Comparison of a new minimum contact locking plate and the limited contact dynamic compression plate in an osteoporotic fracture model

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Abstract The purpose of this study was to investigate the biomechanical properties of a new minimum contact locking plate (MC-LP) compared with the limited contact dynamic compression plate (LC-DCP). Eighteen pairs of fresh human osteoporotic cadaver radii were equally divided into three groups. Each specimen was tested in each of the following force applications: anteroposterior (AP) four point bending, mediolateral (ML) four point bending, and torsion. A 10-mm gap osteotomy model was used to simulate a comminuted diaphyseal radial fracture. For each pair, one radius received a limited contact dynamic compression plate (LC-DCP) and the contralateral radius was fixed with a minimum contact locking plate (MC-LP). Specimens were tested in nondestructive four point bending and torsion on an electronic universal material testing system. The results indicate that the MC-LP system is significantly more stable than the LC-DCP system when tested in four point bending and torsion in an osteoporotic comminuted radial diaphyseal fracture model.

Résumé Le but de cette étude est d'étudier les propriétés biomécaniques d'une nouvelle minimum plaque de verrouillage de contact (MC-LP) en comparant avec la plaque dynamique de compression de contact limité (LC-DCP). Dix-huit paires de rayons d'ostéoporose humains frais de cadavres sont divisées en trois groupes égaux. Chaque spécimen est respectivement examiné sous les charges suivantes : quatre points courbés antéropostérieurs (AP), quatre points courbés médiolatéraux (ML), et torsion. Un modèle de jeu de fracture de 10mm est construit pour chaque spécimen, afin de simuler un modèle de fracture pulvérisée. Pour chaque paire, l'un des rayons est fixé par la plaque dynamique de compression de contact limité (LC-DCP), l'autre est fixé par une minimum plaque de verrouillage de contact (MC-LP). Une épreuve de quatre points courbés et de torsion non-déstructive des spécimens s'est fait dans un système d'essai de matériaux universels électroniques. Les résultats indiquent que dans le modèle de fracture de rayon pulvérisé d'ostéoporose, le système de MC-LP est plus stable que celui de LC-DCP.

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The devices that are the subject of this manuscript are approved by the State Food and Drug Administration of China.

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Introduction

It is widely accepted that compression plating is used to treat diaphyseal forearm fractures. This method achieves its stability through intimate contact and friction between the plate and bone. But the stability of the screws depends on the contact area between the screw and the bone, and the intimate contact may cause vascular damage, osteopaenia beneath the plate, and osteonecrosis [1, 2]. Thus, in comminuted and osteoporotic fractures, the construction will become unstable because of poor quality bone and poor screw purchase [3].

The recent development of biological fixation focusses on stable fixation without extensive soft tissue stripping [4].

Locking plates allow screws to be threaded into the plate, creating a fixed-angle device, without the need for friction between the plate and bone [5]. Compared with traditional compression plating, locking plates can provide more stability in comminuted or osteoporotic fractures [6]. On the other hand, the minimum contact design of the undersurface of the plate can better preserve the blood supply than the lower contact design [7]. Therefore, we developed a new minimum contact locking plate combining the advantages of point contact and locking plating.

We postulated that the new minimum contact locking plate (MC-LP) would have better biomechanical behaviour than a dynamical compression plate when treating comminuted and osteoporotic radial diaphyseal fractures. To test this hypothesis, we used nondestructive four point bending and torsion methods to determine the stiffness of the construction in a cadaver radial diaphyseal fracture model fixed by the minimum contact locking plate or the limited contact dynamical compression plate (LC-DCP). The purpose of the comparison between the biomechanical behaviour of minimum contact locking plates with limited contact dynamic compression plates was to better understand the biomechanical environment of these construction when used to treat fractures. This is an important step in defining the biomechanical behaviour of these constructions in vivo and ultimately understanding their influence on fracture healing and their optimal clinical applications and indications.

Materials and methods

Twenty pairs of fresh human cadaver radii were completely freed of soft tissues. All radii were stored at -20°C until use. The DEXA (dual energy X-ray absorptiometry; Norland, USA) scanning method was then used to assess bone mineral density (BMD) values of all specimens. The eighteen pairs of specimens with the lowest bone mineral density were selected for osteoporotic models.

The MC-LP system is a mixed design of point contact and locking concepts. Both sides of the MC-LP undersurface have protrusions beside each screw hole. The protrusions have point contact between the plate and the bone. The screw holes of the MC-LP were designed to be locking screw holes so that the screw head can be locked into the plate. Thus, the MC-LP not only has lower interface contact to reduce the periosteal vascular damage, but also can provide the biomechanics of the locking plate (Fig. 1).

