Rev esp cir ortop traumatol. 2011;**55(3)**:224-230

ELSEVIER DOYMA

Revista Española de Cirugía Ortopédica y Traumatología

www.elsevier.es/rot

RESEARCH

Experimental study of the consequences of resection of the flexor retinaculum on the stability of the scaphoids

G. Salvà Coll,[a,*] M. García-Elías,[b] M. Llusá Pérez,[c] A. Rodríguez-Baeza[d]

[a] *Unidad de Cirugía de la Mano y Microcirugía, Instituto Ibacma y Hospital Son Llàtzer, Palma de Mallorca, Spain*
[b] *Cirugía de la Mano y Extremidad Superior, Instituto Kaplan, Barcelona, Spain*
[c] *Departamento de Anatomía, Facultad de Medicina, Universidad de Barcelona, Barcelona, Spain*
[d] *Departamento de Ciencias Morfológicas, Unidad de Anatomía y Embriología, Facultad de Medicina, Universidad Autónoma de Barcelona, Barcelona, Spain*

Received November 17, 2010; accepted January 25, 2011

KEYWORDS
Carpus;
Scaphoids;
Carpal tunnel;
Carpal instability

Abstract
Objective: To analyze the consequences of flexor retinaculum (FR) section on the kinetic behavior of the scaphoid, triquetrum and capitate bones under axial load.
Material and method: A 6 degree-of-freedom electromagnetic motion tracking device with sensors attached to the scaphoid, triquetrumcapitate and radius was used to monitor spatial changes in carpal bone alignment as a result of isometrically loading the main motor writs muscles. Six wrists from fresh cadavers were used, in which the principal motor tendons were subjected to loads proportional to physiological cross sectional area of each muscle. The experiment was carried out with the wrist in the neutral position, before and after the FR section.
Results: After FR section, the scaphoid showed less flexion ($P = .05$) and a higher degree of radial inclination ($P = .03$) compared to the same experiment with the FR intact. The kinetic behavior of the triquetrum did not change significantly.
Discussion: According to the results of this study, the isolated section of the FR did not produce greater instability of the scaphoid. If so, the scaphoid should have a higher degree of flexion, but exactly the opposite movement happens.
Conclusion: Resection of the FR alters the kinetic behavior of the scaphoid under axial load, but does not produce greater instability in the carpus. Pillar syndrome may not be as a result of scaphoid instability, but due to another type of dysfunction that needs to be determined in future studies.

*Corresponding author.
E-mail: gsalva@ibacma.com (G. Salvà Coll).

PALABRAS CLAVE
Carpo;
Escafoides;
Túnel carpiano;
Inestabilidad carpiana

Estudio experimental de las consecuencias de la sección del retináculo flexor sobre la estabilidad del escafoides

Resumen
Objetivo: Valorar de forma experimental las consecuencias de la sección del retináculo flexor (RF) en el comportamiento cinético del escafoides, piramidal y hueso grande, bajo carga axial.
Material y método: Utilizando sensores de posición y orientación, tipo Fastrak™, se realizó un registro de los cambios de orientación espacial del escafoides y piramidal en relación al radio, al aplicar una carga axial. Para ello se utilizaron 6 muñecas de cadáver fresco, cuyos principales tendones motores fueron sujetos a cargas proporcionales al área seccional fisiológica de cada músculo. El experimento se llevó a cabo en condiciones de carga isométrica, con la muñeca en posición neutra, antes y después de seccionar el RF.
Resultados: Tras la sección del RF, el escafoides manifestó una menor flexión (p = 0,05) y una mayor inclinación radial (p = 0,03) que cuando la misma carga se aplicó en la muñeca con RF íntegro. El comportamiento cinético del piramidal no cambió significativamente.
Discusión: Según los resultados de este trabajo, la sección aislada del RF no genera una mayor inestabilidad del escafoides. Si fuese así, el escafoides debería presentar un mayor grado de flexión y en cambio ocurre todo lo contrario.
Conclusión: La sección del RF modifica el comportamiento cinético del escafoides bajo carga axial, pero no genera mayor inestabilidad carpiana. El síndrome del pilar no debería ser entendido como la consecuencia de la desestabilización del escafoides, sino de otro tipo de disfunción a determinar en futuros estudios.

