Treatment of Long-Bone Fractures, Malunions, and Nonunions: Experience at Chang Gung Memorial Hospital, Taoyuan, Taiwan

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Long-bone fractures are common in the field of orthopedic trauma and require careful treatment to avoid refractory disabilities. Through advancements of modern medicine and technology, many excellent techniques and devices are continually being invented. Currently, the success rates of treatment have markedly increased while complication rates have been greatly lowered. Even so, complications of failed fracture treatment still occasionally occur. Among these complications, malunions and nonunions are relatively common and disturbing. However, both complications can be reduced if the principles of fracture treatment are strictly followed. All fractures may be treated with nonoperative or operative methods according to individual advantages and disadvantages. In principle, nonoperative methods should be given priority. In this article, principles of treatment of long-bone fractures, malunions, and nonunions are clarified. Current practices which have been published and which are representative of treatment of these issues at the author's institution are reported. Inconsistencies of important viewpoints concerning fracture-related treatment between the author's institution and published articles are discussed. The aims of this study were to assess the academic level of fracture treatment at the author's institution. Then, improved techniques for fracture treatment might be continually developed. Some studies at the author's institution have revealed that the success rates are comparable to those of articles with the highest success rates in the world. *(Chang Gung Med J 2006;29:347-57)*

Key words: fracture, malunion, nonunion.

Long bones normally indicate the humerus, radius, ulna, femur, tibia, and fibula. Except for the fibula, the main functions of the long bones include supporting the trunk to separate it from the ground and providing a firm framework for movement. Therefore, once a long bone is fractured, the ability of movement may be lost immediately. In every case, the utmost speed of repair of a fracture is required.

Following advancements in modern medicine and technology, knowledge of the fracture mechanisms, favorable factors for fracture repair, and

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improved techniques for fracture treatment have greatly progressed. Nowadays, although improved techniques and devices are continually being developed, a few complicated fractures for which convincing treatment methods are not well defined still exist. All fractures may be treated with nonoperative or operative methods according to individual advantages and disadvantages. In principle, nonoperative methods should be given priority.

If acute fractures are not successfully treated, a malunion or nonunion will occur. Then, techniques of treatment for each complication become much more complex. Moreover, the final results may be discouraging. Therefore, fractures always need careful treatment from the initial stage. In this article, principles of treatment of long-bone fractures, malunions, and nonunions are clarified. Because of the limited space for more comprehensive contents, only current practices which have been published and which are representative of the treatment of these issues at the author's institution are reported. Inconsistencies in important viewpoints concerning fracture-related treatment between the author's institution and published articles are discussed. The aim of this study was to assess the academic level of fracture treatment at the author's institution so that improved techniques for fracture treatment can continue to be developed.

Principles of treatment and current published practices

Assessment of fractures

Factors favoring fracture repair are a minimal gap, adequate stability, and sufficient nutrition supply.(1) Lack of any of these 3 factors will cause a malunion or nonunion. To reduce fracture fragments and minimize the fracture gap, either an open or closed reduction may be chosen. However, the former may severely destroy the periosteal vascularity and block the nutrition supply. Therefore, a closed reduction technique should be used if possible. To provide adequate stability, either internal fixation or external immobilization may be chosen. However, external fixation may induce pin tract sepsis and joint stiffness.(2) Therefore, internal fixation should be considered a priority. After all, all operations carry certain degrees of risks for complications. The severest complication may cause death. Therefore, nonoperative and operative treatments must be carefully assessed before the operation. In principle, nonoperative methods should be considered a priority. If operative methods are chosen, intramedullary nails are the treatment of choice for long-bone fractures.(3-5) For the radius, ulna, and fibula, the small caliber of the marrow cavity has interfered with the wide development of intramedullary devices.

