

Anatomical and clinical study of a new mallet fracture classification method

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Abstract

Background: Mallet fracture is avulsion of the terminal extensor tendon from the base of the distal phalangeal bone with a bony fragment. This study was performed to evaluate the anatomical characteristics of mallet fractures, investigate a new mallet fracture classification system using anatomical and imaging methods, and discuss the treatment schemes for different types of mallet fracture.

Methods: Sixty-four fresh cadaveric fingers were divided into four groups, and models of different types of mallet fracture with distal interphalangeal joint instability were established by dissecting 25%, 50%, 75%, and 100% of the bilateral collateral ligaments. The effect of mallet fractures on the stability of the distal interphalangeal joint was then observed. The lateral radiographs of mallet fractures in 168 patients were analyzed and classified according to the involvement of the joint surface in the fracture, the thickness of fracture, the untreated time after injury, and the complication of distal interphalangeal joint palmar subluxation. Forty-seven patients were surgically treated by reconstruction of extensor tendon insertion, the Ishiguro method, or single Kirschner wire fixation.

Results: The established mallet fracture model showed that the distal interphalangeal joint was stable when the bilateral collateral ligaments were cut off by 25% ($t = -0.415$, $P = 0.684$) and significantly unstable when this range was $\geq 50\%$ (50% transection: $t = -6.363$, $P < 0.001$; 75% transection: $t = -17.036$, $P < 0.001$; 100% transection: $t = -30.977$, $P < 0.001$, respectively). The mallet fractures were divided into Types I, II, and III (fracture involving $< 20\%$, $20\% - 50\%$, and $> 50\%$ of the joint surface, respectively). Type II was further divided into Types IIa and IIb according to whether the course of injury was $<$ or ≥ 2 weeks, respectively. The mean post-operative flexion of the distal interphalangeal joint was $63.4^\circ \pm 7.9^\circ$, and the mean extension lag was $6.7^\circ \pm 4.6^\circ$.

Conclusions: The lateral collateral ligament is the main factor that maintains the stability of the distal interphalangeal joint. Classification that combines the involvement of the joint surface in the fracture, the thickness of the fracture, and the untreated time after injury is reasonable and will help to choose an appropriate operational method.

Keywords: Classification; Distal interphalangeal joint; Mallet fracture; Subluxation

Introduction

Mallet fracture is a common hand lesion that is usually caused by rapid flexion to a straight fingertip. After injury, the patient may develop swelling in the basal part of the distal phalanx of the finger, dorsal tenderness, and limited extension of the distal interphalangeal joint. A lateral radiograph of the finger shows a dorsal fracture of the basal part of the distal phalanx, and the fracture involves the joint surface. Because the fracture is pulled by the terminal extensor tendon, the fracture can be dislocated to varying degrees, and some patients also have palmar subluxation of the distal interphalangeal joint.^[1-4] Conservative treatment has achieved satisfactory effects in patients with no fracture displacement. For patients with obvious fracture displacement, especially subluxation of

the distal interphalangeal joint, surgical intervention is often needed to obtain anatomic reduction and strong internal fixation of the joint surface and to avoid the long-term occurrence of mallet fracture deformity, swan-neck deformity, and osteoarthritis of the distal interphalangeal joint, all of which affect the appearance and function of the finger.^[1-3] Conventional surgical methods include closed reduction with dorsal blocking Kirschner wire fixation (Ishiguro method); open reduction with Kirschner wire fixation; wire suture, or bone anchor fixation; and open reduction with hook plate fixation. Each of these surgical methods has its advantages, disadvantages, and specific indications.^[5-10]

Multiple clinical classification systems are used for mallet fractures, including the Wehbe-Schneider classification (1984), Tubiana classification (1986), and Doyle

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classification (1993).^[11-13] The basis of these classifications includes open or closed injury, tendinous or osseous injury, involvement of the epiphysis, the extent of fracture involving the joint surface, and palmar subluxation of the distal interphalangeal joint. These classification systems have played an important role in the choice of treatment.^[11-13] However, with the application of new surgical methods and the progress of research on the stability of interphalangeal joints during the past two decades, the above classification methods have some limitations in guiding clinicians to choose reasonable operational methods. Therefore, the present study was performed to establish a new mallet fracture classification method based on anatomy, imaging findings, clinical data, the range of the joint surface involved with the fracture, the thickness of the fracture, and the untreated time after injury. Choosing a surgical technique according to this classification method has obtained good clinical effects.

