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Biomechanical analysis of load transmission characteristics of limited carpal fusions used to treat Kienböck's disease

Kienböck hastalığı tedavisinde sınırlı karpal füzyonların yük aktarma özelliklerinin biyomekanik analizi

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Amaç: Kienböck hastalığı tedavisinde kullanılan sınırlı karpal füzyonların lunatum üzerindeki yükü azaltarak etki ettikleri düşünülmesine karşın, biyomekanik çalışmalar kapitohamat füzyonunda lunatum yükünün arttığını göstermektedir. Bu deneysel çalışma bu çelişkiyi aydınlatmak amacıyla planlandı.

Çalışma planı: Bu biyomekanik çalışmada, beş taze kadavra el bileğinde, 140 ve 210 newtonluk (N) yüklenmeler altında sağlam eklemlerle ve sınırlı karpal füzyonlarda (skafotrapeziotrapezoid, skafokapitat, kapitohamat) nötral, radial ve ulnar deviyasyonda yük dağılımları incelendi.

Sonuçlar: Yüklenme 140 N iken, skafotrapeziotrapezoid ve skafokapitat füzyon sonrasında her pozisyonda lunatuma gelen yüklerde azalma, kapitohamat füzyon sonrasında artış görüldü. Yüklenme 210 N'ye çıkarıldığında, yüklerin dağılımı sağlam el bileğinde elde edilen değerlerden farklı değildi. Her iki yüklenme altında da, ulnar deviyasyonda iken lunatumun anlamlı derecede daha fazla yük altında kaldığı görüldü.

Çıkarımlar: Bu sonuçlar, 210 N'lik yüklenme altında, sınırlı karpal füzyonların el bileğindeki yük dağılımını değiştirmediğini göstermektedir. Kienböck hastalığı etyolojisinde ulnar deviyasyon yüklenmesi olduğu ve sınırlı karpal füzyonların el bileği yüklenme özelliklerini değiştirerek değil, ulnar deviyasyonu kısıtlayarak etki ettiği düşünülebilir.

Anahtar sözcükler: Artrodez/yöntem; biyomekanik; kadavra; karpal kemikler/cerrahi; osteokondrit/fizyopatoloji/cerrahi; radius/cerrahi; hareket açıklığı, eklem; semilunar kemik/cerrahi; stres, mekanik; ulna/cerrahi; el bileği eklemi/fizyopatoloji/cerrahi.

Objectives: Although limited carpal fusions used in the treatment of Kienböck's disease are thought to act by decreasing the loads on the lunate, biomechanical studies show that capitohamate fusion acts oppositely to what is expected. This experimental study was designed to resolve this paradox,

Methods: In a biomechanical cadaveric study, load transmissions at the radioulnacarpal joint were investigated under 140 and 210 newtons of load with three wrist postures, namely, neutral, ulnar and radial deviations, in five intact wrists and after scaphotrapeziotrapezoid, capitohamate, and scaphocapitate fusions.

Results: Under 140 newtons of load, the loads imposed to the lunate decreased following scaphotrapeziotrapezoid and scaphocapitate fusions, but increased after capitohamate fusion. However, when the load was increased to 210 newtons, there were no differences between intact wrists and limited carpal fusions in respect to the loads exerted on the lunate. In all the situations, the lunate was subjected to a significantly greater load in ulnar deviation.

Conclusion: These results suggest that limited carpal fusions do not alter load transmission characteristics of the wrist joint under 210 newtons of load. The etiology of the Kienböck's disease seems to be related to an overload in ulnar deviation and the beneficial effect of limited carpal fusions seems to be associated with restricted ulnar deviation of the wrist rather than load transmission characteristics.

Key words: Arthrodesis/methods; biomechanics; cadaver; carpal bones/surgery; osteochondritis/physiopathology/surgery; radius/surgery; range of motion, articular; semilunar bone/surgery; stress, mechanical; ulna/surgery; wrist joint/physiopathology/surgery.

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Avascular necrosis of the lunate is thought to be secondary to repetitive trauma with compression of the lunate.[1,2] In order to shift the compressive forces across the wrist, away from the lunate, joint levelling procedures (radial shortening or ulnar lengthening) or limited carpal fusions, such as scaphotrapeziotrapezoid (STT), scaphocapitate (SC) and capitohamate (CH) fusions are advocated and good clinical results were reported for each.[3,6] Although the effectiveness of joint levelling procedures, STT and SC fusions were also proved by biomechanical studies, these studies not only failed to demonstrate any significant change across the radiolunate joint following CH fusion, but some increase.[2,7,8] So the present study was conducted to solve this paradox and clarify the mechanism of limited carpal fusions in the treatment of Kienböck's disease.

