the 60 publications evaluated, 48 were rejected for various reasons (Figure 1). After the review of the reference list of the remaining studies, 18 more studies were identified. At last, 30 studies were included in the present review: 6 studies for femoral segmental fractures, 12 studies for tibial segmental fractures, 10 studies for humerus segmental fractures and 2 studies for forearm segmental fractures.

Successful healing of segmental fractures of long bones depends on the initial condition of the fracture, and especially the initial condition of the soft tissues, since these high energy injuries may compromise the bone fragments blood supply. Moreover, healing depends on patient history and comorbidities (smoking, diabetes mellitus), the timing of treatment, the type of treatment, concomitant injuries, patient compliance, age, etc. Better results are observed in closed fractures compared to open fractures and fractures with soft tissue damage. At last, better results were observed in open fractures Gustillo type II compared to Gustillo type III[8-10]. Appearance of a callus in the proximal fracture line ranges from 2-6 weeks in contrast to the distal fracture line, where callus appears between 3-8 weeks[8-10].

Several methods of treatment of segmental long bone fractures have been described, including non-operative management, various methods of intramedullary nailing and plating, and external fixation. Conservative management has been associated with non-union rates as high as 27.2%. Even when the fracture heals, rates of delayed union and malunion are high, resulting in muscle loss and consequent difficulty in rehabilitating the patient[11]. Intramedullary nailing is considered as the best option, as it preserves soft tissue envelope and allows for immediate full weight-bearing. However, it requires special surgical skills, expensive hardware and image intensifier[12]. Animal studies have shown that reamed nailing has the same results with unreamed nailing, as the reduced endosteal blood supply to the middle fragment led to an increased periosteal blood flow from the muscles[13,14]. Locked nails have the same impact on blood flow with unlocked nails, while they provide rotational stability[15,16]. Close reduction and locked intramedullary nailing have shown good outcomes for segmental long bone fractures[17-19]. If dynamization is required, it can be done after 3-4 months. In low-income countries, where intraoperative fluoroscopy may be unavailable, mini-open intramedullary nailing of long bone segmental fracture has produced a 92% union rate in 4 months postoperatively[20].

Segmental Femoral Fractures

Segmental femoral fractures are a unique fracture type, classified as 32-C2 in AO/OTA classification[21]. The most critical factor that should be taken into consideration is the interruption of endosteal vascularity of both intermediate segment ends, leaving the periosteum as the only source of blood supply. Conservative treatment is not acceptable as it increases malunion rates and shortening. Open reduction and internal fixation, while maintaining stability, it has the disadvantage of destroying periosteal blood supply, affecting grossly the process of healing. Closed reduction and antegrade locked intramedullary nailing has been accepted as an effective method for the management of segmental femoral fracture with the advantage of minimizing soft tissue injury, preserving fracture hematoma and allowing for immediate full-weight bearing, factors that enhance fracture healing[18]. However, the method has the disadvantages of increased surgical difficulty in case of severely displaced fractures and prolonged surgical time[19,22].

Healing problems of the segmental femoral fractures are complications representing a serious socioeconomic problem. In a prospective study by Wu et al, among 35 segmental femoral fractures treated with intramedullary nailing, union rate was 83% and mean union time was 6 months[23]. The combination of intramedullary nailing with screw fixation has been reported to have a mean union time of 18 weeks[24]. Minimally invasive plate osteosynthesis (MIPO) has gained popularity recently and has shown promising results. However, in segmental femoral fractures it has not yielded better results in comparison to traditional open reduction and internal fixation with bone grafting, in terms of time of union (155 days versus 145 days)[25].

Segmental Tibial Fractures

Segmental tibial fractures are classified as 42-C2 in AO/OTA classification[21]. While tibial fractures are the most common among long bone fractures, segmental fractures are only the 4-6% of them. They occur three times more often in men, while the average age of male patients is significantly lower than women (37 years for men - 54 years for women). This epidemiological distribution is easily explained by the most common mechanism for causing these fractures which are motorcycle accidents[26].

