Dynamic Compression Plating with Strategic Screw Fixation in Diaphyseal Transverse Fractures of the Radius: the Biomechanical Effect of Numbers of Screws

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ABSTRACT

Introduction. Diaphyseal fracture of radius could compromise function unless adequately treated. Open reduction and internal fixation with six cortices of screw fixation on either side of the fracture is generally accepted as the best method of treatment. Unfortunately, a very high rate of refracture after plate removal has been observed for as high as up to 22%. Although a number of factors are thought to be the cause of such a high rate, such as the type of plate used, time from plating to plate removal, quality of reduction and compression achieved, type and duration of immobilization after plate removal, nevertheless, the stress riser from the screw holes is also considered as one of the important factor. In accordance with the stress riser from screw holes, number of screws introduced into bone played a very important role. The objective of this study is to biomechanically compare the load to failure between constructs for the treatment of diaphyseal transverse fractures of the radius in skeletally mature bone.

Materials and methods. Sixteen skeletally mature human radii were retrieved, devoid of soft tissue including periosteum. Transverse osteotomy was done in each radius in its midpoint. In the control group, the radius was fixed with 6-holes 6-screws construct. In the test group, the radius was fixed with 6-holes 4-screws construct. All radii were fixed with 3.5mm mini Dynamic Compression Plates. They were then randomly divided into two groups, with each group consisted of four controls and four test specimens. Group I was tested in three-point bending force and group II was tested in axial compression force.

Results. In the three-point bending test, the controls showed slightly higher load to failure but this value was not significant ($p = 0.57$). Meanwhile in the axial compression test, the test group showed higher load to failure with a p-value of 0.05 which was marginally significant.

Conclusions. The 6-holes 6-screws construct showed higher load to failure when compared to the 6-holes 4-screws construct in terms of 3-point bending force although the value was not significant. In contrast, the 6-holes 4-screws construct showed a higher load to failure in terms of axial compression force and the value was deemed marginally significant. Furthermore, failure starting point in this experimental study was observed in the screw holes.

Keywords: load to failure, three-point bending force, axial compression force

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Dynamic Compression Plating dengan Fiksasi Sekrup Strategis pada Fraktur Transversal Diafisis Radius: Efek Biomekanik Jumlah Sekrup

ABSTRAK

Pendahuluan. Fraktur diafisis radius dapat mempengaruhi fungsi jika tidak ditangani dengan benar. Reduksi terbuka dan fiksasi interna dengan pelat dan sekrup pada 6 korteks merupakan penanganan yang terbaik untuk fraktur diafisis radius. Akan tetapi, setelah pencabutan pelat, angka refraktur mencapai 22%. Walaupun banyk faktor yang berperan dalam tingginya angka refraktur, stress dari lubang bekas sekrup merupakan salah satu faktor yang sangat penting. Tujuan dari penelitian ini adalah untuk membandingkan load to failure berbagai konstruksi secara biomekanis pada terapi fraktur diafisis transversal pada tulang radius matur.

Bahan dan cara kerja. Enam belas tulang radius manusia matur dilepas dari jaringan lunaknya termasuk periosteum. Dilakukan osteotomi transversal pada tiap radius tepat di tengah. Pada kelompok kontrol, radius difiksasi menggunakan konstruksi 6-lubang 6-sekrup. Pada kelompok uji, radius difiksasi menggunakan konstruksi 6-lubang 4-sekrup. Semua radius difiksasi dengan *Dynamic Compression Plate* mini ukuran 3.5mm. Kemudian secara acak dibagi menjadi dua grup, di mana setiap grup terdiri dari empat kontrol dan 4 uji. Grup I dites terhadap gaya *three-point bending* dan grup II dites terhadap gaya *axial compression*.

Hasil. Dalam tes *three-point bending*, kelompok kontrol menunjukkan nilai *load to failure* yang lebih baik walaupun nilainya tidak signifikan. (p = 0,57) Pada tes axial compression, kelompok uji menunjukkan nilai *load to failure* dengan nilai p 0,05yang signifikan secara marginal.

Simpulan. Konstruksi 6-lubang 6-sekrup menunjukkan nilai *load to failure* yang lebih baik ibandingkan konstruksi 6-lubang 4-sekrup dalam *three-point bending* walapun tidak signifikan. Sebaliknya, konstruksi 6-lubang 4-sekrup menunjukkan nilai *load to failure* yang lebih baik dalam hal *axial compression* dan nilainya signifikan secara marginal. Lebih jauh, dalam studi eksperimental ini berhasil diamati bahwa titik awal failure dimulai dari lubang sekrup.

