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Effects of DCP and LC-DCP Plates on Resistance of Radius against Axial Compression: Biomechanical Investigation

Dinamik Kompresyon Plak (DCP) ve Sınırlı Temaslı Dinamik Kompresyon (LC-DCP) Plak'ın Aksiyel Yüklenme Karşısında Radius Direnci Üzerindeki Biyomekanik Etkileri

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ABSTRACT

Objective: Dynamic compression plate (DCP) and limited contact dynamic compression plate (LC- DCP) are used for open reduction internal fixation of radial shaft fractures. They are distinguished from other systems by the principles of reduced plate-bone contact and dynamic compression. This study aims to compare the stress and deformation under axial forces in DCP and LC-DCP.

Materials and Methods: The DCP and LC-DCP were applied to 16 artificial radius bones by an experienced surgeon fixed at the distal and proximal of the fracture line with three cortical screws for each. In axial loading tests, the amount of force applied to the sawbones with DCP and LC-DCP and the amount of extension were calculated.

Results: DCP and LCDCP fixation plates on forearm fracture models were found to be statistically similar in terms of the applied force and displacement (p=0.161).

Conclusion: The study showed both implant types (DCP and LC-DCP) could be appropriate for the fixation of forearm fractures and osteotomies due to no mechanically significant difference under axial loadings. The plate to be applied can definitely be chosen considering the cost of the plate and the anatomical requirements.

Keywords: Dynamic Compression Plate, Fixation, Radius Bone, Axial Loading

ÖZET

Amaç: Dinamik kompresyon plağı (DCP) ve sınırlı temaslı dinamik kompresyon plağı (LC-DCP), radius şaft kırıklarının açık redüksiyonlu iç fiksasyonu için kullanılır. Diğer sistemlerden, azaltılmış plak-kemik teması ve dinamik kompresyon prensipleriyle ayrılırlar. Bu çalışma, DCP ve LC-DCP'deki aksiyel kuvvetler altındaki stres ve deformasyonu karşılaştırmayı amaçlamaktadır.

Yöntem: DCP ve LC-DCP, deneyimli bir cerrah tarafından 16 yapay radius kemiğine uygulandı ve her biri için üç kortikal vida ile kırık hattının distal ve proksimaline sabitlendi. Aksiyel yükleme testlerinde, DCP ve LC-DCP ile test sawbone materyallere uygulanan kuvvet miktarı ve ekstansiyon miktarı hesaplandı.

Bulgular: Ön kol kırık modellerinde DCP ve LCDCP fiksasyon plaklarının uygulanan kuvvet ve yer değiştirme açısından istatistiksel olarak benzer olduğu bulundu (p=0,161).

Sonuç: Çalışma, her iki implant tipinin (DCP ve LC-DCP) aksiyel yüklemeler altında mekanik olarak anlamlı bir fark olmaması nedeniyle ön kol kırıkları ve osteotomilerinin fiksasyonu için uygun olabileceğini göstermiştir. Uygulanacak plak, plak maliyeti ve anatomik gereksinimler göz önünde bulundurularak seçilebilir.

Anahtar Kelimeler: Dinamik Kompresyon Plağı, Fiksasyon, Radius Kemiği, Aksiyal Yüklenme

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INTRODUCTION

Forearm diaphyseal fractures are important and common adult injuries that constitute approximately 1% of all fractures (Haseeb et al., 2018). Plating of radial and ulnar shaft fractures has been clearly approved by all orthopaedic groups (Leung & Chow, 2003). Recently, the surgical technique used in the osteosynthesis of long bones such as femur, humerus, and radius is generally performed by internal fixation. Dynamic compression plate (DCP), locking compression plate (LCP), limited contact dynamic compression plate (LC-DCP), locked intramedullary nailing (LIN) (Grubor et al., 2019), and various minimum contact locking compression plates (MCLCP) are also used (Xiong et al., 2010).