Methods

Ethical approval

This study was approved by the Institutional Review Board of the Ethics Committee of Beijing Jishuitan Hospital (No. 201911-13). The study was performed in accordance with the *Declaration of Helsinki*. All the cadaver specimens were provided by Peking University School of Basic Medical Sciences. Informed consent was obtained from all the patients included in this study.

Anatomy

Measurement of collateral ligament

Index fingers, middle fingers, ring fingers, and little fingers were collected from 2 fresh cadavers from voluntary donation to the Peking University School of Basic Medical Sciences, and the width and length of the collateral ligament insertion on the base of distal phalanx of each of these 16 fingers were measured with a Vernier caliper [Figure 1].

Establishment of the models of mallet fractures

The models of mallet fractures were created to study the effect of these fractures on the stability of the distal interphalangeal joint. In total, 64 fingers from fresh cadavers were equally divided into four groups (A, B, C, and D). In each group, eight fingers were for experiment and eight fingers were for control. From the dorsal to palmar side, the bilateral collateral ligaments of the distal interphalangeal joint were cut off by 25% in Group A, by 50% in Group B, by 75% in Group C, and by 100% in Group D. The collateral ligaments of the controls were kept intact in all four groups. During the examination, the middle phalangeal bone was fixed and a 5-kg dorsal or palmar load was applied to the distal phalanx; the range of displacement of the distal phalanx to the dorsal and palmar sides was then measured in each group. Each sample was measured three times, and the average value was recorded [Figure 2].

Classification of mallet fractures

From November 2012 to May 2018, the mallet fractures of 168 patients were classified into three types according to the extent of fracture involvement in the surface of the dorsal base of the distal phalanx, the thickness of the fracture (ie, thickness of the middle part of the fracture fragments in the sagittal plane), and whether the untreated time after injury was more than 2 weeks [Figure 3]. In Type I mallet fractures, the fracture involved <20% of the joint surface, the thickness of the fracture was ≤ 3 mm, and there was no dislocation of the distal interphalangeal joint. In Type II mallet fractures, the fracture involved 20% to 50% of the joint surface, and the fracture thickness was ≤ 3 mm. Type II was further divided into two sub-types: in Type IIa fractures, the untreated time after injury was ≤ 2 weeks; and in Type IIb fractures, the untreated time after injury was ≥ 2 weeks and the fracture was usually complicated by palmar subluxation of the distal interphalangeal joint. In Type III mallet fractures, the fracture involved >50% of the joint surface, and the thickness of the fracture was > 3 mm; most of these fractures were also accompanied by dislocation of the distal interphalangeal joint [Figure 4 and Table 1].

