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Significance of Fracture Gap in Open Tibial Fracture

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The healing pattern of medial and lateral cortical gap in open transverse or short oblique tibial fractures were retrospectively reviewed in 2 groups; In group A, 16 patients were treated by Judet external fixator in rigid mode. In group B, 6 patients were treated in biocompressive mode, which allowed predominantly longitudinal axial motion. The characteristic healing pattern in group A was gap healing without or with minimal periosteal callus. The healing time and time for consolidation per 1mm gap were significantly longer in medial cortices than lateral ones ($p<0.036$, $p<0.024$ respectively). In group B, the fractures were healed with periosteal callus. There was no difference in the healing time and the time for consolidation per 1mm gap between the two cortices. The consolidation time per 1 mm gap in the medial cortices was significantly longer in group A than group B ($p<0.020$). The longitudinal axial motion in open transverse tibial fractures seems to shorten the healing time effectively in the medial cortex.

Key Words: Bone, healing, callus formation, external fixator

Since J.F. Malgaigne introduced the idea of external fixator (EF) in 1840, it has developed for more than a century. In the begining of its development, most effort was forced to improve the stiffness to control the instability of the fracture and pin loosening (Seligson and Dudey 1982; Vidal *et al.* 1990). During the early stage of open fracture healing, good stiffness of the EF has been regarded as a very important factor for soft tissue healing and prevention of fracture end resorption. However, intensive researches in this field revealed that extreme stiffness of the EF hindered the production of periosteal callus. In addition, largely uncontacted fracture surfaces contact each other in only low percentages. Holding apart these surfaces which may be exaggerated by fracture end resorption has been thought as a main cause of delayed and nonunion with external fixation. This has been regarded as the chief drawback of the EF as well as pin tract problems (Mc Kibbin 1978; Wu *et al.* 1984; Chao *et al.* 1989).

Recently, Ilizarov, Lazo de Zbikowsky, and De Bastiani have developed their own external fixators to overcome these problems by longitudinal axial motion at the fracture or osteotomy site. Eventhough exact mechanisms of the above mentioned external fixators may be different each other, the common chief goal is provocation of periosteal callus to shorten the healing time (De Bastiani *et al.* 1984; Lazo de Zbikowski *et al.* 1985; Ilizarov 1989; Vidal *et al.* 1990).

Many studies concerning healing patterns of fracture and of osteotomy were performed in

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animal models and in many clinical trials to shorten the healing time of open tibial fractures. However, characteristics and significance of the fracture gap in external fixation are not yet clearly depicted. The complexity of the fracture lines, variety of soft tissue injury, and various parameters in radiologic techniques are thought as the obstacles for objective comparison of them.

We measured the gap of 22 open transverse and short oblique tibial fractures, which have been treated by Judet EF. Using a 5mm pin as a reference of radiologic enlargement, we analysed the significance of gap and healing patterns in two different modes of application in EF; Rigid Neutralization versus Biocompression

PATIENT

Between 1972 and 1991, 538 adult open tibial fractures (529 patients) were treated in the department of traumatology and orthopedic surgery at Raymond Poincaré Hospital. We reviewed the charts and X-rays of open transverse tibial fracture including short oblique fractures of less than 30° of obliquity. Fractures with gross comminution were discarded due to difficulty in measuring gaps and evaluating the consolidation. Fractures within 8 cm from the plateau and plafond of the tibia were excluded because of rich cancellous tissue in these areas. Fractures which were treated by bone grafts and/or decortication were also excluded due to modification on the contour of the cortices.

We used the classification of open fractures proposed by Cauchoix and Duparc for the description of cutaneous injury; Type 1–Laceration without avulsion and contusion which can be sutured without tension after débridement. Type 2-All lesions with high risk of secondary cutaneous necrosis, laceration with avulsion, and flap and contusion of cutaneous and subcutaneous tissue. In this study, the closed fracture with severe cutaneous contusion was also concerned as type 2 when there was a high risk of secondary necrosis of the cutaneous tissue. Type 3-Loss of soft tissue in pretibial region or in proximity to the fracture site (Cauchoix *et al.* 1957).