Most commonly used invasive osteosynthetic materials (DCP and LCP) for fracture stabilization have been used extensively in clinical practice for many years. These materials provide new opportunities for the surgical treatment of fractures (Aguila et al., 2005). LC-DCP is used for open reduction internal fixation of radial shaft fractures. These plate systems are distinguished from other systems by the principles of reduced plate-bone contact and dynamic compression. Locking compression plates (LCP) with compressive properties and minimal bone-plate contact are also used for the fixation of radial shaft fractures. There are studies in the literature comparing LC and LC-DCP plates (Saikia et al., 2011).

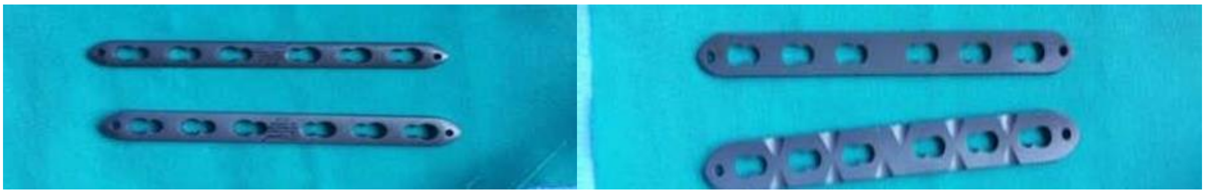
S.P.S. Gill et al. evaluated LC and LC-DCP clinically. Although there is no evidence supporting the superiority of LC plates over LC-DCP plates, it is stated to be an effective implant (Gill et al., 2017). On the other hand, studies are arguing that LC-DCP plates increase stability compared to LC plates (Filipowicz et al., 2009). In addition to LC plates, some studies focus on point contact fixators (Leung & Chow, 2003) and MCLCP plates (Xiong et al., 2010).

In addition to the clinical applications of different implants, biomechanical studies on some plates are also available in the literature. However, there are a limited number of biomechanical studies comparing DCP and LC-DCP plates. In this study, it is aimed to compare the loading and displacement under axial forces in dynamic compression plates (DCP) and limited contact dynamic compression plates (LCDCP).

MATERIALS AND METHODS

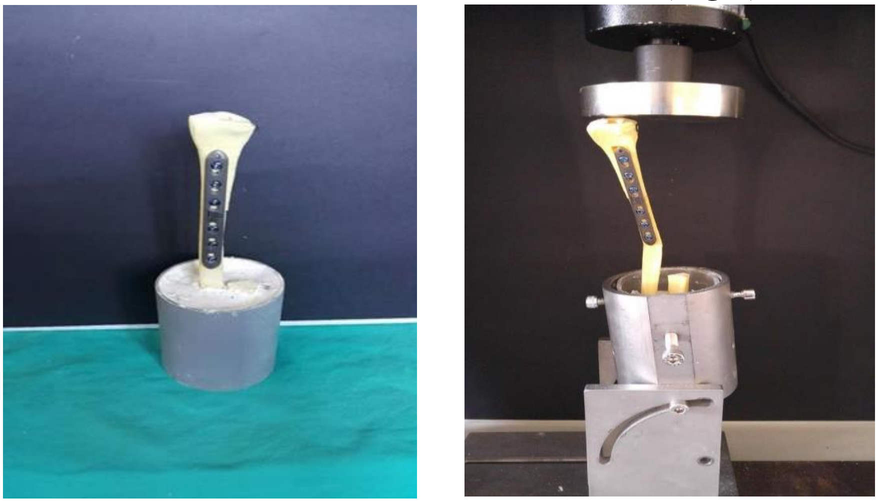
This is a study of biomechanical experimental research, and it was carried out between February 2016 and April 2016 in the research laboratory of the Faculty of Medicine, Department of Orthopedics and Traumatology and Department of Biomechanics. In the study, 16 artificial radius bones (Sawbone Model No: 1022-5, Sweden) were used. Osteotomy was applied to the samples at 70 mm proximal from the distal of the radius as 22-A2 wedge fractures according to AO-OTA classification. The DCP (3.5 and 4.5 mm PlateThin & Narrow DCP Plate, TIPMED, Turkey) and LCDCP (3.5 and 4.5 mm PlateThin & Narrow DCP Plate, TIPMED, Turkey) were applied to these artificial bones by an experienced surgeon (Figure 1).