On the other hand, open fractures need careful treatment to prevent infection. Infection not only interferes with fracture repair, but also causes grave suffering to patients. Every effort should be made to prevent infection. Predisposing factors for infection are numerous, and all operations run a risk of infection. To reduce infection, nonoperative and operative treatment must also be carefully assessed.

a. Humeral fractures

In the literature, treatment of unstable proximal humeral fractures is still controversial.(6,7) Closed cannulated screws were successfully developed at the author's institution,(8) and 84% (16 of 19) patients achieved satisfactory results with their use. Humeral shaft fractures are normally treated with conservative methods.(6) A hanging cast or U-slab splint was applied for 6 weeks, and 70% fractures achieved a clinical union (Fig. 1). Other 30% of fractures were converted to a functional brace and a further 18.5% of fractures healed.(9) Both methods are still working well.

b. Femoral fractures

Femoral neck fractures in young adult patients should be pinned as quickly as possible in order to preserve the femoral head.(6,10) Although a 34.5% osteonecrosis rate and a 14% nonunion rate were reported, this technique is still widely used.(11) Concomitant femoral neck and shaft fractures should be treated with closed intramedullary nails and supplementary pinning.(12) Currently, reconstruction locked nails are gradually replacing combined devices, and the technique has become simpler.(13) Intertrochanteric fractures are preferably treated with sliding compression screws (SCSs).(14) With precise placement of a lag screw in suitable types of fractures, a high union rate and a low complication rate can be achieved.(15,16) As for shaft fractures, closed unlocked or locked intramedullary nails are the treatment of choice (Fig. 2).(17-21)

c. Tibial fractures

Tibial shaft fractures can be treated with casting or intramedullary nails, and both techniques can

Fig. 1 A left humeral shaft fracture treated with closed reduction and hanging cast immobilization. The fracture had healed uneventfully at 3 months.

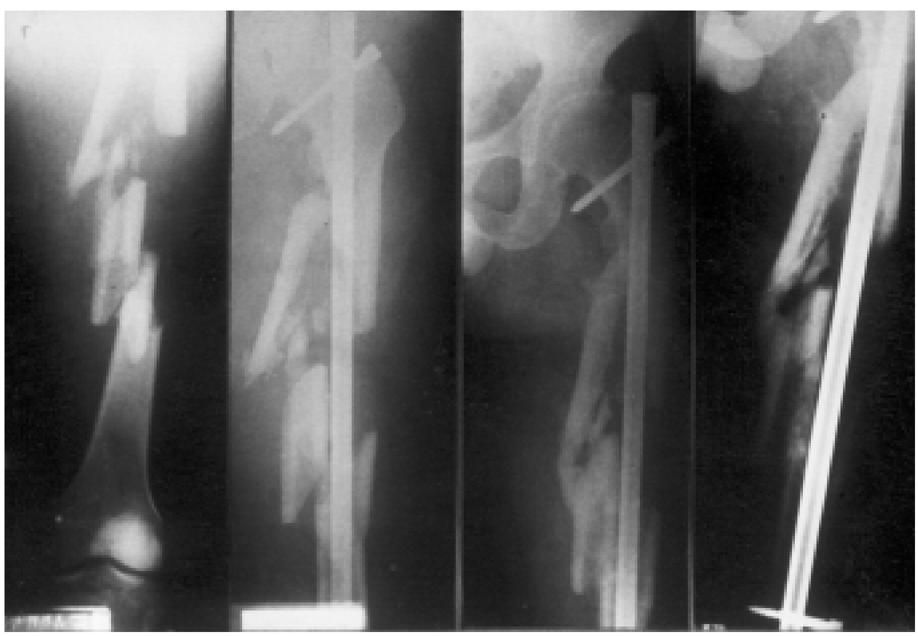

Fig. 2 A left segmental comminuted femoral shaft fracture treated with closed static locked nailing. The fracture had healed uneventfully at 5 months.

achieve a high success rate.[22] Because the anteromedial aspect of the tibia is located subcutaneously, open fractures are common.[23] Prevention of wound infection is a priority. Secondary intramedullary nailing or non-reamed locked nailing has been recommended.[24,25] The choice should depend on the situation at the time. Segmental tibial shaft fractures are preferably treated with interlocking nails.[26]

Assessment of malunions

Malunions include shortening, rotational deformity, and angular deformity.[27] Normally, they are caused by relatively uncertain stabilization or carelessness with fragment alignment during fracture treatment. Malunions in an upper extremity generally can be tolerated without treatment and might not be clinically evident.[9] However, in a lower extremity which requires weight bearing, malunions not only can cause a limp but also can induce joint degeneration.[28] In the literature, treatment of long-bone malunions almost always focuses on the femur or tibia. Regardless of which internal or external techniques are used, the principles of minimizing the gap, providing adequate stability, and ensuring a sufficient nutritional supply always need to be adhered to. To compensate for bony defects after deformity correction, a bone graft is normally required. The bony healing process after a bone graft in malunions is comparable to the fracture healing process.

