Comparison of interface contact profiles of a new minimum contact locking compression plate and the limited contact dynamic compression plate

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Abstract In this study, we investigated whether or not a new minimum contact locking compression plate (MC-LCP) can provide advantages over the limited contact dynamic compression plate (LC-DCP) in the context of interface contact area and force. Six matched pairs of cadaveric bones were used for each of three bone types of the humerus, radius and ulna. For each bone type, one of two bone plates was fixed to either of two matched cadaveric bones at the middle of the diaphysis. The interface contact area and force of the plate fixed to three types of human cadaveric bones were evaluated using Fuji prescale pressure sensitive film. Data were quantitated using computer-assisted image analysis. Results showed that the average force between the MC-LCP and humerus or radius was about half of that of the LC-DCP. And the average force between the MC-LCP and ulna was one third less than that of the LC-DCP. Meanwhile, the interface contact area between the MC-LCP and humerus or radius was also about half of that of the LC-DCP, and the interface contact area between the MC-LCP and ulna was less than one third of that of the LC-DCP. These results indicate that the MC-LCP has lower interface contact area and lower average force than that of the LC-DCP. Thus, the MC-LCP system may be a good alternate to treat forearm diaphyseal fractures.

Introduction

Cortical porosis under plates is a key factor of weak fracture healing and refracture. Although the pathogenesis of the osteopaenia beneath plates has not been defined, necrosis induced by vascular damage at the periosteal surface under the plate is thought to be one possible mechanism [1–5]. According to this mechanism, more and more designs of bone plates have been made to reduce the contact area between the plate and the bone. As a result the conventional dynamic compression plate (DCP) has been replaced by many lower contact plate systems such as the limited contact dynamic compression plate (LC-DCP), the point contact fixator (PC-Fix), and the locked compression plate (LCP) system [6–9].

Recently, we developed a new minimum contact internal fixation plate system [10] and postulated that our new plate would have less interface contact area and force between the plate and the bone than that of the LC-DCP. Our new stainless steel plate, called the minimum contact locking compression plate (MC-LCP), has protrusions on the plate undersurface, two dynamic compression screw holes and six locking screw holes. The compression screw can be used initially to appose the plate to the bone in order to optimise reduction [11]. The hybrid design of compression screw holes and locking screw holes can maintain adequate purchase.

Materials and methods

The MC-LCP is a mixed design of minimum contact, locking and dynamic compression concepts. Two sides of the MC-LCP undersurface have protrusions beside each

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screw hole. The protrusion has a minimum contact effect between the plate and the bone. There were two dynamic compression screw holes in the centre of the MC-LCP and six locking screw holes in the MC-LCP distally (Fig. 1). The compression screw can be placed in the centre compression screw hole initially, to appose the plate to the bone, in order to obtain better reduction and stabilise the fragments. The locking screws can then be locked into the locking screw holes to improve biomechanical effects. Thus, we postulated that the MC-LCP had lower interface contact area and less force between plate and bone to reduce the periosteal vascular damage. To compare the interface contact area and the force of the stainless steel MC-LCP system with the stainless steel LC-DCP system, we used the prescale pressure sensitive film to measure contact area and interface pressure between plate and bone to evaluate the internal fixation plate design.

The eight-hole, 3.5-mm stainless steel MC-LCP and the eight-hole, 3.5-mm stainless steel LC-DCP were selected for this study. First, mechanical testing of the MC-LCP and the LC-DCP in the fixation of 15 pairs of fresh sheep tibial osteotomy was performed. Load–displacement behaviour of each specimen was recorded, and the slope of the linear region of the curve was defined as the bending, torsion or compression stiffness of the construction.