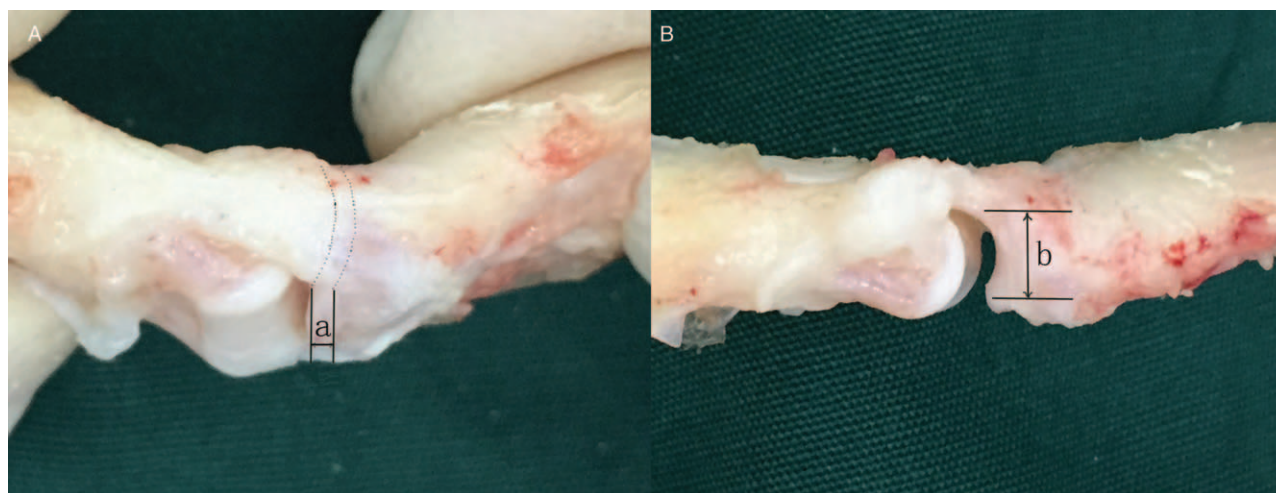


Figure 1: The width and length of the lateral collateral ligament of the distal interphalangeal joint at the insertion of the distal phalanx base. (A) “a” is the width of the lateral collateral ligament insertion. (B) “b” is the length of the lateral collateral ligament insertion.

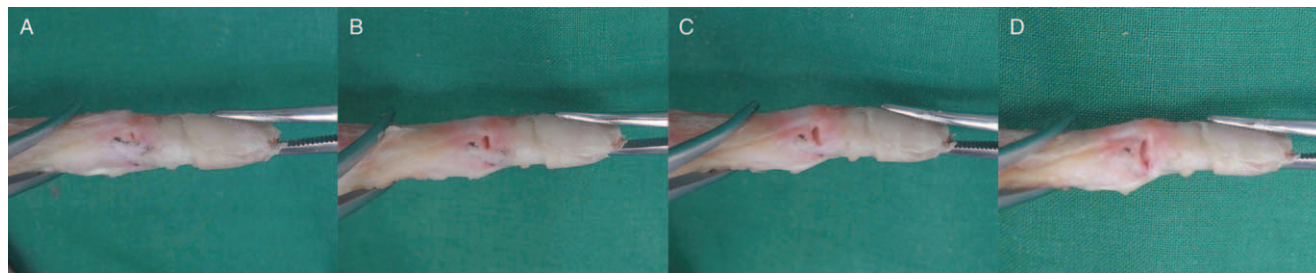


Figure 2: The model of mallet fracture was made to test the effect of fracture on the stability of distal interphalangeal joint. In the experimental group, the bilateral collateral ligaments of distal interphalangeal joint were cut from dorsal side to the palm, 25% in Group (A), 50% in Group (B), 75% in Group (C) and 100% in Group (D).

Surgical plan

Patients who underwent conservative treatment, patients without a surgery preference, and patients with traumatic osteoarthritis were excluded from the study. In total, 47 patients with mallet fractures were treated surgically. The patients included 32 males and 15 females with a mean age of 31.7 ± 8.4 years (range: 18.0–49.0 years). Different surgical treatment methods were selected according to the new classification system. The preferred procedures were as follows. Type I fractures were treated with reconstruction of extensor tendon insertion, Type II fractures were preferentially treated with closed reduction and Ishiguro fixation, and Type III fractures were treated with open reduction and single Kirschner wire fixation [Figure 5 and Table 1].

Reconstruction of extensor tendon insertion

A U-shaped or S-shaped incision was made on the dorsal side of the distal interphalangeal joint to expose the terminal extensor tendon and the dorsal base fracture of the distal phalanx. After release of the terminal extensor tendon, the fracture was reduced. If the fracture fragment was small or satisfactorily reduced, the fracture fragment was retained;

otherwise, the fracture fragment was excised. The terminal extensor tendon and fracture fragment were fixed on the dorsal side of the distal phalanx by inserting a 1.6-mm MICROFIX Absorbable Anchor (Johnson & Johnson, New Brunswick, NJ, USA) or by steel wire fixation. A 1.0-mm Kirschner wire was used to fix the distal interphalangeal joint in a slightly overextended position.