a. Femoral malunions

A femoral malunion is normally defined as shortening by more than 2 cm or angular or rotational deformity of more than 10°.[29] With a leg length discrepancy (LLD) of more than 2 cm, a limp is observed.[30] The long-term effect of a limp has not clearly been defined. In the literature, chronic back pain is imputed to be 1 of the complications of a limp.[31] In principle, an LLD of 2~4 cm should be treated with a shoe-lift. With an LLD of more than 4 cm, surgical correction is recommended.[30] At the author's institution, 1-stage or gradual femoral lengthening can be performed. However, each technique has certain advantages and disadvantages which are relevant to different situations. One-stage femoral lengthening normally should not be used for more than 4 cm, or sciatic nerve injury may occur.[32] Gradual femoral lengthening normally requires insertion of external fixation. Pin tract sepsis and knee joint stiffness or deformity may occur.[33] As for angular or rotational deformities, an osteotomy with locked or unlocked intramedullary nail stabilization is generally successful.[29] An angular deformity may induce hip and knee joint degeneration, after which the treatment becomes very complex (Fig. 3).[34]

b. Tibial malunions

Tibial malunions are not well defined in the literature. Normally, shortening of more than 2 cm, angular deformity of more than 5°, internal rotation of more than 5°, or external rotation of more than

Fig. 3 A right distal femoral shaft malunion with angular deformity and shortening treated with a femoral osteotomy, 1-stage femoral lengthening of 3 cm, static locked nail stabilization, and corticocancellous bone grafting. The osteotomy site had healed uneventfully at 3 months.

10° is considered unacceptable.(35) Correction of tibial shortening may refer to the principle of the femur. However, a shoe-lift may be used with a wider range. The knee joint may tolerate a ± 2-cm difference in height compared to the contralateral knee joint. If lengthening is performed, gradual lengthening with external fixation is always necessary.(36) Similarly, this runs the risk of pin tract sepsis and ankle stiffness or deformity. Angular deformity of the tibia may induce knee and ankle joint degeneration, after which treatment also becomes very complex.(28,35) At the author's institution, an osteotomy with locked or unlocked intramedullary nail stabilization has successfully been developed.(37)

Assessment of nonunions

Normally, a nonunion is defined as a fracture that has not healed after 1 year of treatment, or repeated surgeries must be performed to achieve union.(17,21) A union is defined as clinically having no pain, no tenderness, and no need of assistance for movement; and radiographically as trabeculae having passed through the fracture gap or the solid cortical callus having bridged both fragments.(17,21) In practice, nonunions are divided into atrophic or hypertrophic types according to the convenience of treatment.(38) Atrophic nonunions are caused by loss of osteogenic power, such as a large fracture defect, severe vascular destruction around the fracture site, and infection. Hypertrophic nonunions are caused by insufficient stability. Therefore, if adequate treatment focuses on the actual mechanism causing the nonunion, the success rate can be markedly elevated. When nonunions are noted, a septic or aseptic cause should be carefully determined. Clinical and laboratory information must be checked, then, adequate treatment methods designed. Associated shortening must concomitantly be considered when treatment methods are designed.(39) Although nonoperative methods, such as load bearing, electrical stimulation, ultrasound, or shock waves, may be effective, the success rate is generally lower than with operative methods.(40-43) Therefore, patient selection is important. In the literature, regardless of whether atrophic or hypertrophic nonunions are treated surgically, cancellous bone grafting to elevate the union rate is recommended.(44)

a. Humeral nonunions

Infected humeral shaft nonunions are treated with staged operations and stabilized with external fixation. Almost all patients can achieve a good union.(45) For aseptic nonunions, plating and locked nailing have similar success rates, but the latter is technically simpler.(46) To reinforce the rotational stability, a locked nail can be augmented with staples.(47)