One radius from each pair was randomly assigned to undergo MC-LP fixation, whereas the contralateral radius received LC-DCP fixation. Six pairs of radii were randomly assigned to the anteroposterior (AP) group to be tested in four point bending in the anteroposterior tension band direction. Six pairs were randomly assigned to the medio-

Fig. 1 The minimum contact locking plate (MC-LP) plating systems interface profile

lateral (ML) group to be tested in four point bending in the mediolateral direction. The final six pairs of radii were assigned to the torsion (T) group and were tested in torsion.

All eight-hole 3.5 mm stainless steel MC-LP and LC-DCP systems were slightly contoured to fit the shape of the radius and placed on the lateral surface to simulate the clinical operation process. In each plate, the central two screw holes were not used. Thus, a total of six screws were placed on one specimen with three screws placed on either side of the specimen. The MC-LP system was fixed with bicortical self-tapping locked screws in holes 1, 2, 3, 6, 7, and 8. The LC-DCP system was fixed with bicortical unlocked compression screws in holes 1, 2, 3, 6, 7, and 8. After plating, we used an oscillating bone saw to create a 10-mm transverse osteotomy gap to simulate the comminuted diaphyseal fracture model. Thus, there was no bone contact between the fragments during mechanical testing (Fig. 2).

The proximal and distal ends of the specimens were embedded in dental cement. The specimens then underwent a series of nondestructive four point bending tests with an electronic universal materials testing system (AG-5000A MTS Systems, Shimadzu, Japan). In the four point bending tests, the outer pair bending points were placed 20 cm apart and the inner pair bending points were placed 10 cm apart. All the four point bending tests were carried out in anteroposterior and mediolateral planes with a maximum strength of 150 N and a rate of 2.5 mm/s. The torsion tests were carried out

Fig. 2 Cadaver radius instrumented with eight-hole minimum contact locking plate (MC-LP) or limited contact dynamic compression plate (LC-DCP), in which bicortical screws were placed in holes 1, 2, 3, 6, 7, and 8

by using an electronic universal materials testing system (RGT-5AT, MTS Systems) with a rate of 5 degrees/s to a maximum torque of 10 N·m. The load–displacement behaviour of each specimen was recorded, and the slope of the linear region of the curve was defined as the stiffness of the construction.

All data were analysed by SPSS software (SPSS Inc., Chicago, Illinois). Statistical comparisons of the construction stiffness from the groups were carried out by using a two-paired sample *t*-test. The level of significance was set at $P<0.05$. The graphic images were carried out with the graphics and statistics program Microsoft Office Excel 2003 (Microsoft Corp., USA).

Results

DEXA scan results

Average donor age was 70 (range, 60–83) years, and 12 of the 18 donors were female. The mean BMD value of specimens fixed with the MC-LP was 0.60 (range, 0.22–0.81) g/cm². The mean BMD value of specimens fixed with the LC-DCP was 0.59 (range, 0.20–0.82) g/cm². In each group, the difference in BMD means and variances between the MC-LP fixation specimens and the LC-DCP fixation specimens was not statistically significant ($P>0.1$).

Stiffness

The mean values and standard deviations of the measured stiffness data are listed in Table 1. In the same fixation type, the average values of four point bending stiffness in the AP direction were significantly higher than the values of four point bending stiffness in the ML direction ($P<0.05$). In the AP directional four point bending testing, the average bending stiffness of the MC-LP construction was 21% higher than the average bending stiffness of the LC-DCP construction ($P<0.05$). In the ML four point bending groups, the average bending stiffness of the MC-LP construction was also significantly higher than the average bending stiffness of the LC-DCP construction ($P<0.01$, Fig. 3), and a 43% increase was obtained for the MC-LP

Table 1 Bending stiffness and torsion stiffness of the three groups

System	AP bending (N/mm)	ML bending (N/mm)	Torsion (N·m/degree)
MC-LP	129.7±32.9	93.5±30.1	0.41±0.09
LC-DCP	107.3±24.1	65.5±34.2	0.27±0.06

AP bending, four point anteroposterior bending; ML bending, mediolateral bending; MC-LP, minimum contact locking plate; LC-DCP, limited contact dynamic compression plate

Fig. 3 Mean (SD) bending stiffness under four point bending in the anteroposterior (AP) and mediolateral (ML) directions

system. In the torsion groups, the average torsion strength of the MC-LP construction tended to be higher than the average torsion strength of the LC-DCP construction, but the difference was not significant ($P=0.27$). However, the MC-LP construction had significantly higher torsion stiffness compared with the LC-DCP construction ($P<0.01$) and achieved a 52% increase ($P<0.01$, Fig. 4).