Ishiguro method

The distal interphalangeal joint was flexed and the fracture fragment was pulled distally. A 1.0-mm block Kirschner wire was placed at the proximal end of the fracture fragment, from the distal dorsal side to the proximal palm side; the entry point was located on the dorsal distal side of the middle phalanx, and the angle between the block Kirschner wire and the phalanx was 45° . After the block Kirschner wire was placed, the distal interphalangeal joint was extended and the fracture was pushed and reduced by the block Kirschner wire and distal phalanx. After satisfactory reduction of fracture, another 1.0 mm Kirschner wire was used to fix the distal interphalangeal joint in the extension position.

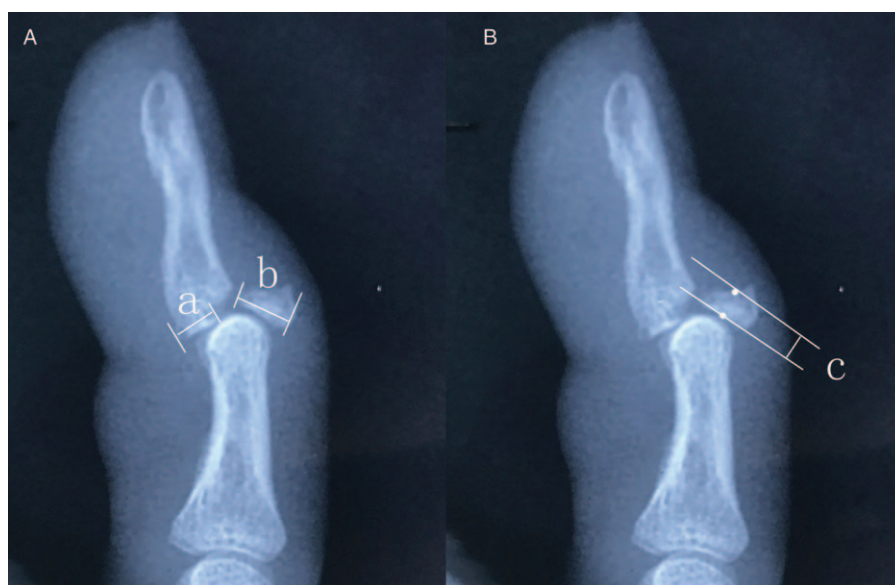


Figure 3: Measurement of the fracture fragment in the mallet fracture. (A) In lateral X-ray film, the range of fracture fragments involving distal phalanx basal articular surface was $a/(a + b)$. (B) The thickness of middle part of fracture fragment was “c.”



Figure 4: Classification of mallet fracture. (A) Lateral view of Type I. (B) Lateral view of Type IIa. (C) Lateral view of Type IIb. (D) Lateral view of Type III.

Table 1: New classification, characteristics, and recommended surgical methods for mallet fracture.

Types	Fracture fragments			Thickness of fracture fragments		Palmar subluxation of distal interphalangeal joint	Untreated time ≥ 2 weeks	Recommended surgical methods
	<20%	20–50%	>50%	≤ 3 mm	>3 mm			
Type I	✓			✓				Reconstruction of extensor tendon insertion
Type IIa		✓		✓				Ishiguro procedure
Type IIb		✓		✓		✓	✓	Ishiguro procedure
Type III			✓		✓	✓		Open reduction and single Kirschner wire fixation