Next, 18 pairs of fresh human cadaveric specimens including six pairs of humerus, six pairs of ulna and six pairs of radius were donated. The average donor age was 45 years (range, 33–50) and ten of the 18 donors were female. Bones were stored in moist towels at -20°C until used. The plate was applied in the middle diaphysis of the cadaveric bone in a neutral plate configuration. The plates were applied in a surgically appropriate location (humerus–antero–medial; radius–volar; ulna–medial). The level of each screw torque was applied at 1.5 Nm for consistency [12, 13]. The screw torque was fixed and maintained for

Table 1 Bending, torsion and compression stiffness of the minimum contact locking compression plate (MC-LCP) and the limited contact dynamic compression plate (LC-DCP)

Group	Bending stiffness (N/mm)	Torsion stiffness (Nm/degree)	Compression stiffness (N/mm)
MC-LCP	227.41±29.98	0.58±0.067	2205.47±68.56
LC-DCP	202.75±44.49	0.67±0.137	2194.37±285.27

two minutes using a torque controlling device (Torqometer, Japan) at 23°C and a relative humidity of 65%.

The Fuji prescale pressure sensitive film (Fuji film Co. Ltd, Tokyo, Japan) was placed between the bone and the plate. The film can bear a pressure range from 10 to 50 MPa. The film was calibrated by applying and analysing ten known loads within the sensitivity range of the film [13, 14]. The image of each film was digitised using computerised image analysis techniques within two hours. Using a densitometer FDP 305 (Fuji film Co. Ltd, Tokyo, Japan) and a pressure translator FPD-306 (Fuji film Co. Ltd, Tokyo, Japan), we recorded the pressure of the contact area. The interface contact area between the plate and the bone was analysed using AutoCAD2000 (Autodesk Company, USA) and ANSYS 10.0 (ANSYS Inc., Pennsylvania, USA). According to the pressure formula and the digital image, the average force and interface contact area were quantified. The interface contact areas were visible and analysed using the computer.

Results were expressed as mean $\pm$ standard deviation (SD). Statistical analysis was performed using the SPSS13.0 software with the method of analysis of variance. Differences between groups for continuous data were analysed with a two-tailed paired Student's *t* test. A *P* value <0.05 was considered statistically significant.

MC-LCP

LC-DCP

Fig. 1 Interface profiles for the minimum contact locking compression plate (MC-LCP) and the limited contact dynamic compression plate (LC-DCP) plating systems

Table 2 Data reflecting the mechanical characteristics of the bone–plate interface in comparison of the minimum contact locking compression plate (MC-LCP) and the limited contact dynamic compression plate (LC-DCP) systems

Mechanical characteristics	Humerus		Radius		Ulna	
	LC-DCP	MC-LCP	LC-DCP	MC-LCP	LC-DCP	MC-LCP
Average pressure (Mpa)	40.82±0.70	43.67±0.54	39.06±1.31	42.28±1.54	38.75±0.76	41.25±1.44
Average force (N)	1435±120	761±18	1561±209	477±57	2433±75	656±36
Interface contact (%)	3.86±0.36	1.71±0.05	3.15±0.24	1.15±0.16	5.61±0.23	1.58±0.05

Values are expressed as mean $\pm$ standard deviation ($n=6$)

Results

First, the bending, torsion and compression stiffness of the MC-LCP and LC-DCP were obtained. The average bending, torsion or compression stiffness of the MC-LCP construction tended to be higher than the average torsion stiffness of the LC-DCP construction, but the difference was not significant ($P>0.05$; Table 1).

Six repeated stains were obtained for each plate type (MC-LCP or LC-DCP) in each bone specimen. The interface contact parameters of average pressure, average force and percentage contact for either bone plate design applied to either the humerus, radius or ulna were quantified (Table 2). The digitised and computer-assisted images of the interface contact were visualised (Figs. 2, 3, 4). The average force between the MC-LCP and humerus was about half of that of the LC-DCP ($P<0.01$). In the radius, we observed the same result. However, the average force between the MC-LCP and ulna was less than one third of that of the LC-DCP ($P<0.01$). Meanwhile, the contact area between the MC-LCP and humerus or radius was also about half of that of the LC-DCP. The interface contact area between the MC-LCP and ulna was less than one third of that of the LC-DCP. In each type of bone specimen, there was no significant difference in the average pressure between the MC-LCP and the LC-DCP ($P>0.05$).