Materials and methods

Five fresh unembelmed adult cadaver upper extremity specimens were studied. Gross examination of the ranges of motion of the wrists and radiographs were used to exclude previous fracture or carpal pathology. With a dorsal midline incision, entire radioulnocarpal, STT, SC and CH joints were exposed and the capsule of the radioulnocarpal joint was opened.

The specimens were mounted in the loading apparatus with a polyurethane pad distal to the metacarpal heads, between the hand and the apparatus (Figure 1). This pad allowed better distribution of the forces and angled pads allowed loading in ulnar and radial deviations.

After the specimen was mounted in the loading apparatus, a pressure-sensitive film transducer (Fuji Prescal Film, U.S.A) was inserted into the radioulnocarpal joint. The superlow film (0.5 - 2.5 MPa) was used throughout the study. Each specimen was loaded by 140 and 210 Newtons for 15 seconds and tested in three wrist positions (25 degrees of the ulnar deviation, neutral and 15 degrees of radial deviation). The STT, SC and CH fusions were simulated using one or two staples between the bones and the loading procedure with two loads and three different positions were repeated.

Pressure transducers were then scanned and digitised at 300 dpi and 256 colour resolution with the calibration strip and pressure maps were produced by a computer programme (Lucia 4, 21). Then the percentage of loads carried by ulnotriquetral, ulnolunate, radiolunate, radioscaphoid and radiotrapezial (only in radial deviation) joints were calculated. Wilcoxon signed rank test was used for statistical analysis.

Results

The percentage of loads carried by radioulocarpal joint under 140 Newtons are displayed in Table 1. In the intact joint most of the loads were dissipated through radioscaphoid joint (46.2 %) in neutral position. These loads were increased to 65.0 % in radial deviation but decrease significantly when the wrist as brought in ulnar deviation ($p<0.05$) and the most of the loads were transmitted to radiolunate joint (11.5 vs 41.0%). In radial deviation, some of the loads were shifted to radiotrapezial (12%) and ulnolunate (9.5 %) joints which were totally unloaded in ulnar deviation (Table 1).

After STT and SC fusions were performed, the loads borned by lunate either by radiolunate or ulnalunate joint, were decreased in neutral and radial deviation, but increased again in ulnar deviation ($p<0.05$). Although CH fusion, increased the loads of lunate in neutral position and this was especially significant in ulnar deviation, loads were decreased in radial deviation (Table 1).

Figure 1. The specimen and the loading apparatus.

Table 1. Load percentage at radioulnocarpal joint with 140 and 210 Newtons

	Intact			STT fusion			SC fusion			CH fusion		
Joint	N	R	U	N	R	U	N	R	U	N	R	U
140 Newtons*												
Ulnotriquetral	12.8±1.3	5.5±0.5	47.5±5.0	7.7±0.8	4.4±0.4	46.4±5.0	8.4±1.0	4.6±0.5	36.4±3.7	7.7±0.8	3.9±0.3	28.7±3.2
Ulnolunate	13.0±1.2	9.5±1.0	–	11.8±2.1	9.8±1.0	–	11.2±1.1	8.3±1.2	–	15.3±1.6	12.2±1.1	–
Radiolunate	28.0±3.1	8.0±1.0	41.0±4.2	24.2±2.5	7.2±1.0	44.4±4.2	22.3±2.4	11.3±1.2	38.4±4.2	33.2±3.3	17.3±1.6	48.3±5.2
Radioscaphoid	46.2±5.2	65.0±7.1	11.5±1.2	56.3±6.1	68.6±6.7	9.6±1.1	58.1±6.2	71.6±6.9	25.2±2.7	43.8±4.6	63.3±6.4	23.0±2.4
Radiotrapezial	–	12.0±1.1	–	–	10.0±1.3	–	–	4.2±0.5	–	–	3.3±0.4	–
210 Newtons**												
Ulnotriquetral	13.1±1.2	5.5±0.5	45.2±5.3	12.4±1.4	5.6±0.6	44.4±3.9	14.2±1.6	5.6±0.6	44.7±4.2	14.3±1.3	5.4±0.5	43.8±4.4
Ulnolunate	12.9±1.4	9.8±1.2	–	12.5±1.3	10.1±1.1	–	13.3±1.2	9.9±1.1	–	12.2±1.3	10.2±1.0	–
Radiolunate	28.6	8.6±1.2	39.3±4.2	27.3±3.2	8.2±1.3	41.3±5.0	29.3±3.3	8.3±1.0	41.8±4.2	30.1±3.1	8.6±1.2	41.7±3.9
Radioscaphoid	45.4±5.2	64.2±6.5	15.5±2.1	47.8±5.3	62.2±6.4	14.3±1.6	43.2±4.2	65.6±6.7	13.5±1.4	43.4±4.2	64.4±6.5	13.5±1.4
Radiotrapezial	–	11.9±1.2	–	–	13.9±1.3	–	–	10.6±1.2	–	–	11.4±0.9	–

* All data show significant difference when compared with the intact wrist (p<0.05). ** There is no significant difference when compared with the intact wrist (p>0.05). STT: Scaphotrapeziotrapezoid; SC: Scaphocapitate; CH: Capitohamate; N: Neutral; R: Radial deviation; U: Ulnar deviation.