Introduction

Carpal tunnel syndrome is one of the most frequently-treated hand surgery pathologies. In cases where symptomatology is progressive, with pain and significant paresthesias, the treatment of choice is surgical decompression of the median nerve by resection of the anterior annular ligament or flexor retinaculum (FR) of the carpus. Despite the fact that the majority of patients improve with surgical treatment, there is a significant number of patients who present disabling postoperative symptoms, with constant pain in the proximal palmar scar together with loss of strength. This is the so-called "pillar pain syndrome". There has been speculation as to whether this type of complication is related to an alleged carpal instability.[1-4] According to this hypothesis, the FR would help to prevent scaphoid collapse by preventing its flexion under axial load. With the aim of clearing this up, a trial study was undertaken on the spatial changes of the scaphoid, triquetrum and capitate bones produced by applying an isometric axial load, in a neutral position, before and after resecting the FR.

Material and method

Six upper limbs belonging to fresh cadavers donated by the Faculty of Medicine at the Autonomous University of Barcelona were used to carry out this study. The mean age of the specimens was 77 years (range: 55-88 years); there were 3 males and 3 females, 4 left arms and 2 right arms, all with a type I lunate, that is, without an independent distal articular facet for the hamate bone. Preparation of the anatomical part consisted of skin and subcutaneous tissue resection, identification and isolation of the major wrist motor tendons in the middle third of the forearm, maintaining the retinaculum of the extensors and flexors intact. The tendons of the extensor carpi radialis longus (ECRL), abductor pollicis longus (APL), extensor carpi ulnaris (ECU), flexor carpi radialis (FCR) and flexor carpi ulnaris (FCU) in the middle third of the forearm were thus isolated. All fingers were disarticulated at the metacarpophalangeal joint. The dorsal carpal ligaments were identified and a limited capsular resection was undertaken so as to not damage the extrinsic dorsal radio-piramidal and transverse radiocarpal ligaments, or intrinsic ligaments so that sensors could be correctly fitted. The extensor carpi radialis brevis tendon had to be resected so that the scaphoid sensor could be correctly positioned. The anatomical part was placed in a support that was specially designed for this study, in an upright and neutral supine position with two Steinman nails placed in the radius and ulna. The wrist position was controlled by an intramedullary Kirschner wire in the third metacarpal. This wire was connected to a semicircular device joined to the upper part of the support, which allowed the wrist to be placed in any position for its subsequent isometric load. The support had a proximal-distal sliding mechanism in its upper part that allowed adjusting the curvature centre of the semicircular guide of

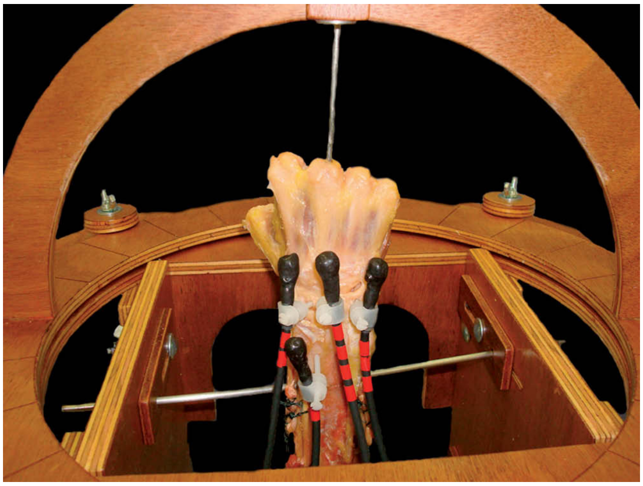

Figure 1 Anatomical part placed in an upright and neutral supine position on the support specifically designed for this study. The Fastrak™ sensors were placed on the radius, triquetrum, capitate bone and scaphoid with a screw and a nylon clamp.