Kata kunci: *load to failure, three-point bending, axial compression*

Introduction

Diaphyseal fractures of the radius in adults remain as one of the most common fractures.[1] These fractures although rarely a life-threatening condition but could compromise function unless adequately treated. These fractures present specific problems in addition to those common to all fractures of the shaft of the long bones. Aside from regaining length, apposition and axial alignment are necessary if good range of pronation and supination are to be restored.[2-4]

Malunion and nonunion occur more frequently because of the difficulty in reduction and maintaining the reduction of the two parallel bones in the presence of the pronating and supinating muscles that have angulatory as well as rotational influences.[2,4] Because of these factors, open reduction and internal fixation is generally accepted as the best method of treatment, with six cortices of screw fixation on either side of the fracture.[5] With the proper surgical technique, this approach offers excellent and superior results.[1-5]

This mode of treatment is still the current treatment of choice with union rate as high as 96-98% coupled with excellent functional results in studies.[1,4] Unfortunately, a very high rate of refracture after plate removal has been observed for as high as up to 22%.[5-7] Although a number of factors are thought to be the cause of such a high rate, such as the type of plate used, time from plating to plate removal, quality of reduction and compression achieved, type and duration of immobilization after plate removal, nevertheless, the stress riser from the screw holes is also considered as one of the important factor.[5]

In accordance with the stress riser from screw holes, the number of screws introduced into the bone therefore play a very important role.[5] In other words, more screw holes mean more stress riser. It is due to this thought that the proponents of this study would like to investigate and compare the strength between 6-holes 6-screws construct with 6-holes 4-screws construct.

The search for better treatment options has been mainly based on optimizing results and minimizing complications. With the recent recommended treatment, problems sometime arise intra-operatively, or after plate removal. This study would have a bearing on cost-effective, reduced operation time, possibly lesser refracture rate after plate removal, and above all, a possible better patient care.

Materials and methods

Sixteen mature human radii were retrieved for use in this experiment. After being thawed and stripped of all remaining soft tissue and periosteum, the bones were kept moist with saline-soaked gauze. Profile of the bone specimens showed an average weight of twenty-nine grams (range from 19 to 50 grams). The bones had a relatively straight diaphyseal segment measuring an average of twenty-two centimeters long (range from 20.3 to 25.3 centimeters) and four centimeters in circumference (range from 3.2 to 4.8 centimeters). The radii were then randomly divided into two groups of eight matched pairs. The first group was used to test 6-holes 6-screws construct, and the second group was used to test 6-holes 4-screws construct. This study made use of 3.5-millimeter mini dynamic compression plates (DCP) on each specimen.

Each radius was measured along its long axis and the midpoint determined. A transverse osteotomy was performed along the mid shaft diaphyseal area. A six-hole 3.5-millimeter stainless steel DCP was applied on the volar surface of each radius. Anatomic reduction was obtained on both groups. For the control group, plate was fixed with six bicortical screws in each side as described in the AO technique of plate and screw fixation. For the test group, plate was fixed with four bicortical screws strategically on the holes near the fracture line and on the holes furthest from the fracture line. In other words, the intermediate screw holes were left vacant (Fig. 1). All measurement, preparation and surgery were done by 1 surgeon to minimize bias.

The bone–implant constructs were then mounted on equal sulfur-cement testing preparation and loaded by an Instron model Universal Testing Machine (Qualitest Solutions and Technologies Incorporated, Davao City, Philippines) in the elastic range to determine their slope of load–displacement curve on oscilloscope. The whole process of mounting of specimens, preparation and machine testing were operated by 1 person to minimize bias. Two modes of load to failure testing were performed: axial compression and three-point bending (center and lateral, with the plate at right angles to the bending plane) forces until the bone-implant construct (BIC) failed. Screw holes were numbered from distal to proximal direction.

Results

The mean bending strength of the 6 holes 6-screws construct was 0.7175 kN (range from 0.54 to 0.89 kN). Mean bending strength of the 6-holes 4-screw construct was lower at 0.605 kN (range from 0.34 to 1.07 kN). Thus the

Figure 1. Six hole six-screws construct (left) and Six-holes four-screws construct (right)

difference of the two constructs was 0.13 kN and this is deemed not significant. ($p = 0.57$)

The 6-screws 4-holes constructs showed no pattern in failure. Two BICs failed at screw numbers 1 and 3 with screw number 1 being the most common. Meanwhile, the remaining two BICs failed at screw numbers 3 and 4. Surprisingly, as further load was applied, the plate failed instead of the bone resulting in a bent BIC.

From the 6-screws 6-holes constructs, two BICs failed at screw numbers 4, 5, and 6 while the other two BICs failed at screw numbers 5 and 6, and in all specimens failure at screw hole number 5 was the most common. These tests also resulted in bent BICs as further load was applied.