Mode of failure

After four point bending testing, the residual specimens underwent the AP four point bending tests until failure of the construction occurred. Because it was very difficult to quantify screw loosening at the moment of failure, we only investigated the failure patterns of the constructions. The typical failure pattern of the LC-DCP groups had a fracture at the site of one distal screw hole (Fig. 5). Similar results were also obtained by other researchers [8]. In the MC-LP group, the modes of failure were complicated. The two major modes of failure included a fracture through several distal screw holes and a fracture at the ends of the radius not involving a screw hole (Fig. 6).

Fig. 4 Mean (SD) construction stiffness in the torsion group

Fig. 5 Typical pattern of failure of an limited contact dynamic compression plate (LC-DCP) specimen

Discussion

Conventional compression plates including the LC-DCP provide stability by the biomechanical principle of friction between the plate and bone. The frictional force depends on the force normal to the plate and the frictional coefficient between the plate and the bone. The force normal to the plate is equal to the axial force generated by the screw torque [9]. Therefore the screw with the maximum torque bears the maximum load.

In osteoporotic bone, there is a significant correlation between the pull-out strength and the cortical layer and its thickness [10]. Bone mineral density correlates linearly with the holding power of screws [11, 12]. So in osteoporotic or comminuted fractures, the pull-out strength of the screws is significantly reduced because their is less

Fig. 6 Typical patterns of failure were frequently seen in the minimum contact locking plate (MC-LP) constructs, either at multiple screw sites simultaneously or not involving a screw hole

cortical and cancellous bone [13]. When the screws begin to toggle, the compression plate begins to loosen and the fractures become unstable. On the other hand, conventional compression plates can damage the periosteal blood supply, lead to cortical porosis under the plate, and necrosis induced by vascular damage, which increase the complication rate, including infection, refracture, delayed union, and nonunion [14–16].

After the first locking plates were introduced about two decades ago by spinal and maxillofacial surgeons, they were considered to be a good method to treat osteoporotic and comminuted fractures [17–20]. Compared with the dynamic compression plate, locking plates maintain the stability of the screw–bone and the screw–plate interface. Because the screws are locked into the plate, all screws and the plate are tightened together. In locking plates, the strength of fixation is equal to the strength of all screw–bone interfaces rather than that of the single screw’s axial stiffness or pullout resistance [20]. Therefore, a single screw is difficult to pull out unless several adjacent screws are also pulled out. This kind of locking biomechanical principle increases the stability of the internal fixation, especially in osteoporotic bone, comminuted fractures, or highly unstable fractures [6, 21]. At the same time, the locking plate structure can avoid stress shielding below the plate and reduce the need for soft tissue dissection. Thus, in theory, the locking plate can preserve periosteal blood supply, accelerate bone healing, and decrease the incidence of infection [22, 23].

In this study, we compared the biomechanics of the MC-LP with the LC-DCP in an osteoporotic cadaver radial model. In accordance with the most common method of forearm fracture internal fixation, we selected a total of six screws for each eight-hole plate to be tightened. An osteotomy with 10-mm gap was made to simulate a comminuted fracture model. Our study found that the MC-LP construction had significantly higher stability than the LC-DCP construction. In the AP group, the bending stiffness of the MC-LP increased by 21% over that of the LC-DCP. In the ML group, the bending stiffness of the MC-LP increased by 43% over that of the LC-DCP. In the T group, the torsion stiffness of the MC-LP increased by 52% over that of the LC-DCP.

In the failure mode of four point bending, the fracture site of the MC-LP specimen occurred at several distal screws or at the ends of the radius. The reason was that all screws of the locking plate were locked into the plate and resisted the pull-out strength together [20]. However, the fracture site of the LC-DCP specimen occurred at the site of the distal screw holes. Because when the compression plate was placed on the tension side of the bone, the screws of the distal screw holes in the plates would bear the highest shear stresses caused by the bending load [6].

In summary, findings from this study show that the biomechanics of the MC-LP construction is superior to the LC-DCP construction. When they are tested in four point bending and torsion in an osteoporotic comminuted radial diaphyseal fracture model, the MC-LP system is significantly more stable than the LC-DCP system. Certainly, further comparative clinical studies are necessary to verify this concept, but the MC-LP system may be an optimal method to treat the comminuted osteoporotic radial diaphyseal fracture.

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

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