the device to the carpal rotation axis at capitate head level (fig. 1). The tendons were connected to a system of pulleys with a thick nylon thread, to which weights were applied to simulate muscle forearm contraction. The Fastrak™ system (Polhemus Inc., Colchester, Vermont, USA) was used to register movement changes in the carpal bones. This consisted of placing sensors in the bones to be studied and creating an electromagnetic field where we could dynamically detect the position (in Cartesian coordinates X, Y and Z) and orientation (Euler angles: azimuth, elevation and rotation) in real time of each mobile element to be studied. Four sensors were used for this study, operating on a 30Hz refresh rate frequency and with a short range transmitter (specially designed for follow-up areas) that covered a radius of 2.54cm to 60.9cm. The precision of this system was 0.08cm for position and 0.15º for spatial orientation. The sensors were firmly placed on the dorsal area of the radius, scaphoid, triquetrum and capitate bones using nylon screws, and avoiding the use of metallic fixings, which could interfere with the electromagnetic field. Following recommendations from previous publications,[5-7] the load applied to each tendon was proportional to the transverse sectional area of ??the corresponding muscle and to the electromyographic activity present when fists are clenched. A load with an equivalent weight of 1.5 Newton (N) was placed on each tendon so as to mimic muscular tone at rest. Weights equivalent to 9.8N for APL, 24.5 N for ECRL, 14.7 N for ECU, 13.7 N for FCR and 21.5 N for ECU were used to mimic muscle contraction. The transmitter coordinate system and 4 receptors were calculated according to the longitudinal axis of the radius. The Z axis was defined along the longitudinal axis of the radius, the Y axis was established along the frontal plane perpendicular to the Z axis, and the X axis was located in the sagittal plane, perpendicular to the Z and Y axes. Consequently, the rotation around the Z axis (azimuth) corresponded to pronation and supination, rotation around the Y axis (elevation) corresponded to flexion and extension, and rotation around the X axis (rotation) corresponded to radial and ulnar tilt.

To assess the FR section effect, we compared the spatial position changes caused by axial load of the sensors located in the radius, scaphoid, triquetrum and capitate bones, before and after its section. Five consecutive determinations were carried out in all cases and the mean was used to determine the sensor changes of position. These measurements were statistically analysed using the Wilcoxon test for paired data, with SPSS v15 software. The difference was considered statistically significant when $p<0.05$.

Results

The data collected and statistical analysis are summarised in tables 1, 2 and 3. With the FR whole, the application of an axial load determined a synchronous bone movement in the flexed proximal row. The scaphoid flexes an average (± standard deviation) of 2.41º±0086º and the triquetrum, 2.41°±0.80°. Aside from the flexion, we also detected rotations on the transversal plane as scaphoid supination (0.60º±0.71º) and pyramidal pronation (0.14º±0.77º).

After the FR section, although the overall movement direction in its pronation/supination and flexion/extension was the same as when the FR was intact, the scaphoid magnitude of rotation registered statistically significant changes, with a lesser flexion ($p<0.05$) and greater radial tilt ($p<0.03$) (table 4). In contrast, the kinetic behaviour of the triquetrum after the FR section was not statistically different to that registered with a complete FR.

Discussion

Carpal tunnel syndrome is the most common peripheral compression neuropathy in the upper limbs.[1,8] There are more than 7,000 articles related to carpal tunnel syndrome and yet the best diagnostic and treatment method for this pathology, together with the results of the different surgical treatments used, are still disputed.[9]

The transverse palmar carpal ligament, also called the anterior annular ligament or (more commonly) flexor retinaculum (FR), has been classically defined as the palmar carpal tunnel limit. This structure originates on an ulnar level in the pisiform and uncinate apophysis of the hamate bone, and on a radial level in the scaphoid and trapezius ridge. According to Cobb et al,[10] the FR is made up of three segments: firstly, by the proximal segment, formed by a thickening of the antebrachial fascia; secondly, the transverse carpal ligament; and in the distal area, by the aponeurosis between the thenar and hypothenar muscles. Based on this study, Cobb et al emphasised the importance of carrying out greater release in cases of median nerve compression.