Figure 1. DCP (Dynamic Compression Plate) [left] and LCDCP (Limited Contact Dynamic Compression Plate) [right]



The plates were fixed at the distal and proximal of the fracture line with three cortical screws for each (Ø 3.5 mm small cortical screw, TIPMED, Turkey). Then, all the samples were embedded in PVC (polyvinyl chloride) proximally using cement and potting was performed. SHIMADZU Autograph AG-5kNG universal tester (Shimadzu Corp., Tokyo, Japan) was used as the compression tool in the experiment. In axial loading tests, the amount of force applied to the sawbones with DCP and LCDCP and the amount of displacement were calculated (Figure 2).
The analysis was performed by SPSS 20.0 (IBM Inc, Chicago, IL, USA) software. The descriptive statistics were presented as mean±SD and median. The comparison between the measurements by Wilcoxon Signed Ranked Test. A $p<0.05$ value was considered a statistically significant result.

Figure 2. Radius Sawbone Fixed with LCDCP in cement (Left), Radius Sawbone Implanted Under Electromechanical Actuator (Right)



RESULTS

Eight sawbones to which DCP was applied showed an average displacement of 3.94 mm when an average axial force of 450.56 Newton was applied. Similarly, 8 sawbones to which LCDCP was applied also failed, showing an average displacement of 4.19 mm when an average axial force of 493.30 Newton was applied (Table 1).

Table 1. Results of force and extension tests between DCP and LCDCP (n = 8)

	Min.	Max.	$\bar{x}$ ∓SD	Median	*P
DCP axial force	311.71	544.06	450.56∓ 89.26	456.32	0.16
LC-DCP axial force	375.93	637.34	493.30∓ 88.94	474.14	
DCP extension force	3.50	4.65	3.94∓ 0.35	3.93	0.48
LC-DCP extension force	2.94	4.70	4.05∓0.53	4.19	

$\bar{x}$: Mean, **SD:** Standard Deviation, ***p>0.05, Wilcoxon Signed Rank Test

In the axial loading test performed for 8 sawbones to which DCP was applied and 8 sawbones to which LCDCP was applied, the maximum force that they failed with displacement was calculated and compared statistically. DCP and LCDCP plates were found to be statistically similar in terms of the applied force and displacement (p=0.16 and p=0.48) (Figure 3a - 3b).

Figure 3a. Axial forces of sawbones for DCP [left], axial forces of sawbones for LCDCP [right]