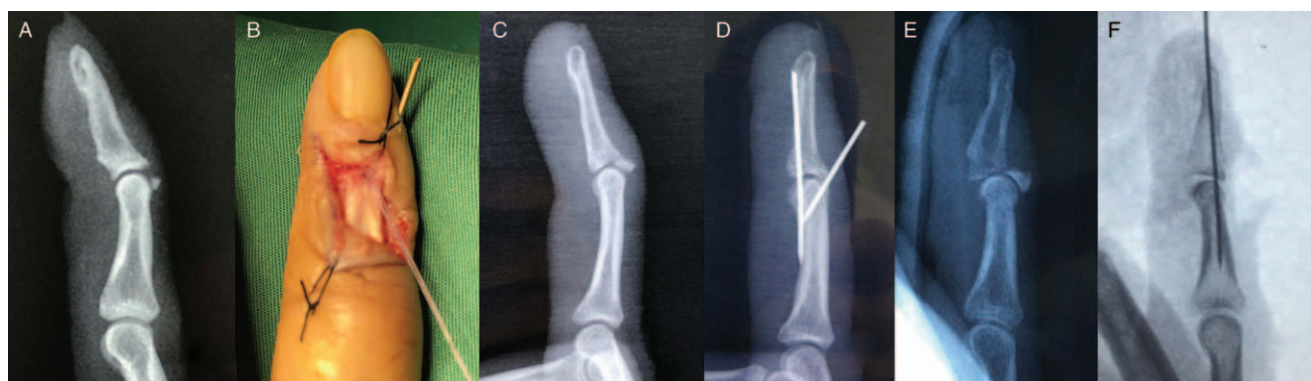


Figure 5: According to the new classification, different surgical methods were selected. (A) Pre-operative lateral view of Type I. (B) Reconstruction of extensor tendon insertion in Type I. (C) Pre-operative lateral view of Type II. (D) Treatment with close reduction and extension block with Kirschner wire (Ishiguro) in Type II. (E) Pre-operative lateral view of Type III. (F) Open reduction and single Kirschner wire fixation in Type III.

Single Kirschner wire fixation

A U-shaped or S-shaped incision was made on the dorsal side of the distal interphalangeal joint to expose the terminal extensor tendon and the dorsal base fracture of the distal phalanx. A 1.0-mm Kirschner wire was placed longitudinally at the fracture of the distal phalanx from proximal to distal, and the Kirschner wire was drawn from the fingertip until the tip of the Kirschner wire was left at the fracture site.

After reduction of the fracture and dislocation of distal interphalangeal joint, the Kirschner wire was drilled back to fix the fracture and distal interphalangeal joint.

After the operation, the finger was fixed with plaster or a brace for 6 weeks before the Kirschner wire was removed, and from then on, extension-flexion exercises were conducted. Normal use of the finger began 3 months after the operation.

Table 2: The effect of different degrees of lateral collateral ligament transection on the stability of distal interphalangeal joint (mm).

Groups	n	25% Transection	50% Transection	75% Transection	100% Transection
Control group	8	1.04 ± 0.14	1.08 ± 0.23	1.11 ± 0.22	1.07 ± 0.22
Experimental group	8	1.05 ± 0.20	2.03 ± 0.49	3.03 ± 0.42	6.01 ± 0.59
t		-0.415	-6.363	-17.036	-30.977
P		0.684	< 0.001	< 0.001	< 0.001

Follow-up and evaluation of curative effect

The patients were followed up at 2, 4, 6, 8 weeks, and 3, 6, 9, 12 months after the operation and every 6 months thereafter. The patients were not restricted from additional visits if any discomfort occurred. Follow-up was conducted by re-examination of the patients in the hospital, including a clinical physical examination and imaging examination. The clinical examination indexes were the pain visual analog scale score and the degrees of active flexion and extension of the distal interphalangeal joint of the finger. The imaging examination indexes were the fracture healing and malunion on posterior anterior and lateral radiographs of the finger.

Statistical analysis

SPSS 17.0 statistical software (SPSS, Inc., Chicago, IL, USA) was used for the statistical analysis. The collected data exhibited a normal distribution and were presented as mean ± standard deviation (SD). A paired *t*-test was used to compare the data between the two groups, and a bilateral α value of 0.05 was used for evaluation of statistical significance.

Results

Anatomy

The mean width and length of the collateral ligament insertion on the base of distal phalanx were 2.64 ± 0.07 and 3.76 ± 0.11 mm, respectively.