Despite the fact that carpal tunnel surgery is considered curative, there are many patients who have postoperative complications, such as scar pain, so-called pillar syndrome, recurrence of symptoms and loss of strength. These symptoms appear regardless of which type of surgery has been carried out, and whether this is open or endoscopic.[9,11-13] We are still unable to establish precisely what the causes of

Table 1 Descriptive statistics of information gathered before and after the flexor retinaculum section at a scaphoid level

	Tendon load with a whole retinaculum			Tendon load with retinaculum section		
	Pronation/supination	Flexion/extension	Radial/ulnar tilt	Pronation/supination	Flexion/extension	Radial/ulnar tilt
Total No.	6	6	6	6	6	6
Mean	0.60	−2.42	0.01	0.37	−1.78	0.46
Median	0.53	−2.26	0.00	0.42	−1.81	0.46
Standard mean error	0.29	0.35	0.12	0.40	0.15	0.12
Minimum	−0.37	−3.82	−0.30	−1.27	−2.16	−0.01
Maximum	1.58	−1.42	0.44	1.46	−1.21	0.89
Standard Dev	0.72	0.87	0.29	0.99	0.36	0.30
Variance	0.51	0.76	0.08	0.97	0.13	0.09

Interpretation of the results: pronation (-), supination (+), flexion (-), extension (+), ulnar tilt (-), radial tilt (+).

Table 2 Descriptive statistics of information gathered before and after the flexor retinaculum section at a triquetrum level

	Tendon load with a whole retinaculum			Tendon load with retinaculum section		
	Pronation/supination	Flexion/extension	Radial/ulnar tilt	Pronation/supination	Flexion/extension	Radial/ulnar tilt
Total N	6	6	6	6	6	6
Mean	−0.15	−2.41	−0.11	−0.33	−1.75	0.45
Median	−0.20	−2.38	0.04	−0.17	−1.45	0.28
Standard mean error	0.32	0.33	0.22	0.31	0.50	0.39
Minimum	−1.26	−3.46	−0.98	−1.40	−3.67	−0.49
Maximum	0.97	−1.37	0.37	0.57	−0.25	1.56
Standard Dev	0.78	0.80	0.53	0.77	1.21	0.96
Variance	0.61	0.65	0.28	0.59	1.47	0.92

Interpretation of the results: pronation (-), supination (+), flexion (-), extension (+), ulnar tilt (-), radial tilt (+).

Table 3 Descriptive statistics of information gathered before and after the flexor retinaculum section at a capitate bone level

	Tendon load with a whole retinaculum			Tendon load with retinaculum section		
	Pronation/supination	**Flexion/extension**	**Radial/ulnar tilt**	**Pronation/supination**	**Flexion/extension**	**Radial/ulnar tilt**
Total N	6	6	6	6	6	6
Mean	2.41	−0.34	−0.39	2.03	−0.32	0.44
Median	2.09	−0.29	−0.36	2.16	−0.47	0.39
Standard mean error	0.49	0.24	0.21	0.68	0.27	0.22
Minimum	1.46	−1.07	−1.14	−0.47	−1.21	−0.29
Maximum	4.72	0.66	0.22	3.97	0.66	1.07
Standard Dev	1.20	0.59	0.51	1.68	0.67	0.53
Variance	1.43	0.35	0.26	2.81	0.44	0.29

Interpretation of the results: pronation (-), supination (+), flexion (-), extension (+), ulnar tilt (-), radial tilt (+).