A different phenomenon was observed in the axial compression group. The 6-screws 4-holes construct could withstand up to a mean of 4.14 kN (range from 2.97 to 5.34 kN) when subjected to axial compression load before they fail. The 6-holes 6-screws construct withstood a mean of 2.48 kN (range from 1.7 to 3.24 kN) when subjected to the same load before they started to fail. There was a mean difference of 1.68 kN between the two groups, which was marginally significant ($p = 0.05$). An interesting observation was that three measurements from the 6-holes 4-screws constructs were higher than the maximum stiffness of the 6-holes 6-screws constructs.

Failure in 6-holes 4-screws constructs was demonstrated in screw numbers 4 and 6, with screw number 4 being the most common. As load was further applied, the BIC demonstrated failure from the failed screw hole to the osteotomy site resulting in a screw pull-out. Failure in 6-holes 6-screws constructs started at screw holes number 4, 5, and 6 with screw hole number 5 being the most common. As load was further applied, the bone failed in a linear fashion connecting the failed screw holes.

Discussions

The use of plates for the treatment of diaphyseal fractures of the forearm was first reported by Lane in London and Lambotte in Belgium in the early 1900s. After the work of Venables and associates in 1937 on electrolysis of metals for implantation it began to receive world attention. After a period of disfavor due to frequent failures, Eggers in 1948 introduced the "contact-splint" slotted plate with nonunion rate of only 4.2%. The idea of using plate with active compression was suggested by Danis in 1949. In 1963 the AO group first published the technique for using this plate, which was then followed by various reports of excellent results with the use of this technique and implant.[4]

The purpose and goal of fracture fixation is to achieve and maintain accurate reduction of fracture fragments with sufficient stability to provide a suitable environment for bone healing and to allow for immediate mobilization.[4,8] This would include preservation of blood supply to bone fragments and the surrounding soft tissue. In the forearm, it is long and widely accepted that such goals could be accomplished with the use of plates.[9] Bone healing with the use of plates has been described to be primary with little or no callus formation.[2]

To result in primary healing, a certain number of screws have to be applied on each fracture fragment, providing stability, or rigidity.[2,8] Rigidity of a construct is directly related to micromotion at the fracture site, with insufficient rigidity will eventually lead to delayed union or nonunion. To achieve the desired healing, a fixation construct must be able to withstand large forces without loss of fixation.[8] However, there has been little consensus on the length of the plate and the number of screws to be applied to a given fracture. Recommendations on these issues are based mainly on anecdotal reports and clinical experience of mechanical failure.[5,8]

The operative decision must be made on an individual basis, taking into consideration patient and fracture characteristics. Balance between construct choice, soft tissue stripping, vascular insult, and additional stress riser production has to be achieved.[8] A sound judgment with the proper surgical technique would ensure the optimum treatment for a given patient.

Our study attempted to compare the load to failure between 6-holes 6-screws construct with 6-holes 4-screws construct and observed the starting point of failure in each construct. In 3-point bending, the result is comparable, the 6-6 construct with a higher load to failure but this is not significant ($p < 0.05$). All failures started at screw holes but resulted in bent constructs as further load was applied. In 6-holes 6-screws construct failure started at screw holes number 4, 5, and 6 while in the 6-holes 4-screws construct no pattern of failure was able to be observed.

In the axial compression testing, the result favored the 6-holes 4-screws construct with a p-value of 0.05, which is marginally significant. Failures in the 6-holes 4-screws construct started at screw holes numbers 4 and 6 with screw pull-out as the result of further applied load. Failures in the 6-holes 6-screws construct started at screw holes number 4-5-6 and as further load was applied the bone failed in a linear fashion connecting the failed screw holes.

There were potential limitations in our study. Small sample size due to unavailability of bone samples and limited funds to procure implants is one factor to consider. Fortunately our sample size was deemed sufficient for statistical purposes. We chose a simple transverse fracture because it was reproducible, appropriate with plate fixation, and avoided variability which might exist in comminuted or less stable fractures with bone loss. In the real situation, a degree of comminution and bone loss sometimes exist. Other limitation was the unavailability of a torsion testing machine, whereas torsion was considered as one of the most frequently experienced physiologic load.

Conclusions

The 6-holes 6-screws construct showed higher load to failure when compared to the 6-holes 4-screws construct in terms of 3-point bending force although the value was not significant. The 6-holes 4-screws construct showed a higher load to failure in terms of axial compression force and the value was marginally significant. Furthermore, the 6-holes 4-screws construct has theoretical advantages such as shorter operative time, lesser blood loss, lesser soft tissue stripping, cost-effective, and above all, lesser stress riser production which might result in a higher rate of refracture after plate removal.

In the future, we recommend further studies to be done with more sample size and further attention for measurement of distortion as it might be able to propose the stiffness of a specific bone-implant construct. A prospective randomized clinical trial with the use of the construct measuring functional outcome and rate of refracture after plate removal might be interesting.

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