In the experimental groups, 25% (Group A), 50% (Group B), 75% (Group C), and 100% (Group D) of the bilateral collateral ligaments of the distal interphalangeal joint were cut off from the dorsal to palmar side. After application of loading forces, the mean range of palmar and dorsal movement of the distal phalanx in Groups A to D was 1.05 ± 0.20 , 2.03 ± 0.49 , 3.03 ± 0.42 , and 6.01 ± 0.59 mm, respectively. There was no significant difference in the range of distal phalanx movement in Group A between the fingers for experiment and those for control ($t = -0.415$, $P = 0.684$); however, significant differences were found in Group B ($t = -6.363$, $P < 0.001$), Group C ($t = -17.036$, $P < 0.001$), and Group D ($t = -30.977$, $P < 0.001$) [Table 2].

Mallet fracture classification

The closed mallet fractures of all 168 patients were classified into three types according to the involvement of the joint surface in the fracture, the thickness of the fracture, and the untreated time after injury. The 168 fractures included 41 (24.4%) Type I fractures, 72 (42.9%) Type IIa fractures, 33 (19.6%) Type IIb fractures,

and 22 (13.1%) Type III fractures. The incidence of palmar subluxation of the distal interphalangeal joint was 0 of 41 Type I fractures, 7 of 72 (9.7%) Type IIa fractures, 18 of 33 (54.5%) Type IIb fractures, and 20 of 22 (90.9%) Type III fractures.

Surgical treatment

All 47 patients who underwent surgical treatment of their mallet fractures were followed up for 13 to 22 months (mean ± SD: 15 ± 2 months), and all fractures healed completely after 5 to 10 weeks (mean ± SD: 7 ± 1 weeks). The Kirschner wire was removed in all except three patients at 6 to 7 weeks after the operation. The healing of the fracture was judged according to the posterior anterior and lateral radiograph of the finger and the results of a clinical physical examination. The standard of fracture healing was blurring or disappearance of the fracture line and no obvious tenderness at the site of fracture. No patients developed non-union or malunion of the fracture or palmar subluxation of the distal interphalangeal joint. At the last follow-up, the visual analog scale score ranged from 0 to 3.0 (mean ± SD: 1.3 ± 1.0). The flexion of the distal interphalangeal joint was $63.4^\circ \pm 7.9^\circ$, and the extension lag was $6.7^\circ \pm 4.6^\circ$. Two cases were mild nail deformity, and superficial pin-track infection occurred in two cases, who were cured by intensive wound dressing change and oral antibiotics.

Discussion

Analysis of anatomy and biomechanical results

The lateral collateral ligament is important for stabilizing the distal interphalangeal joint. Previous studies have confirmed that the involvement of the fracture in the surface of the distal phalanx base is closely associated with palmar subluxation of the distal interphalangeal joint.^[14-16] Kim *et al*^[14] found that when the fracture involved 48% of the joint surface, subluxation of the distal interphalangeal joint occurred. Husain *et al*^[15] performed a biomechanical study and confirmed that subluxation of the distal interphalangeal joint occurred when the fracture involved half of the joint surface. By studying a large number of clinical data, Moradi *et al*^[16] confirmed that distal interphalangeal joint dislocation occurred when the fracture involved more than 39% of the joint surface and that the risk of palmar subluxation of the distal interphalangeal joint increased by 4% with each 1% increase in fracture involvement. In the present study, we measured the width and length of the collateral ligament insertion on the base of distal phalanx. We found that the width of the terminal part was ≤ 3 mm (mean, 2.6 mm);

therefore, a fracture thickness of >3 mm might affect the stability of the joint. In addition, the lateral collateral ligament ranges from the dorsal to the palmar side at the base of distal phalanx, and the mallet fracture must therefore involve the lateral collateral ligament of the distal interphalangeal joint. We established the model of mallet fracture on this basis. The results showed that the distal interphalangeal joint was stable when the range of rupture of the lateral collateral ligament was $\leq 25\%$, while rupture of $\geq 50\%$ significantly affected the stability of the distal interphalangeal joint.