Table 4 Contrast statistics. Mean load comparison of all tendons before and after flexor retinaculum resection carried out with the Wilcoxon test for paired data

	P/S Scaphoid	**F/E Scaphoid**	**RD/UD Scaphoid**	**P/S Pyramidal**	**F/E Pyramidal**	**RD/UD Pyramidal**	**P/S Capitate Bone**	**F/E Capitate Bone**	**RD/UD Capitate Bone**
Z	−.105[a]	−1.992[b]	−2.201[b]	−.524[a]	−1.153[b]	−1.782[b]	−.524[a]	−.105[b]	−2.201[b]
Bilateral asyntot. sig.	.917	.046	.028	.600	.249	.075	.600	.917	.028

Results are considered statistically significant when the value is<0.05.
F/E: flexion/extension; P/S: pronation/supination; RD/UD: radial deviation/ulnar deviation.
[a]Based on positive ranges; [b]based on negative ranges.

these complications are. It is obvious that carpal tunnel decompression must have some kind of biomechanical effect on the carpal. There are different studies in the medical literature that have assessed the effect of FR resection on the transverse carpal arch structure, the kinetic behaviour of the scaphoids and carpal tunnel volume.[2-4,14,15] However, the relationship of these changes to possible dysfunctions that can appear after the operation continue is unknown.

García-Elías et al[2] carried out a cadaver study on the mechanical characteristics of the transverse carpal arch and analysed the elastic properties of the ligaments involved in this structure. In this study, they concluded that FR is not a vitally important structure in maintaining the carpal arch, given that its resection only reduces the structural rigidity of the arch by 7.5%. However, the intercarpal ligaments that connect the distal row bones are essential for maintaining carpal tunnel stability. In another study on 31 patients published by the same group,[3] the dynamic behaviour of the transverse carpal arch was assessed, as determined by the distance between two Kirschner wires placed on the uncinate apophysis of the hamate bone and on the trapezius, when flexing and extending the wrist and before and after FR resection. Despite the fact that an increase in distance between the wires was recorded after the procedure (an average of 11%), no substantial change was found in the dynamic behaviour of the transverse carpal arch.

Guoa et al[14] used a 3-dimensional model of the wrist's finite elements and carried out a computerised carpal biomechanical analysis after the FR was sectioned. In this study, they concluded that such sectioning provoked an overall radial tilt increase of the carpal bones and that the load distribution on a carpal joint level was modified.

Ishiko et al[15] carried out a cadaver trial study to determine the kinetic repercussion on the scaphoid in ulnar and radial deviation movements, when the transverse carpal ligament is sectioned. They analysed scaphoid behaviour in 6 cadaver forearms before and after sectioning the transverse carpal ligament, using a computerised camera to monitor this. The data obtained from this study showed statistically-significant changes in scaphoid position when the wrist was placed in a position of ulna deviation starting from 15º. A statistically-significant change in scaphoid extension with the wrist at 5° of radial deviation and with 5º or more of ulnar deviation was also found. Once the FR had been sectioned, a larger scaphoid extension starting from 15° of ulnar deviation was found. Once the skin incision had been closed, there was a reduced movement of scaphoid extension, but this movement was still greater and with statistically-significant differences from 20º of ulnar deviation. In that study, they concluded that FR sectioning alters the scaphoid kinetic behaviour and that this alteration could have long term consequences, and contribute to some of the complications related to carpal tunnel syndrome surgery.