b. Femoral nonunions

Femoral neck nonunions are treated with a subtrochanteric osteotomy and stabilized with SCS. In 1 report, all neck nonunions healed, but a 7.7% osteonecrosis rate and a 3.8% nonunion rate in the osteotomy site occurred.(48) For infected intertrochanteric nonunions, the 1-stage revision technique can still achieve a high success rate. The greatest advantage is marked shortening of the treatment period.(49) As for infected shaft nonunions, 2 different strategies can be chosen and each has its own advantages and disadvantages. One is treatment of the infection first with the nonunion being treated later, and the other technique is the concomitant treatment of the infection and nonunion.(50) The first choice for treatment of aseptic shaft nonunions is intramedullary nails. Sometimes, plate augmentation may be useful near the metaphysic.(51) Nonunions sometimes may be combined with shortening of more than 2 cm. For such nonunions, 1-stage or gradual lengthening should be performed (Fig. 4).(39,52)

c. Tibial nonunions

Infected tibial shaft nonunions may be treated with staged operations and stabilized with external fixation or a 1-stage revision technique (Fig. 5).(53) Each technique also has its own advantages and disadvantages. For aseptic shaft nonunions, intramedullary nails should be considered a priority (Fig. 6).(54) When nonunions are combined with shortening of more than 2 cm, gradual lengthening with secondary internal fixation may be performed, and a high success rate may be achieved.(36)

Discussion

The long bones normally must sustain huge loads of axial compression, bending, and torsion during daily activities. Particularly in the lower extremities, the top loads may be as high as 3~5 times the body weight.(55,56) Therefore, fracture stabilization must strictly abide by biomechanical principles, or implants can easily fail. Because the long bones are suitable for intramedullary nail insertion and this

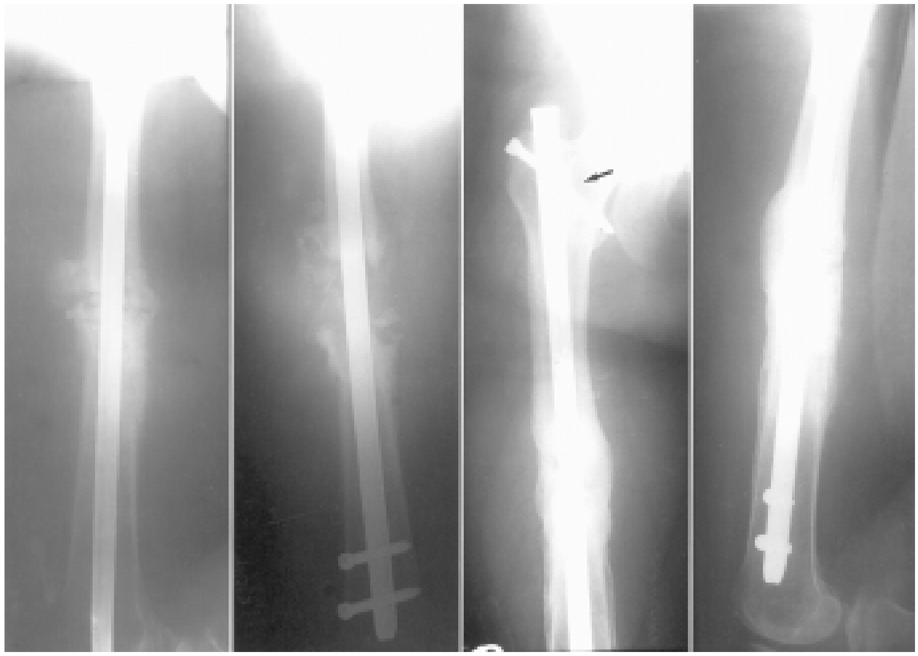

Fig. 4 A right femoral shaft nonunion with shortening treated with 1-stage femoral lengthening of 4 cm, static locked nail stabilization, and corticocancellous bone grafting. The nonunion site had healed uneventfully at 4 months despite breakage of the proximal locked screw (arrow).

Fig. 5 An infected right distal tibial nonunion treated by intramedullary reaming to achieve cancellous bone grafting and stabilization with external fixation. The nonunion site had healed uneventfully at 6 months.

device has both biomechanical and biological advantages, intramedullary nails are the treatment of choice for long-bone stabilization.[3-5] With a closed technique, the infection rate is markedly lowered.