To compare the deep soft tissue damages around the fracture site, we measured the initial displacement of the fractures. The amount of displacement was divided by the width of the diaphysis at the same level.

The characteristics of Judet EF is the U-shaped bar of stainless steel. The two sides of this bar are pierced with regularly shaped holes, round or oval. Bars with holes for 5mm pins were used in all cases. This kind of EF does not allow the modification of alignment after application, so it is necessary to obtain a reduction as perfect as possible during the application through open wound or incision. There are two kinds of bars. One is with regular round holes to fix the all pins in tight position. The other is with oval holes in one side of the bar, which is closer to the bone, allowing axial motion at the fracture site by weight bearing (Judet *et al.*1982; Bonnel *et al.* 1983; Vidal *et al.* 1990)

All operations were done within 24 hours after the accidents, except one case which was transfered from other unit and was operated at 2 week. All fractures were reduced under direct vision. All pins were placed through the holes of the bar which was held parallel to the bone by the assistant. The pins in the round holes were fixed to the bars by metal blocking plates. We divided the patients into two groups in this study, according to the mode of application, namely the type of side bar; Group A-unilateral monoplane or biplane rigid round hole bar(s). Group B - unilateral monoplane or biplane bar(s) with oval holes, allowing axial motion. In both groups connection rods were used in selected cases. All patients were followed up monthly until complete consolidation.

METHODS

Gap distance between the two fragments was measured in medial and lateral cortices. Due to triangular configuration of the tibial diaphysis, posteromedial and posterolateral angles were the easiest point of measurement. We only used the postoperative reontgenogram of those within 6 weeks to avoid measuring enlarged blurred gap margin by fracture end resorption. Five millimeter pin closest to the fracture site was used as a guide of radiologic enlargement. The diameter of the pin was measured at the level near the cortex. Real gap distance was calculated by following the equation:

$$\text{real gap distance(mm)} = \frac{\text{measured gap distance} \times 5}{\text{measured pin diameter}}$$

Each measurement was performed by Townley femur caliper of 0.02 mm accuracy and was repeated 3 times.

The healing time (HT) was defined as the gap was completely obliterated by healing bone and/or surround by dense periosteal callus without interruption at the fracture site. The time for consolidation for 1 mm gap (TC) was calculated by dividing the HT by individual gap distance.

Wilcoxon test was used to compare the gap distance, HT, and TC in medial cortices with those of lateral ones within the same group. Mann-Whitney-Wilcoxon test was used to compare TC in one group with that of the corresponding cortex in the other group.

RESULTS

Among 538 open fractures, only 22 cases (22 patients) fullfilled the above mentioned conditions. 16 patients were treated in rigid mode (group A), and 6 patients by biocompression (group B). Age, body weight, cutaneous injury, amount of initial displacement, associated injury and pin loosening were described in table 1. We couldn't find any difference between the two groups except in pin loosening. There was no statistical significance in the multifactor analysis between the two groups. All except one in group A kept their system until consolidation. One case in group A was treated by secondary intramedullary nailing after the removal of EF due to nonunion of the fracture. Characteristic healing pattern in group A was gap healing without or with minimal periosteal callus (Fig. 1). There was no difference in the gap distance in medial and lateral cortices. HT, however, was significantly longer in the medial cortices than the lateral ones ($p<0.036$). The means and stan-

Table 1.

	Group A (16 cases)	Group B (6 cases)
Age(year, range)	27, 9(16-63)	24, 8(17-33)
Body weight(kg, range)	62, 4(50-80)	69, 4(50-75)
Initial displacement		
0~39%	4	1
40~69%	5	3
70~99%	2	1
>100%	5	1
Cutaneous injury		
type 1	5	2
type 2	7	3
type 3	4	1
Associated injury		
head-spine	7	2
LE*	4	1
UE**	2	1
LE+UE	1	0
Pin loosening(%)	31/130(23.7)	21/50(42)

*lower extremity
**uper extremity

Table 2.