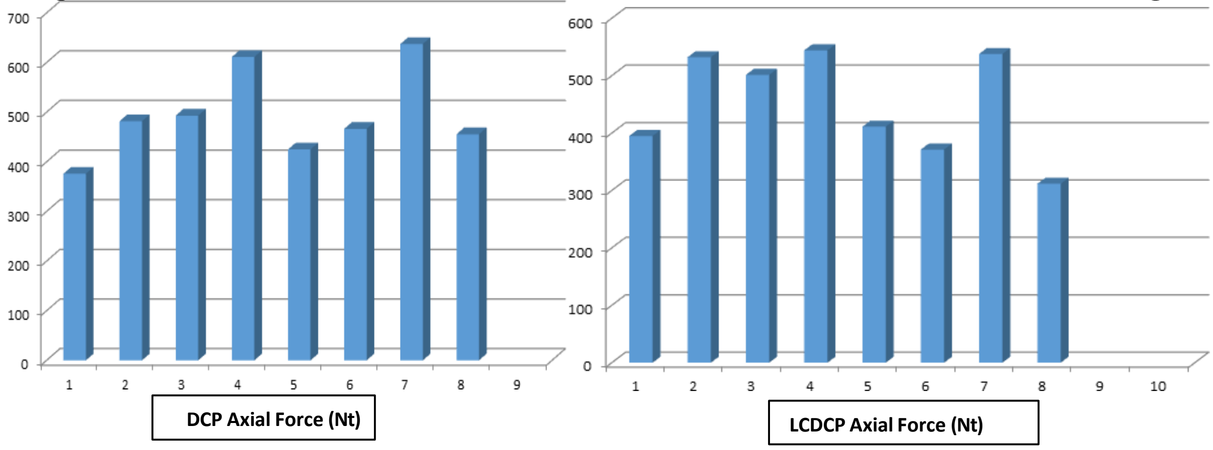
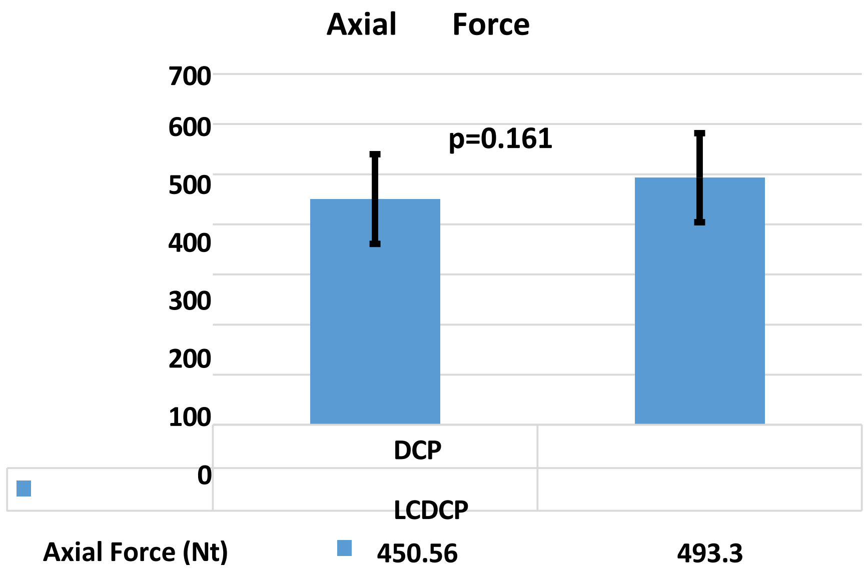


Figure 3b. DCP and LCDCP axial forces for each sawbone and the mean axial force in each plate



DISCUSSION

The treatment of adult forearm fractures is complex and difficult, and open reduction and internal fixation methods have become the generally accepted treatment methods (Leung & Chow, 2006; Perren et al., 1991). Even if closed reduction is achieved in forearm shaft fractures, reduction loss is frequently encountered, and it is stated that poor functional results are obtained due to long-term immobilization (Chapman et al., 1989). Since most forearm shaft fractures are not non-displaced, most authors agree that the anatomical reduction of the fracture should be achieved, there should be careful monitoring until recovery, and the extremity should be rehabilitated early to achieve successful functional results in such fractures (Grace & Eversmann, 1980; Langkamer & Ackroyd, 1991; Leung & Chow, 2006). Today, the treatment of adult forearm shaft fractures is not conservative, and although there are various fixation materials (intramedullary, nails, external fixators, various plates), many authors have reached a consensus that these fractures can best be treated with compression plates (Klaue et al., 1991; Schulte et al., 2014). However, there has also been a search for different plates (Xiong et al., 2010). One of the first comprehensive case series, in which forearm double fractures were applied internal fixation with an open reduction compression plate, was published by Anderson et al. (1975) the study was conducted with 244 patients with radius and/or ulna fractures. There were a total of 330 forearm fractures, and they reported successful union in 97.3% of the fractures, skin infection in 2.9% of the fractures, and non-union in 2.9% of the fractures. In another large case series by Chapman et al. (1989) (87 patients, 129 forearm diaphyseal fractures), they reported similar findings to Anderson's study. There are studies stating that in addition to the plate type, fracture reduction and surgical technique are better in clinical studies of the implants used (Azbay et al., 2013; Xue et al., 2016). As far as the implant failure that occurs after the use of fixation materials is concerned, Langkamer et al. (1991) analyzed 156 forearm diaphyseal fractures treated with DCP retrospectively. They concluded that 12.9% of the patients they treated with DCP had early fixation failure. When these cases with implant failure were examined, they reported that there was no rigid fixation in any of these cases; the reduction was insufficient in ten cases, early fixation failure occurred after the fracture during fixation in five cases, and plate fracture was observed in two cases (1.8%).

