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The contribution of locked screw-plate fixation with varying angle configurations to stability of osteoporotic fractures: an experimental study

Osteoporotik kemikte kilitli plak ve açılı vida kullanımının stabilizasyonun dayanıklılığına katkısı: Deneysel çalışma

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Amaç: Bu deneysel çalışmada, konvansiyonel kilitli plak yönteminden farklı olarak, vidaların konfigürasyon ve geometrilerinde yapılan değişikliklerle yaşlı osteoporotik hastalarda stabilizasyonun dayanıklılığını artırmanın yolları arandı.

Çalışma planı: Farklı vidalama açılarına sahip dört plak-kemik konfigürasyonu oluşturuldu. Yüksek kaliteli 40 adet demir plak (100x35x3 mm) dört gruba ayrıldıktan sonra, her birine 15 mm aralıkla ve 3 mm çapında iki adet delik açıldı. Grup A'da delikler vidaların paralel (0°) gönderileceği şekilde, grup B'de vidaların eksenleri bir noktada birleşecek şekilde (konverjan 15°), grup C ve D'de ise vida eksenleri birbirinden uzaklaşacak şekilde (diverjan, sırasıyla 15° ve 30°) açıldı. Vida testi için, modifiye osteoporotik kemik (Osteoporotic Generic Bone, Synbone) modellerine tespit edilmiş plaklar Instron materyal test cihazına yerleştirilerek 0.1 mm/sn hızında aksiyel sıyrılma uygulandı. Her örnek için dayanma gücünü aşan yük seviyeleri yük-yer değiştirme eğrilerinden okundu ve yetersizlik tipi kaydedildi.

Sonuçlar: En yüksek sıyrılma direncini diverjan düzenekler (grup C'de 83.3 N/mm; grup D'de 80.8 N/mm) gösterdi. Ortalama sıyrılma direnci konverjan düzenekte 72 N/mm, klasik paralel düzenekte 66.7 N/mm bulundu. Yetersizlik tipi diverjan düzeneklerde kemik kırılması iken, konverjan ve paralel düzeneklerde vida sıyrılması şeklindeydi.

Çıkarımlar: Osteoporozlu hastalardaki kemik kırıklarının tedavisinde diverjan düzenekler, klasik vida yerleşiminin yerini alabilecek bir seçenek olabilir.

Anahtar sözcükler: Biyomekanik; kemik plağı; kemik vidası; kırık tespiti, internal/yöntem; osteoropoz; protez tasarımı; stres, mekanik.

Objectives: This experimental study was designed to find new ways of improving stabilization of fractures in osteoporotic elderly patients through alterations made in the configuration and geometry of locked screw-plate fixation used in the conventional plate technique.

Methods: Four screw configurations with varying angulations were used for plate-bone construction. Forty iron plates of high quality (100x35x3 mm) were divided into four groups and two screw holes, 3 mm in diameter, were drilled on each plate at a distance of 15 mm. In group A, the holes were drilled so that the screws would be vertically sent to the bone interface. In the remaining groups, the holes were drilled for convergent (group B, 15°) and divergent (group C, 15°; group D, 30°) screw orientation. Screw-plate fixation was tested in a modified osteoporotic bone (Osteoporotic Generic Bone, Synbone) on an Instron materials testing system with an axial pullout force of 0.1 mm/sec. Failure loads were read from load-displacement curves and the type of failure was noted.

Results: Screws placed in divergent orientations showed the highest axial pull-out strength (group C, 83.3 N/mm; group D, 80.8 N/mm), followed by convergent placement (72 N/mm) and vertical placement (66.7 N/mm). The type of failure was breakage of the bone sample in divergent configurations, and screw pull-out in convergent and vertical configurations.

Conclusion: Divergent constructs may be a promising alternative to conventional screw placement in treating osteoporotic fractures.

Key words: Biomechanics; bone plates; bone screws; fracture fixation, internal/methods; osteoporosis; prosthesis design; stress, mechanical.