Bones under axial load in the proximal row tend to rotate synchronously,[7] despite there being significant differences in magnitude of rotation between the three bones in the proximal row. Due to the peculiar arrangement of the palmar ligaments and scaphoid trapezium and trapezoid dorsoradial ligaments, the scaphoid can rotate more in flexion and pronation than in lunate, while the triquetrum is the bone most firmly connected to the distal row. If the dorsal scapholunate ligaments or the lunopiramidal palmar ligament are intact, these angular rotation differences cause torque and progressive intercarpal coaptation between the scaphoid and the lunate, and between the lunate and the pyramidal, hence contributing to its stability. If there is scapholunate ligament injury, the scaphoid is no longer constrained by the rest of the carpal bones and, due to its slant with respect to the radial axis, tends to collapse in an abnormal position of pronation and flexion; simultaneously, the lunate is drawn into an abnormal extension under the influence of the ulnar arcuate ligament. This anomalous situation is known as DISI (from the English terminology initials "dorsal intercalated segment instability"). Scaphoid inflexion is restricted proximally by the scapholunate ligament and distally by scaphoid trapezium and trapezoid ligaments.[16] Consequently, when we discuss scaphoid instability, we refer to scaphoid collapse in flexion and pronation.

When we analyse results obtained from the cadaver trial study carried out, we see that on applying an isometric axial load, there is a tri-dimensional movement at carpal bone level, similar to those described by Kobayashi et al.[7] Using a trial kinetic analysis model with a biplaner radiographic method, those investigators concluded that the carpal bones under load produced a flexion movement, ulnar tilt and supination. The agreement of the results obtained from our study compared to those of Kobayashi et al confirm the validity of our trial model, by obtaining similar results with different measurement methods. We see from our study that there is a synchronous flexion movement in the proximal row. The scaphoid moves in a supine direction and tilts radially, while the pyramidal pronates and tilts to the ulnar. This movement produces an increase in the coaptation of the articular surfaces between the scaphoid and lunate, and between the lunate and pyramidal. This coaptation decreases the tension generated at interosseous ligament level and has a potential protective effect on these ligaments against a possible lesion. In the distal row, the capitate bone flexes, supines and tilts radially. The magnitude of supination of the distal row is 4 times greater than the magnitude of the proximal. This difference causes an increase in stability at the midcarpal joint level through tension of the palmar midcarpal ligaments.

When the FR is sectioned, there are statistically-significant differences at the scaphoid level. Under isometric load, the scaphoid magnitude of flexion decreases around 27%. The scaphoid radial tilt degree also significantly increases. This increase in carpal bone radial tilt confirms the findings of Guoa et al.[14] The reason for the biomechanical behaviour changes of these bones is probably related to the disruption of the FR connection to the pisiform and the hamate, and to the scaphoid and trapezium (fig. 2). Once sectioned, the load distribution that crosses through the carpal is modified in such a way that muscles that provoke a radial tilt - FCR, APL and ECRL- predominate when referring to tilts. The decrease in scaphoid flexion could be related to the restrictive effect that the FR has on scaphoid extension.

In this study, we see that resection of the anterior annular ligament causes a change in the biomechanical scaphoid

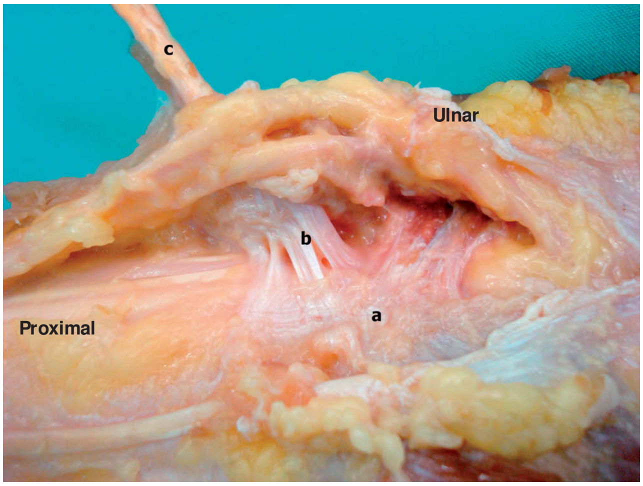

Figure 2 Anatomical preparation showing the flexor retinaculum of the wrist, connections to the triquetrum and the union between the aponeurosis of the thenar and hypothenar muscles. [a]Flexor retinaculum, [b]Flexor retinaculum connection to the triquetrum and [c]Flexor carpi ulnaris.

behaviour in such a way that when this is sectioned, there is less scaphoid flexion and radial deviation movement not only in the proximal but also the distal row. Despite this change in kinetic behaviour, if the scaphoid is destabilised, it would present greater degrees of flexion and pronation under axial load, an effect not observed in our study.