Severe soft tissue injury affects blood flow to segmental tibial fractures leading to an increased risk of poor fracture healing (up to 50%). Optimal fixation of these fractures should therefore minimize further soft tissue and bone injury, maintain residual blood supply, and provide a mechanical environment that will promote bone union[2]. Segmental tibial fractures are mainly treated surgically either with the use of plates, or with the use of intramedullary nails or with the use of external fixators. Robertson et al have reported that 66.6% of segmental tibial fractures require more than one surgery[27]. According to Audige et al, fractures of the distal tibia are more unstable. Delayed union of all distal tibia fractures is a well known condition. Therefore in this area, fixation should be as stable as possible, something that usually cannot be achieved by intramedullary nailing[28].

Regarding the fixation of segmental tibial fractures, intramedullary nailing is preferred. However, reduction is

often difficult due to the instability of the intermediate bone fragment and the need for additional plates and screws[2]. In a study comparing healing problems between reamed and unreamed nailing in the treatment of tibial fracture, authors found that unreamed nailing is associated with higher rates of malunions and re-operations in comparison to reamed nailing[29]. Another large series by Kakar et al, assessed 51 patients with segmental tibial fractures treated with closed unreamed intramedullary nailing. Average time of union was 4.6 months for closed fractures and 5.9 months for open fractures. 21% of the patients were reoperated to achieve union, and malunion occurred in 6% of the patients[8].

External fixation has been used to treat such fractures. The main advantages of this method include good fixation, minimal blood loss and early mobilization. It is also a simple, fast and economical method that causes minimal surgical trauma[5,30]. Taking into account all these parameters, Ilizarov type external fixation is an excellent choice for achieving therapeutic goals in such a fracture[5,30]. In a retrospective study by Giotakis et al, external fixation resulted in 10% rate of non-union, with a mean time to union 22 weeks[30]. A similar study by Ozturkmen et al showed a 100% of union rate among 24 patients with segmental tibial fractures. The mean time for proximal fracture union was 36.4 weeks and 39.8 weeks for the distal fractures ($p>0.05$)[9]. Including 45 patients with segmental tibial fractures treated with Ilizarov external fixation, Makhdoom et al observed that there was no difference in union time among open and close fractures[31]. A recent study included 32 patients with segmental tibial fractures with Mitkovic-type external fixators and compared open with close fractures. Average time of union was about 6 months in both open and close fractures. The rate of non-union was 19% and was higher in patients with open fractures[32].

High union rates were reported by Ma et al who evaluated 25 patients with segmental tibial fractures treated with a 2-stage approach: application of a low-profile locking plate for the temporary stabilization of fractures and a definitive minimally invasive plate osteosynthesis at a 2nd stage[33].

A retrospective study by Teraa et al compared the healing complications among 30 patients with segmental tibia fractures and 30 patients with non-segmental tibial fractures. Median time to healing was 34 weeks. Union time, rate of healing problems and risk of re-operation was higher in segmental tibial fractures ($p<0.001$ for union time)[2]. Segmental fractures initially treated with intramedullary nailing healed faster ($p=0.040$) than fractures treated with plating or external fixation, whereas segmental fractures treated with gently reamed intramedullary nailing united faster ($p=0.031$) than fractures treated with unreamed intramedullary nailing. Non-unions occurred only in open segmental fractures[2].

Giannoudis et al assessed 27 patients with segmental tibial fractures, treated with intramedullary nailing (n=16), external fixation (n=8), plating (n=2) and conservatively (n=1). The mean time to union of the proximal segment was 38.8 weeks and 41.4 weeks for the distal segment, respectively. One case of malunion was observed in the patient treated non-operatively. Closed fractures healed faster than open fractures[6]. A similar older study compared internal fixation and external fixation in 40 patients with segmental fractures of the tibial shaft. In the group of internal fixation, 4 cases of non-union and 1 case of malunion were observed. In patients treated with external fixation, 4 cases of non-union, 1 case of delayed union and 1 case of malunion were observed[7].