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Skeletal fractures associated with osteoporosis are common orthopedic conditions. Due to longer life expectancies, the increase in the elderly population in industrialized nations is continuing. A related growth is reflected in the number of patients with senile osteoporosis and in traumatologic emergencies related with osteoporotic fractures. The treatment goals are rapid mobilization and return to normal activities by achieving stable fracture fixation.[1,2]

Bone plates and screws are commonly used implants for fixation of fractures and stabilizing bone transplants. Recently, researchers are investigating ways to increase the support strength using various configurations and geometries of the screws. The primary mode of failure of internal fixation is the inability of the osteoporotic bone to support the fixation device. Osteoporotic bone may lack the strength to support rigid fixation devices such as plates and screws.[3]

In this study, we aim to reach this goal using a novel application technique of the locking-plates. The proposed technique differs from the conventional locking-plate system in that the screws are not perpendicularly fastened to the bone but at inclined angles

Materials and method

The iron plates were subdivided into four groups of 10 according to the angles of the screw holes; having parallel 30° and 15 divergent and 15° convergent holes. In 40 high qualities iron plates (100*35*3 mm), two holes were drilled in 3 mm diameter at 15 mm intervals. The drill-holes directed sequentially in 0, 15, and 30° divergent and 15° convergent manner. The holes were tapered in 3.2 mm diameter.(Table 1)

The bone pieces were bicortical made from polyurethane foam (Synbone AG; generic bone, osteoporotic 0080) for screw testing and demonstration in osteoporotic-like situations. (Material: Modified osteoporotic bone-like polyurethane (PUR), Technical data: Failure loads with a 4.0mm cancellous bone screw; Strip-out torque Nm: 0.293 +/- 0.0523; Strip-out force kN: 0.323 +/- 0.0225; Pull-out force kN: 0.360 +/- 0.0329).

Bone samples were prepared at 80 mm length. Each plate was subsequently clamped to the bone piece with a Verbruge bone clamp. Drill hole of 3 mm diameter were formed, and two screws of appropriate length and size were applied in the direction of plate screw holes angle. Screws were tightened to the bone and plate together. The axial pull-out was performed to our models (Figure 1) formed by plates applied to Synbone osteoporotic bone model with two locking screws. Uniaxial load to failure was applied under displacement control at a rate of 0.1 mm/sec using an Instron 5596 materials testing machine.

Results

Initially, it was observed that the sample with highest pullout strength in terms of failure load was the conventional construct (A), followed by the divergent constructs (C and D). The sample with the lowest strength was the convergent construct. It takes a more careful investigation, however, to note that similar results will not apply when one takes the average pullout stiffness as a criterion. Here, we define the average pullout stiffness of the structure as kp as:$k_p=F/\delta$ where, F is the change in load, and d is the change in displacement, for a region in the load-displacement curve that remains relatively linear. As an example, in Figure 2, the load-displacement curve for the con-

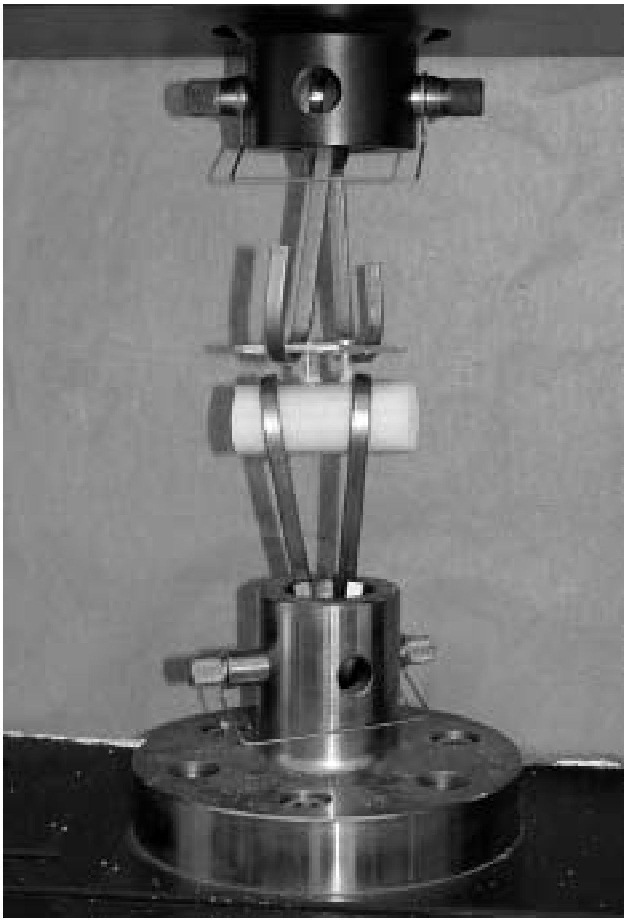

Figure 1. The axial pull-out of the plates applied to Synbone osteoporotic bone model with two locking screws.