After locked nails were invented, metaphyseal fractures could be stabilized by intramedullary

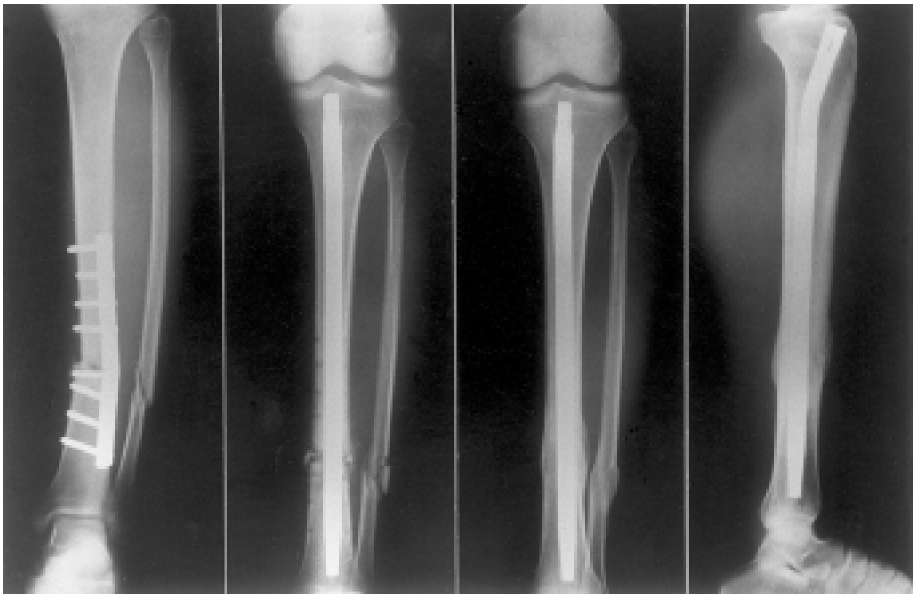

Fig. 6 A left distal tibial aseptic nonunion treated with Kuntscher nailing after intramedullary reaming. Although no extra cancellous bone graft was added, the nonunion site had still healed uneventfully at 4 months.

nails.[17,18] Currently, use of plate fixation has been greatly restricted. However, in metaphyseal fractures, a nail hole in close proximity to the fracture site can induce huge bending stresses, and occurrences of implant failure are not uncommon.[57,58] For such fractures, a plate or a retrograde locked nail may be more suitable.[59]

Nonoperative treatment of fractures or nonunions may be effective in some long bones. However, adequate stability must be maintained. If the stability is in doubt, reinforcing devices must be used for supplementary support. In the literature, the success rates for nonoperative treatment of long-bone nonunions with electrical stimulation, ultrasound, or shock waves are 80%~86%.[41-43] Those of cancellous bone grafting are usually above 90%~95%.[60]

In proximal humeral fractures, fractures of 2 parts have traditionally been treated with closed reduction and those of 3 parts, with open reduction.[6,7] At the author's institution, fractures of 2 or 3 parts are successfully treated with closed reduction and fixation using cannulated screws.[8] All advantages of closed treatment are achieved with this technique. Operative treatment of humeral shaft fractures runs the risk of iatrogenic radial nerve injury. Additionally, the union rate is not evidently higher compared to nonoperative methods.[9,61] Therefore, nonoperative treatment should have the priority.

The key to treatment of concomitant femoral neck and shaft fractures is the healing process of shaft fractures.[12] Often, the shaft fracture is greatly comminuted due to dissipation of most of the energy. Therefore, closed intramedullary nailing is much superior to plating. However, concomitant stabilization of the neck fracture is technically demanding. A reconstruction nail is suitable for such use. For shaft fractures without comminution, plating the shaft fractures and pinning the neck fractures are technically simpler.[62]

Although using SCS to treat intertrochanteric fractures can achieve a high success rate, some types of fractures are contraindicated. These fractures include reversed oblique fractures, comminuted lateral cortex fractures, and comminuted basal neck fractures.[63,64] With these fractures, the lag screw can markedly slide downward. Complications including shortening, penetration, a cut-out, or implant failure may occur. It is better to use static devices without sliding or cement augmentation.[64]