When the experiments were repeated under 210 Newtons (Table 1), the percentage of the loads carried by each radioulnocarpal joint was not changed significantly in intact wrist, when compared with loading at 140 Newtons (p>0.05). Again, the loads of the lunate were decreased by radial deviation and increased by ulnar deviation (Table 1). The results after STT, SC or CH fusions were identical to intact wrist in each position that the unloading effects of STT and SC fusions, and the loading effect of CH fusion on lunate were lost (Table 1).

Discussion

Although the pathogenesis of Kienböck's disease remains unknown, repetitive stress with compression of the lunate appears as the most widely accepted causative factor.[1,2] Based on this concept, limited carpal fusions have been used with success[5-8] and confirmed by biomechanical studies.[2,7-10] However, CH fusion appears as the exception that while satisfactory clinical results were reported4, biomechanical studies showed increase in the compressive forces carried by lunate.[2,7-10] The dilemma of theory and praxis necessitates the theory to be re-evaluated.

All of the studies evaluating the lunate unloading procedures, either experimental or theoretical have used a total of 100 to 145 Newtons compression load.[2,7-11] The rationale for this amount of load is, that would be experienced in vivo while grasping with a 1 kg of force.[8] However, it is not clear how much load is required, either repetitive or acute, to result in Kienböck's disease and during grasp, the applied force may reach 200 to 250 Newtons.[12] In the present study, we repeated the experiments using 140 and 210 Newtons. When 140 Newtons of load was applied, the results were comparable with the previous studies that, STT and SC fusions shifted the load from lunate to scaphoid in neutral position but CH fusion paradoxically loaded the lunate more (Table 1). However, when the load was increased by 50 percent (210 Newtons), the advantages of STT and SC fusions and the disadvantage of CH fusion were lost and similar distribution of loads with intact wrist at radioulnocarpal joint was observed in neutral position (Table 1). The explanation may be the number of the joints, from metacarpals to the forearm. In intact wrist, the loads should cross three joints; carpometacarpal, intermetacarpal and radioulnocarpal. However, when the bones of proximal and distal carpal rows are fused, as in STT and SC fusions, the number of the joints from metacarpals to scaphoid is decreased and more loads are borne by scaphoid than lunate in relatively small loads. When the load is increased to collapse all joints between metacarpals and forearm, the distribution of forces becomes identical to intact wrist. In CH fusion, no decrease in the number of the joints is produced. However, for the most loads borne by lunate, primarily come from capitate the load of lunate is increased by CH fusion in relatively small loads for the loads from the hamate are also directly transferred to capitate, then to lunate. When more loads are applied, the wrist joint again collapses and similar force distribution as in intact wrist and other carpal fusions is produced.

Our results suggest that, limited carpal fusions do not unload the lunate under 210 Newtons of force. However, loading in ulnar deviation seems as a possible mechanism for Kienböck's disease. It is not clear whether the limited carpal fusions limit ulnar deviation, for the commonly used evaluation systems do not include ulnar deviation values[13,14] but in the experimental study of Douglas et al.[15], all limited carpal fusions, except from the CH fusion, were found to limit carpal motion in all planes. They suggest that, due to the need for prolonged postoperative immobilisation and formation of scar tissue, the postoperative range of motion after an actual surgical procedure would be anticipated to be less than they had found.[15]

It seems logical, to suppose that Kienböck's disease is the result of excessive loading in ulnar deviation. During daily activities, the wrist joint is ulnar deviated and lunate bears more load than scaphoid[11] and grip strength increases with ulnar deviation.[16] For our results show that, the limited carpal fusions do not alter the load distribution at the wrist when the loads are increased by 50 percent, the possible mechanism of these procedures is the limitation of ulnar deviation of the wrist. This is in accordance with the results of joint levelling proceeding used to treat Kienböck's disease that, either shortening of the radius or lengthening of the ulna reduces the ulnar deviation of the wrist.[17,18] Additionally, it is well known that the individuals with ulna minus wrists, have a greater range of ulnar deviation than the others.[19]

In conclusion, our results seem to explain the paradox between the clinical and experimental studies, regarding CH fusions and how limited carpal fusions act in the treatment of Kienböck's disease. Of course these results need to be supported by clinical series by measuring the ulnar deviation pre and postoperatively.

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