Table 1. Configurations and results

Sample	Screw Configuratio	Angle of Alignment (°)	Failure Load (N)	Mode of Failure	Average Pull-out Stiffness (N/mm)
A	Parallel	0	720	Pull-out of the screw	66.7
B	Convergent	15	380	Pull-out of the screw and wedge shaped bone piece	72.0
C	Divergent	15	550	Bone fracture	83.3
D	Divergent	30	540	Bone fracture	80.5

ventional construct (A); the curve was observed to behave linearly for values of d between 2 and 8 mm. Similarly for B, C, and D, the linear d ranges were read (Figures 3-5) as between 0 - 5, 0 - 5 and 6.5 - 10 mms, respectively.

Using these values as a basis, the average pullout stiffness for all of the samples were calculated and tabulated in Table 1.

Discussion

Bone is a composite material composed of a protein matrix impregnate with a mineral matrix impregnated with mineral phase.[5] The failure of osteosynthesis is determined by the maximum load that can be assessed by axial pullout strength. Pullout strength is crucial factor in the osteoporotic bone.[6] Several plating techniques are used for open reduction internal fixation of the fractures. In conventional plate osteosynthesis, the stability of fracture fixation is directly related to the friction between bone surface and the plate achieved by the hold of screws. Stability depends on the holding power of the screws in the cortical bone.[5] The bending stiffness of the screws and the friction between the screw and the plate seems to prevent motion. Experiments show that with conventional plates, motion is prevented by friction and depends upon the axial force of the screw, pressing the plate onto the bone.[7,8]

Fixation of osteoporotic bone with poor quality can cause certain difficulties.[9] Bone mineral density correlates linearly with holding power of screw. [10] Osteopo-