For femoral supracondylar fractures, an antegrade locked nail may be unsuitable due to the short distal bony stock.[18] A plate was traditionally used, or currently a retrograde locked nail is used, which can be inserted using a closed technique. The success rates are high.[59]

Tibial shaft fractures traditionally have been treated with casting or functional bracing, with high success rates.[22] Currently, closed intramedullary nailing has become popular to reduce patient suffering. However, tibial fractures are often open types which run a high risk of infection. To prevent infection, external fixation with or without secondary nailing or non-reamed locked nailing can be used.[24,25]

Treatment of long-bone malunions is difficult. Normally, the marrow cavity near the lesion site has disappeared. Recanalization of the marrow cavity may require a large dissection wound. Although long bones are suitable for intramedullary nail use, the technique is quite complex. Plating is easier but is unsuitable for concomitant lengthening. After lengthening of the long bone, a gap on the opposite cortex can induce plate breakage.[65] In the literature, using Ilizarov external fixation to correct long-bone malunions has been reported.[66] Complications of external fixation cannot be avoided. The most ideal implant is still a locked nail.

Nonunions are common if prior fractures were treated with open reduction. In the femur, significant shortening is often combined with nonunion. The causes may be due to insufficient initial care being paid to providing adequate reduction for comminuted fractures or to progressive shortening with dynamic fixation.[39,52] For perfect treatment of nonunions in the lower extremity, concomitant lengthening should be carried out whenever necessary. Normally, after a mean of 3 months, patients can achieve a completely normal gait.[52] At the author's institution, a method for 1-stage femoral lengthening of no more than 4 cm has been skillfully developed.

Because the first choice of treatment of femoral shaft fractures is intramedullary nailing, clinically cases of femoral shaft nonunions largely occur with those using inserted intramedullary nails. For these nonunions, exchange nailing is the treatment of choice for cases requiring no concomitant lengthening.[67] The success rates of exchange femoral nailing are 53%~100% and for exchange tibial nailing, are 95%~100%.[54,67] At the author's institution, a success rate of 92% has been reported, which is higher than nonoperative techniques reported in the literature, of 80%~86%.[41-43]

Conclusions

Following advancements of modern medicine and technology, treatments of long-bone fractures, malunions, and nonunions have made great progress. As long as the principles of fracture treatment are strictly followed, high success rates can normally be achieved. Not all fractures require operative treatment, and nonoperative treatment should be a priority. Should treatment of a fracture fail, a malunion or nonunion can be treated according to established principles by choosing the most suitable technique based on the individual situation. The success rate of treatment can still remain high. Some studies at the author's institution have revealed that success rates are comparable to articles with the highest success rates in the world.

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長骨的骨折、癒合不良、以及不癒合的治療：林口長庚紀念醫院的經驗

吳基銓

長骨的骨折在骨科外傷的領域中很常見，需要謹慎的治療，以避免演變成很難處理的後患。隨著現代醫學及工程學的進步，許多優秀的技術及工具，不斷地被研發出來。目前，治療的成功率比以前已有大幅度提高，而併發症率則有大幅度下降。即便如此，治療骨折失敗後的併發症，仍然有時可見。在這些併發症中，癒合不良或不癒合，相對地常見及造成很大困擾。但是，這兩種併發症，如果能夠嚴格遵照骨折治療的原則，則可減少。所有的骨折，可以依照個別的有利或不利條件，做非手術或手術的治療。原則上，非手術治療應優先考慮。本研究中，長骨的骨折、癒合不良、以及不癒合的治療原則，將被詳細澄清。在筆者服務機構，現行治療以上標題的作法，經論文刊登且具代表性者，將被提出報告。針對筆者服務機構與文獻上有不一致的重要觀點，將被提出討論。本研究的目地，在評估筆者服務機構，在治療骨折的學術層級。因而，治療骨折的更先進的技術，將能繼續地被研發。從一些筆者服務機構的發表中顯示：其治療成功率和世界級的最高成功率，有些可以相提並論。(長庚醫誌 2006;29:347-57)

關鍵字：骨折，癒合不良，不癒合。

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