		Gap (mm)	HT[1] (month)	TC[2] (month/mm)
Group A	medial	0.8±0.60*	8.4±3.20	13.3±7.00
	lateral	1.1±0.72	7.1±1.92	8.5±4.92
Group B	medial	1.0±0.49	6.8±3.27	5.9±3.00
	lateral	1.4±0.81	5.2±1.49	6.0±2.61

[1]. HT: healing time
[2]. TC: time for consolidation per 1 mm gap
*: Mean±standard deviation

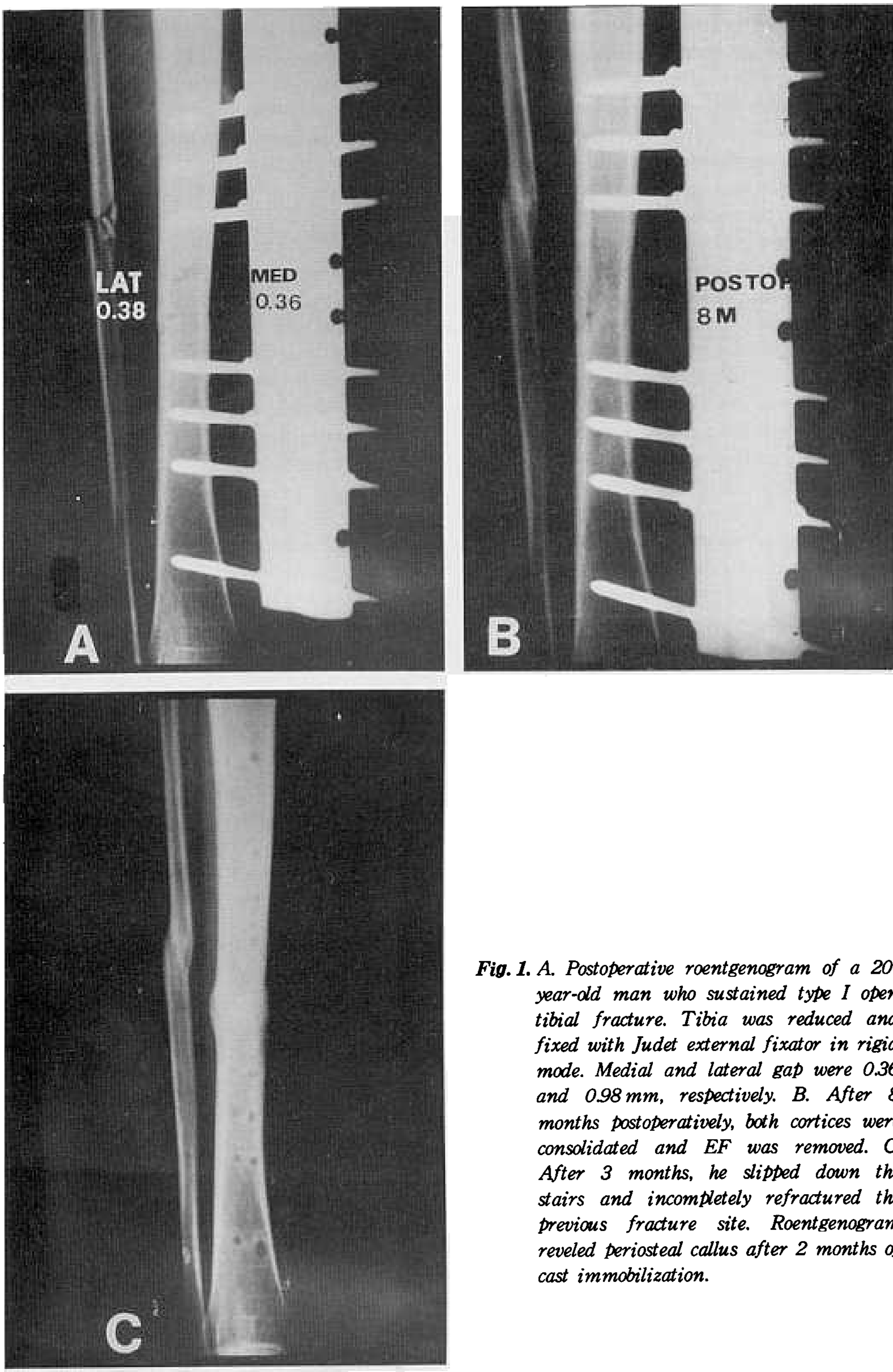

Fig. 1. *A. Postoperative roentgenogram of a 20-year-old man who sustained type I open tibial fracture. Tibia was reduced and fixed with Judet external fixator in rigid mode. Medial and lateral gap were 0.36 and 0.98 mm, respectively. B. After 8 months postoperatively, both cortices were consolidated and EF was removed. C. After 3 months, he slipped down the stairs and incompletely refractured the previous fracture site. Roentgenogram reveled periosteal callus after 2 months of cast immobilization.*

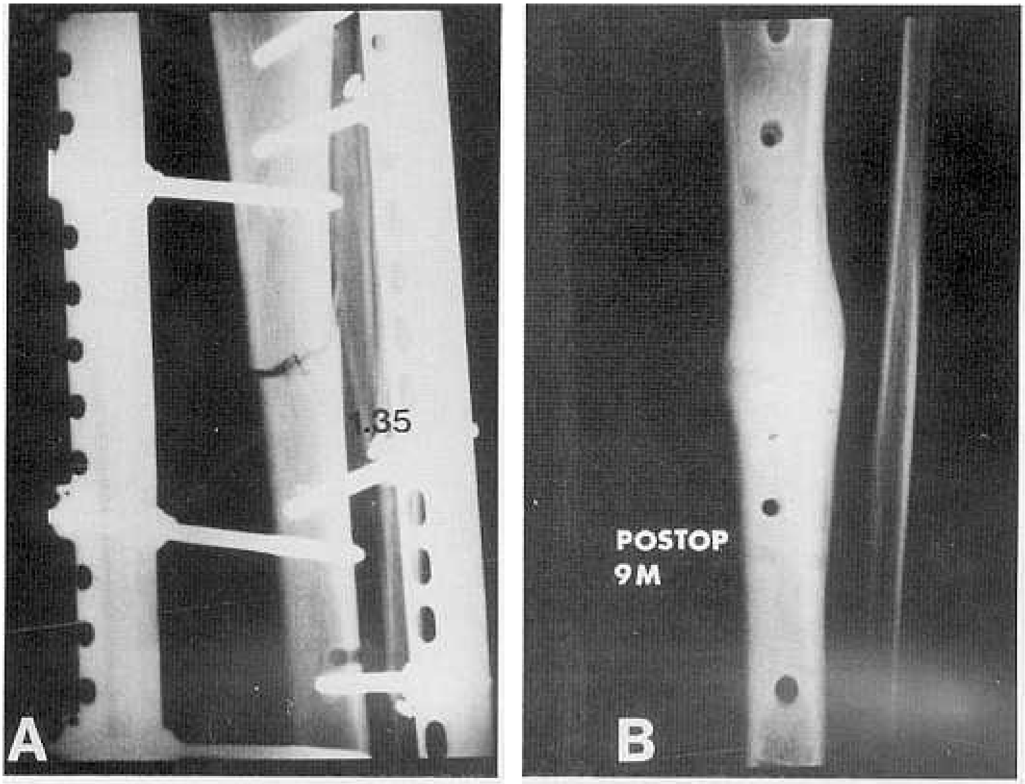

Fig. 2. A. Postoperative roentgenogram of a 27-year-old man who sustained a type 2 open transverse tibial fracture. Tibia was reduced and fixed with a Judet external fixator in biocompressive mode. The gap in medial cortex was 1.35 mm. B. After 9 months postoperatively, the fracture was healed with matured periosteal callus.

dard deviation of TC for medial and lateral cortices in group A were 13.3±7.00 month / mm and 8.5±4.92 month/mm, respectively ($p < 0.024$, Table 2). Healing pattern of group B was associated with gross periosteal callus except one medial cortex of type III open fracture (Fig. 2). There was neither difference in the gap distance nor in HT between the two cortices. The means and standard deviation of TC in medial and lateral cortices in group B were 5.9±3.00 month/mm and 6.0±2.61 month/ mm, respectively ($p > 0.90$, Table 2). TC in medial cortices of group A was significantly longer than that of group B ($p < 0.020$), excluding the lateral ones ($p > 0.249$).