An important issue in fracture healing is the studies on the optimal compression required at the fracture site. Lucas and Lee (2016) have recently investigated the effects of external stretching with an eccentric perforated plate for optimal compression.

Another important issue emphasized in the literature is controlled dynamization and its effects on fracture healing. Bottlang et al. (2010) demonstrated that controlled dynamization reduces callus formation and improves healing. There are also studies on the dynamic stabilization of the fracture site. These studies showed that dynamic plates called active o-plates lead to better callus formation and healing compared to conventional plates. Various strategies have been used to increase dynamization. The effects of the distance between the plate and the locking screw and between the plate and the fracture site and the effect of the distance between the plate and the bone have been shown in studies (Kandemir et al., 2017). This concept which focuses on locked plate placement and design is defined as DLS (dynamic locking screw). This system provides dynamization to the cortex under the plate and an increase in axial movement in loading. However, this examination, which was conducted theoretically and pre-clinically, could not be demonstrated clinically (Augat & Rüden, 2018). On the other hand, they stated that fracture reduction, obtaining the correct axis, and sufficient mechanical and biological conditions are important in fracture healing (Augat & Rüden, 2018). However, the type of the loss in the biomechanical strength of the plate caused by the changes made in the lower surface of the plate to protect the blood supply has been discussed in the literature and has been tested with different methods [29]. There are also some studies conducted with new implants (Gautier & Perren, 1992; Perren et al., 1990). Miclau et al. (1995) created a transverse fracture model in sheep tibia and evaluated DCP, LC-DCP, and point contact fixator plates in terms of biomechanics. Only torsion and bending tests were applied to the samples, and no biomechanical differences were found between these three plate types.

In their follow-up study of more than 5 years, Matsuura et al. (2017), examined 15 adult patients with forearm fractures treated with plate osteosynthesis. They made comparisons using computational tomography and evaluated bone thickness, local bone mineral density, and bone strength without plate reinforcement based on finite element analysis. After the long-term follow-up, they showed that the use of the LC-DCP plate caused more bone atrophy than the traditional plates. No difference was found between the functional results of the patients. In another study performed on cadaver bone, the plate-bone contact area of DCP and LC-DCP plates was compared; however, no significant difference was found between the plate-bone contact interface (Augila et al., 2005). This finding contradicts Gautier and Perren's (1992) claim that LC-DCP reduces the plate-bone contact interface area by 50%.