Classification of mallet fracture

Actually, magnetic resonance imaging is a more direct imaging method to examine the injury of the collateral ligament. However, it is difficult to judge the extent of the injury on magnetic resonance imaging because of the structure of the collateral ligament on the distal interphalangeal joint is quite small. Through anatomic study, we have defined the range of the collateral ligament insertion at the base of the distal phalanx, so it may be more accurate and reasonable to estimate the range of the damaged collateral ligament indirectly by the fracture size involving the articular surface and the thickness of the fracture on the X-ray film. By combining the imaging features of mallet fractures, previous anatomical findings, and previous studies on fracture classification, we consider the following factors as the basis for the new mallet fracture classification: the involvement of the joint surface in the fracture fragment, the thickness of the fracture fragment, and the untreated time after injury. The above classification factors also basically determine the stability of the distal interphalangeal joint and the volume of the fracture, which are also major factors in choosing the most appropriate surgical method. The fractures were classified into three types mainly according to the involvement of the mallet fracture in the joint surface: Type I fractures were characterized by $<20\%$ involvement, Type II by 20% to 50% involvement, and Type III by $>50\%$ involvement. In addition to the extent of the joint surface involved, the untreated time after injury and the thickness of the fracture fragment were the other two factors related to the occurrence of subluxation of the distal interphalangeal joint. Among Type II fractures, the proportion of palmar subluxation of the distal interphalangeal joint was 54.5% when the untreated time after injury was ≥ 2 weeks, while the incidence was only 9.7% when the untreated time after injury was <2 weeks. Therefore, according to the untreated time after injury, we further divided Type II fractures into two sub-types: Type IIa and Type IIb. Finally, the thickness of the fracture is also an important factor leading to palmar subluxation of the distal interphalangeal joint. The thickness of the fracture fragments of Type III in this study was >3 mm, and the proportion of palmar subluxation of distal interphalangeal joint in this type was as high as 90.9% .

Selection of surgical procedures

Palmar subluxation of the distal interphalangeal joint and the volume of the fracture fragment are closely related to the choice of surgical method.^[16,17] The classification

method established in this study can basically determine the stability of the distal interphalangeal joint and the volume of the fracture fragment. Type I fracture fragments are small, and direct fixation or block Kirschner wire fixation are difficult and will increase the risk of fracture fragment broken; therefore, reconstruction of extensor tendon insertion is more suitable. A steel wire or 1.6-mm absorbable anchor can be used in reconstruction of extensor tendon insertion. In patients with unsatisfactory reduction of the fracture, the fracture fragment can be resected before conducting reconstruction of extensor tendon insertion. Type IIa fractures are relatively large and the injury time is <2 weeks; therefore, most of these fractures can be treated with the Ishiguro method. In Type IIb fractures, the untreated time after injury is relatively long, so the closed-reduction Ishiguro fixation can be used firstly, and open reduction is suggested if the result of closed reduction is not satisfactory. In the case of a small fracture fragment, a steel wire can be used to fix the fracture, and a Kirschner wire can be used to fix the distal interphalangeal joint; for larger fracture blocks, a single Kirschner wire can be used to fix the fracture and distal interphalangeal joint. Type III fracture has large fracture fragments, and it is difficult to ensure a smooth joint surface in closed reduction; therefore, open reduction is preferred, and a single Kirschner wire can be used to fix the fracture and the distal interphalangeal joint simultaneously. The most appropriate surgical procedure was chosen according to the new classification method, and the functional recovery was satisfactory. In this study, the flexion of the distal interphalangeal joint was 63.4° , the extension lag was 6.7° , and the active range of motion was 56.7° .

In summary, the lateral collateral ligament is the main factor involved in maintaining the stability of the distal interphalangeal joint, and a mallet fracture involves the lateral collateral ligament to varying degrees. It is reasonable for a mallet fracture classification method to combine the involvement of the joint surface in the fracture, the thickness of the fracture, and the untreated time after injury. Choosing a surgical plan according to this classification can help to achieve satisfactory clinical results.

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Conflicts of interest

None.

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