Across all bone specimens, the MC-LCP appeared more stable in surface topography. Conversely, the LC-DCP appeared more inconsistent in surface topography. The average force of the MC-LCP among three kinds of bone specimens varied significantly as did the interface contact area, but there was no significant difference in average pressure ($P>0.05$). Across all bone specimens, the average pressure of the LC-DCP or the average force of the LC-DCP had the same value as the MC-LCP.

Discussion

Some studies have reported that bone porosis under plates can be observed during the first few months after operation

Fig. 2 Interface contact images for the eight-hole, 3.5-mm minimum contact locking compression plate (MC-LCP) and limited contact dynamic compression plate (LC-DCP) plating systems when applied to the humeral diaphysis. The image represents the threshold and edited image of the film representing points of contact with the bone

Fig. 3 Interface contact images for eight-hole, 3.5-mm minimum contact locking compression plate (MC-LCP) and limited contact dynamic compression plate (LC-DCP) plating systems when applied to the radius diaphysis. The image represents the threshold and edited image of the film representing points of contact with the bone

[2]. Although the porosis is an early and temporary effect, it will cause weakening of the bone. Many studies revealed that the possible mechanism of bone porosis under plates is the damage of cortical perfusion [2, 3]. Thus, if we can reduce vascular damage at the fracture site using lower-contact plates, we can reduce the porosis and improve fracture healing. According to this theory, many lower-contact plates such as the LC-DCP system have been designed [6]. Field et al. measured the bone–plate contact area of the DCP and the LC-DCP fixed to the human humeral or femoral cadaveric bone [13]. But they found no significant difference in interface contact area in the femoral cadaveric bone. Jain et al. measured cortical blood flow of canine tibias fixed with the LC-DCP or DCP [15]. They also found no significant difference in cortical blood flow between the LC-DCP and DCP groups. These studies demonstrated that the LC-DCP has no advantages in reducing cortical bone perfusion and improving fracture healing [16]. Thus, we designed the MC-LCP system to reduce the interface contact area.

In addition to the design of the internal fixation plate, many factors such as the screw torque and the surface topography of the bone can also influence the interface contact area [17]. All technology and data were selected to comply with clinical practice. In this study, Fuji pressure sensitive film was used to quantify the interface contact area, force and pressure. The results show that the MC-LCP

Fig. 4 Interface contact images for eight-hole, 3.5-mm minimum contact locking compression plate (MC-LCP) and limited contact dynamic compression plate (LC-DCP) plating systems when applied to the ulnar diaphysis. The image represents the threshold and edited image of the film representing points of contact with the bone

has significantly lower interface contact area than the LC-DCP. When fixed to different bones, the MC-LCP had no significant changes in the interface contact areas. Conversely, the LC-DCP had significant changes in the contact area, and the LC-DCP fixed to the radius had the lowest interface contact area. We think that these differences are the result of the design of protrusion on both sides of the MC-LCP system (Fig. 1). However, when we used the same level of screw torque on the plate, the plate should bear the same force. Thus, we believe that the higher average pressure of the MC-LCP is also the result of the lower interface contact area.

Field et al. [13, 18] found that the average force of the ten-hole, 3.5-mm LC-DCP and the ten-hole, 3.5-mm contour plus plate systems is surprisingly high, ranging from 3,000 to 5,000 N. In this study, we used the eight-hole, 3.5-mm MC-LCP and the eight-hole, 3.5-mm LC-DCP systems. Our results showed that the average force across the interface of two plate systems ranged from 500 to 2,500 N. The MC-LCP has significantly lower average force than the LC-DCP, and this mechanical characteristic may play a role in reducing osteopaenia and vascular damage. Although the pathogenesis of the bone porosis under the plate remains ill-defined, we designed a significantly lower interface contact area bone plate. If impairment of vascular supply is of concern, the MC-LCP may have a role to play in reducing the vascular damage. In a further clinical application, the MC-LCP system may be a good alternate to treat diaphyseal fractures of the humerus, radius and ulna compared with the LC-DCP system.

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Conflict of interest None of the authors have any conflict of interest.

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