In a retrospective study by Marcheix et al. (2016) in which 131 adult forearm fractures were examined, a DCP plate was used in 91 patients and LC-DCP was used in 40 patients. Non-union was detected in 9 patients. When the prognostic factors affecting the onset of fracture union (age, alcoholism, smoking, head trauma, skin opening, preoperative neurological impairment, type of fracture, type of plate fixation, number of screws on either side of the fracture site, duration of elbow immobilization) were evaluated, only advanced age was shown to negatively affect the union. It was shown that plate type did not affect the onset of union. The study of Ravi and Mathew (2017) demonstrated that in comminuted fractures and osteoporotic bone, the limited contact dynamic compression plate (LC-DCP) has a definite advantage over the dynamic compression plate (DCP) in terms of union and screw insertion time. In our study, DCP and LC-DCP plates were compared under axial loading, and no significant difference was found in terms of mechanics. In another study, the combined use of an LCP plate and LC-DCP plate with an intramedullary rod in a dog cadaver femur fracture model was compared biomechanically. While the LCP plate was fixed to the femur of the dog cadaver with a bicortical screw, the LC-DCP plate was combined with the intramedullary rod and was fixed with a unicortical screw. Compared to LCP, the combination of the LC-DCP plate with the intramedullary rod achieved a higher level of stiffness, ultimate load, and less motion between fracture ends (Matres-Lorenzo et al., 2016). It has been stated that MC-LCP plates, which are among the new plate structures, offer the advantage of less contact on the bone cortex surface compared to LC-DCP plates (Xiong et al., 2010). In another study, the effects of different LCP plate configurations on mesenchymal cell activation in the fracture site were shown, and it was stated that mechanoregulation, cellular activities and tissue regeneration were important (Carter et al., 1998). Another study revealed that external loadings have effects on the activity of the cells in the fracture site (Klein et al., 2003). Uhl et al. (2008) created a gap model in two different cylindrical Polyurethane foam (PUF) to schematize the osteopenic and normal bone structure and compared the DCP, LC-DCP and LCP plates. In our study, no significant mechanical difference was observed between DCP and LC-DCP plates under axial loading. This supports previous randomized controlled trials that reported LC-DCP plates provided faster union times and more favorable outcomes in osteoporotic and comminuted fractures compared to DCP, without altering surgical technique or increasing complications **(**Ravi, Mathew, & Madhusudan, 2017). When evaluated mechanically under cyclic axial loading, it was found that gap closing occurred in LC-DCP and DCP plates, while there was no gap closing in LCP plates. In low-density osteoporotic bone models, LCP plates showed similar properties to LC-DCP and DCP plates. No significant differences were found in biomechanical tests performed with LC-DCP and DCP plates. In that sense, Uhl et al.'s (2008) study support our findings. Recent clinical trials comparing LCP and LC-DCP in adult both-bone forearm fractures have also confirmed no functional superiority of either method**,** although LC-DCP showed a statistically faster union time when used in compression mode **(**IOSR-JDMS, 2020**)**. In addition to the studies on plates, studies on locking screws defined as dynamic locking screws are also striking (Döbele et al., 2010; Plecko et al., 2013; Richter et al., 2015). In our study, the dynamic compression plate (DCP) and the low-contact dynamic compression plate (LC-DCP) were evaluated biomechanically in the artificial radius bone (Sawbone Model No: 1022-5, Sweden) wedge fracture fixation model. In this study, instead of torsion and bending loadings, which are the physiological forces exposed during the recovery period, we created an axial loading model that can simulate the loads transferred to the forearm through the open hand as a result of an acute fall. While LC-DCP has advantages in specific fracture types, some studies comparing DCP with locking compression plates (LCP) have shown no statistically significant difference in range of motion or fracture union**,** reinforcing the idea that proper surgical technique and fixation strategy are often more critical than implant type (Shevate et al., 2022).

They created samples that were tested under axial loadings. In the artificial radius wedge fracture model, no biomechanically significant difference was found in the comparison of the application of the DCP plate and the LC-DCP plate ($p>0.05$). Dynamic compression plates (DCP) and low-contact dynamic compression plates (LC-DCP) which are in clinical use touch the bone and create pressure. This pressure, which occurs due to the tightening of the cortical screws, also provides sufficient friction between the plate and the bone during the bone healing process and resists mechanical loads that cannot be met only by the bone. LC-DCP plates have been obtained as a result of redeveloping the surface of the plate that is in contact with the bone, as it disrupts periosteal blood circulation less. Due to the mechanical properties of LC-DCPs, periosteal blood flow is protected more compared to the DCPs, indicating that there is less avascular site formation in the bone under the plate, and correspondingly less early transient bone resorption and infection. One of the limitations of our study is that we did not use forearm bones with different densities. Moreover, some strength test of implants or single-cycle mechanical test in different directions could not be evaluated. However, this is a comparison study of two different fixation plates.

CONCLUSION

As a result, no mechanically significant difference was observed between the two compression plates under axial loadings. However, although limited, mechanical differences were shown. We believe that it would be useful to develop and use more biological plate structures without sacrificing mechanical data and stability. The plate to be applied can definitely be chosen considering the cost of the plate and the anatomical requirements.

Conflict of Interest

The authors declare no conflict of interest regarding the publication of this study.

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Author Contributions

Research Idea/Concept: FS, HH
Research Design: FS, HH
Supervision/Consultancy: HH
Data Collection and/or Processing: FS
Analysis and/or Interpretation of Data: FS, YEB
Literature Review: FS, YEB, OG, AİK
Article Writing: FS, YEB, BH, OG
Critical Review: HH

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