A retrospective study by Beardi et al compared intramedullary nailing, plate osteosynthesis and external fixation in 26 patients with segmental fractures of the tibial shaft. Mean time of union was 11.4 months. Authors suggested that conventional intramedullary nailing may not be appropriate for fixation of segmental fractures with a short metaphyseal fracture fragment; thus nails with proximal and distal interlocking in three different planes offer better stability[4].

When surgical methods for the treatment of segmental tibial fractures are compared, results have shown that intramedullary nailing results in faster union than internal fixation and external fixation; however there are concerns about the rate of thromboembolic events. Rates of malunion are higher in open reduction and internal fixation (15%) compared to nailing (9%) and external fixation (9%)[3].

Segmental Humerus Fractures

Segmental fractures of humerus may predispose to high non-union rates[34]. Healing impairment has been attributed to the injury of the nutrient vessels and soft tissue envelope vascularity caused by high-energy trauma[34]. Among 63 patients with segmental humeral fractures, treated conservatively (n=22), with nailing (n=25), plating (n=17) and external fixation (n=5), Fogerty et al found a 22.2% non-union rate[11].

Conservative treatment with functional bracing of acute segmental humeral shaft fractures has been associated with a 97% union rate[35]. Internal fixation with plates, is not recommended for segmental humerus fractures as extensive periosteal stripping may compromise the blood supply of the intermediate fragment, decrease the periosteal osteogenesis and result in healing problems[36-38]. In case there are absolute indications for plating, special techniques should be used, such as indirect reduction, atraumatic approaches, and long plates.

Locked intramedullary nailing with minimal soft tissue injury has been recommended for segmental humeral fractures[39-41]. Lin et al reported a 91% union rate after locked intramedullary nailing of segmental humerus fractures, with a mean union time of 13 weeks. Non-union rate was 9% and these cases were treated with revision nailing and bone grafting[42]. Unlocked intramedullary nailing has the disadvantage of low mechanical stability[43].

Segmental Forearm Fractures

Segmental fractures of forearm are very rare with a reported incidence of 0.1% of all fractures. In a retrospective study, 9 segmental forearm fractures were treated by open reduction and internal fixation, 2 other similar fractures required additional nailing while one fracture was treated with isolated nailing. Mean union time was 27 weeks (range 20 – 40). Delayed union (40 weeks) was observed in the fracture treated with nailing[44]. Minimally invasive plate osteosynthesis is a suitable option for distal segmental radial fractures with a 10% rate of delayed healing[45].

Conclusions

The incidence of segmental long bone fracture is increasing as a result of increasing high-energy trauma, especially in low- and medium-income countries. Healing is usually compromised in segmental fractures of long bones because of injury to the surrounding soft tissues in addition to the compromised blood supply to the intermediate segment, leading to nonunion or delayed union.

Conclusively, segmental fractures of long bones take longer to heal compared to non-segmental fractures. Segmental fractures are characterized by a defective union process and often a high incidence of complications such as delayed union in particular, and non-union, which is commonly accepted in the international literature. It should also be emphasized that especially in open fractures the complications are proportionally more frequent. There is no significant difference in union between the two fracture lines that define segmental fracture, although there is a faster union in the proximal fracture site, mainly due to instability in the distal fragment of the fracture. In the case of segmental tibial fractures, union is achieved earlier with the use of reamed intramedullary nailing compared to unreamed nailing, suggesting that the use of mildly reamed nails may have potentially better results in treating segmental tibial fractures. In addition, there was a greater need for reoperation in patients with segmental fractures compared to patients with simple fractures, which is attributed to the increased incidence of bone healing problems and the higher incidence of infections. Intramedullary nailing of femoral and tibial segmental fractures have excellent results in terms of reduction and union, with low rates of non-union and infection.

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