To summarise, FR resection alters scaphoid kinetic behaviour under axial load, but does not cause greater instability due to this. We have yet to see up to which point this change can explain the appearance of certain types of dysfunctions appearing after the operation in carpal tunnel syndrome surgery.

Evidence level

Evidence level III.

Financing

Grant from the Fundación SECOT for research projects 2008.

Grant from Societat Catalana de Cirurgia Ortopèdica i Traumatología to undertake doctoral thesis 2008.

Conflict of interest

The authors declare no conflict of interest.

References

1. Brooks JJ, Schiller JR, Allen SD, Akelman E. Biomechanical and Anatomical Consequences of Carpal Tunnel Release. Clin Biomech. 2003;18:685—93.
2. García-Elías M, An KN, Cooney III WP, Linscheid RL, Chao EYS. Stability of the transverse carpal arch: An experimental study. J Hand Surg Am. 1989;14:277—82.
3. García-Elías M, Sánchez-Freijo JM, Salo JM, Lluch AL. Dynamic changes of the transverse carpal arch during flexion-extension of the wrist: Effects of sectioning the transverse carpal ligament. J Hand Surg Am. 1992;17:1017—9.
4. García-Elías M, An KN, Cooney III WP, Linscheid RL, Chao EYS. Transverse Stability of the Carpus. An Analytical Study. J Orthop Res. 1989;7:738—43.
5. An KN, Horii E, Ryu J. Muscle function. In: An KN, Berger RH, Cooney W, editors. *Biomechanics of the Wrist Joint*. New York: Springer; 1991. p. 157—69.
6. Brand PW. Relative tension and potential excursion of muscles in forearm and hand. J Hand Surg Am. 1981;6:209—19.
7. Kobayashi M, Berger RA, Nagy L, Linscheid RL, Uchiyama S, Ritt MJ, et al. Normal kinematics of carpal bones: a threedimensional analysis of carpal bone motion relative to the radius. J Biomech. 1997;30:787—93.
8. Lin R, Lin E, Engel J, Bubis JJ. Histo-mechanical aspects of carpal tunnel syndrome. Hand. 1983;15:305—9.
9. Bickel KD. Carpal tunnel Syndrome. J Hand Surg Am. 2010;35:147—52.
10. Cobb TK, Dalley BK, Posteraro RH, Lewis RC. Anatomy of the flexor retinaculum. J Hand Surg Am. 1993;18:91—9.
11. Citron ND, Bendall SP. Local symptoms after open carpal tunnel release: A randomized prospective trial of two incisions. J Hand Surg Br. 1997;22:317—21.
12. Boya H, Ozcan O, Oztekin HH. Long-term complications of open carpal tunnel release. Muscle & nerve. 2008;38:1443—6.
13. Dias J, Bhowal B, Wildin CJ, Thompson JR. Carpal Tunnel decompression. Is lengthening of the flexor retinaculum better than simple division? J Hand Surg Br. 2004;29:271—6.
14. Guoa X, Fan Y, Li Z-M. Effects of dividing the transverse carpal ligament on the mechanical behaviour of the carpal bones under axial compressive load: A finite element study. Med Eng Phys. 2008;31:188—94.
15. IshikoT, Puttlitz CM, Lotz JC, Diao E. Scaphoid kinematics behaviour after division of the transverse carpal ligament. J Hand Surg Am. 2003;28:267—71.
16. García-Elías M, Geissler WB. Carpal instability. In: Green DP, Hotchkiss RN, Pederson WC, Wolfe SW, editors. *Green's operative hand surgery*. Philadelphia: Elsevier Churchill Livingstone; 2005. p. 535—604.