DISCUSSION

Unchanging principles in the treament of open tibial fracture are early intervention consistent with irrigation, débridement, reduction, and fixation. These are necessary to obtain early anatomical and functional restoration of the injured limb. During the last few decades, improvement on the stability of EF and introduction of the prophylactic antibiotics have lessened the incidence of sepsis and pseudoarthrosis. Therefore, EF established an invaluable place in the fixation of open tibial fractures.

However the problems in pin bone junction and frequent delayed union have been pointed out as major drawbacks in this system and they are yet to be completely solved (Gustilo and Anderson 1976; Burny *et al.* 1979; De Bastiani *et al.* 1984; Chao *et al.* 1989; Vidal *et al.* 1990; Pennig 1991).

Mc kibbin (1978) classified the healing process into 4 types: primary callus response, external bridging callus, late medullary callus, and primary cortical healing. External bridging callus rapidly produces the external mantle to stabilize the fracture fragments. Therefore the amount of external callus formed is related to the amount of fracture site movement. The development of more rigid internal and external fixations has diminished or even abolished this response. On the other hand, late medullary callus is relatively not affected by mechanical stability. It slowly and restlessly fills up the gap. However, exact mechanical conditions required for various stages of healing have yet to be defined. Recently increasing evidences are gathered that certain amount of motion in the longitudinal axis promotes the physiologic periosteal callus response. Dynamic compression has been advocated as it seems to diminish the distance of fracture gap and time of consolidation by early formation of stable periosteal callus. (Mc Kibbin 1978; De Bastiani *et al.* 1984; Chao and Aro 1989; Kenwright and Goodship 1989).

Chao *et al.* (1990) classified the dynamization into passive, active, and controlled, and pointed out the advantage of the active and controlled dynamization over the passive. The beneficial effect of the dynamization seems to depend on the early restoration of cortical blood flow in the devascularized fragments. This may be one of the reason that the types of EF is not very important in the severe type III open fractures (Court-Brown *et al.* 1990; Wallace *et al.* 1991). However, the exact mechanism of the dynamization in the bone healing is not yet fully understood. Kenwright and Goodship (1989), and Kenwright *et al.* (1991), performed a randomized prospective study of controlled dynamization in open tibial fractures. They confirmed the beneficial effect of axial micromotion on fracture healing. Biocompressive mode of fixation used in this study allows some longitudinal motion at the fracture site and at the same time it may diminish the gap by compression force during the healing process as described by De Bastiani *et al.* in their concept of dynamization.

As shown in our results, rigid type fixation revealed significant differences in HT and in TC between the two cortices. The medial side has less soft tissue covering than the lateral, and that is the usual place of laceration in open tibial fractures. Accordingly the gap in medial cortex in rigid fixation seems to be more deteriorative for the fracture healing. In the biocompression group, HT and TC in both cortices were stastistically insignifiant. They all healed with periosteal callus except one medial cortex in type III open fracture. However low stiffness in this mode of externel fixation resulted in the increased rate of pin loosening as mentionned by Chao (1989). In comparison of TC in two groups, medial side revealed beneficial effect of axial motion and periosteal callus.

Our study was based on the accurate measurement of the gaps and evaluation of cortical healing. Practically measuring the fracture gaps in the roentgengrams are very deceptive due to different roentgenographic techniques (radiation dose, distance, position of the patient, and center of the ray) and fracture patterns. To minimized the errors in measurement, we had to select the predominantly transverse fracture with clearly visible gaps in both sides. We also excluded the cases of gross comminution and bone defect to evaluate the pure effect of fixation mechanism. This is one of the reasons that we could only select 22 cases available in 538 cases over 20 years. Five millimeter pin worked as an excellent guide of radiological enlargement.

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