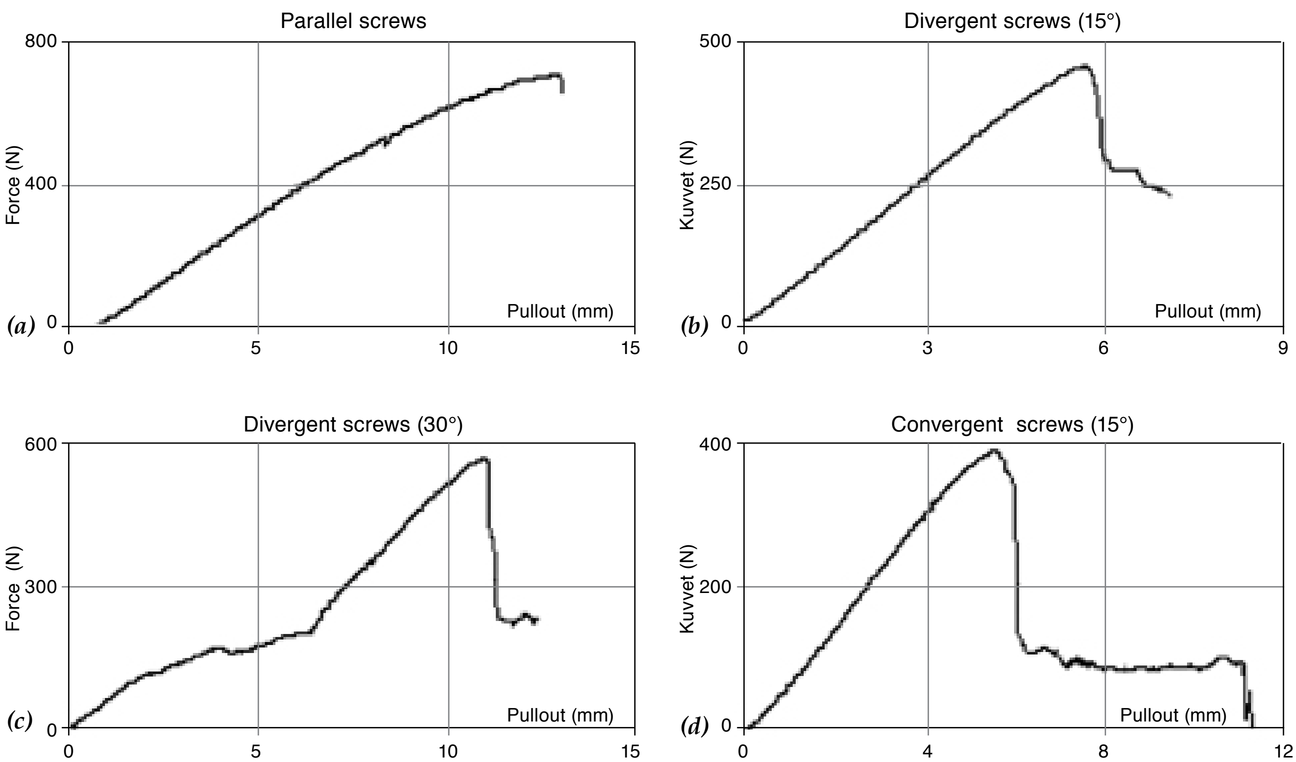

Figure 2. The load-displacement curves of the **(a)** parallel screws pullout, **(b)** 15° divergent screws pullout, **(c)** 30° divergent screw pullout, **(d)** 15° convergent screw pullout.

rotic bone allows approximately 3 Nm of screw torque.[11] Experimentally, 3 Nm of screw torque allows motion of plate and bone at load of 500 N.[7,8]

Such a movement causes excessive strains that exceed limits for primary or even secondary bone healing.[9] New locked plates control the axial motion, thereby creating a single screw-plate-bone beam construct. Single beam constructs are four times stronger than load-sharing conventional beam constructs. In locked plates, the strength of fixation equals the sum of all screw-bone interfaces. But even in this stronger model of fixation, strength of the system is directly related to the pull-out stiffness of the screw.

Synthetic bone has the advantages of less individual variation and more consistent test results, greater availability, and easier specimens handling by pull-out and push-out tests.[12-14] After many clinical experiences, new stabilization techniques' locked plates improved fixation properties in poor metaphyseal and osteoporotic bones.[15, 16] It was reported that locking plates must be stronger when used in osteoporotic fractures.[16-19]

In this principle "locking screws," screws were locked to the plate. But paradoxically to the locking principle, we can't observe any new technique for locking screws to the bone. The new plate technology gives us many possibilities to change our design so that we are now able to lock our screw to the plate at different angles, achieving a more secure fixation system to bone. The locking mechanism may be so simple as to take a divergent tongue in a convergent recess, historically known since ancient Egypt and used at arch of architect and mortise of carpenter.

In this study, it is immediately noticed that samples producing the highest stiffness are those prepared as divergent constructs (C and D), followed by the convergent construct (B), and, finally, Sample A produced the lowest stiffness. Also note that the initial portion of the load-displacement curve for Sample D (30° divergent screws) is highly non-linear, although the curve then assumes a linear shape. The stiffness obtained in the linear region of Sample D and that of Sample C are quite close in comparison.

This initial deviation in the curve of 30° divergent screws may be explained by a self-aligning motion of the screws as the load is applied, during which the angle of alignment tends to decrease towards a smaller angle. As the angle gets closer to that of Sample C and the curve becomes linear, the stiffness produced by Sample D approaches that of Sample C. In addition, the mode of failure should also be taken under consideration. The fact that Samples C and D produce fractured bone points, according to the authors, a higher degree of load is transferred from the plate to the bone. A greater amount of load transfer means that the attachment of the bone to the plate is stronger for this (divergent) configuration compared to the other configurations (conventional and convergent). Also, failure due to more pull-out of the screw (as in the case of the conventional construct) should be viewed as a disadvantage in terms of the stability of the attachment, especially for osteoporosis cases for which the bone has lost much of its adhesion strength. Many methods of augmenting implant fixation in osteoporosis like polymethylmethacrylate (PMMA), calcium phosphate cement, calcium phosphate, or hidroxiapatit coated implants have been described.[20, 21]

According to Kääb et al.,[22] proper locking of screw is essential for providing stable fixation. In their experimental study, under bending load, more tilting was observed at locking screws inserted at 5° or 10°. But in their study, directions of plate hole and screwing were completely different, and the problem was in the locking mechanism of the plate and screws, not at the divergence of screws. Kearny et al.[23] state in their study about the effect of divergent screw placement that varying the screw angle decreased the pull-out resistance but increased the strength of plate fixation to bone. In our study, we observed that when the angle of screw differs from 90°, the number of threads acting diminishes and that may cause decrease in plate-screw locking capacity. This may be solved by changing plate configuration near screw hole. This will be the subject of another study.

As a result, we think the divergent constructs to be a promising alternative to the conventional set of screws in treating fractures involving osteoporotic bones. Moreover, research needs to be focused on determination of an optimal angle of alignment, the number of screws to be used, and the optimal distance between each screw for the divergent construct.

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