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Three-dimensional morphometric analysis of the coracohumeral distance using magnetic resonance imaging

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Abstract

There have been no studies investigating three-dimensional (3D) alteration of the coracohumeral distance (CHD) associated with shoulder motion. The aim of this study was to investigate the change of 3D-CHD with the arm in flexion/internal rotation and horizontal adduction. Six intact shoulders of four healthy volunteers were obtained for this study. MRI was taken in four arm positions: with the arm in internal rotation at 0°, 45°, and 90° of flexion, and 90° of flexion with maximum horizontal adduction. Using a motion analysis system, 3D models of the coracoid process and proximal humerus were created from MRI data. The CHD among the four positions were compared, and the closest part of coracoid process to the proximal humerus was also assessed. 3D-CHD significantly decreased with the arm in 90° of flexion and in 90° of flexion with horizontal adduction comparing with that in 0° flexion ($P<0.05$). In all subjects, lateral part of the coracoid process was the closest to the proximal humerus in these positions. *In vivo* quasi-static motion analysis revealed that the 3D-CHD was narrower in the arm position of flexion with horizontal abduction than that in 0° flexion. The lateral part on the coracoid process should be considered to be closest to the proximal humerus during the motion.

Introduction

Subcoracoid impingement has been considered as a potential cause of anterior shoulder pain since the first description by Goldthwait.[1] Although several authors indicated that subcoracoid impingement was an uncommon pathology caused by the contact of the coracoid process with the lesser tuberosity,[2,3] its clinical entity has not yet been fully established.

There have been radiologic studies that deal with the assessment of coracohumeral distance (CHD). Some authors believed that a narrowed CHD measured either with CT scan or MRI could be used as a clinical index for subcoracoid impingement.[4-13] Gerber *et al*.[10] measured CHD in 47 normal shoulders using axial CT images. They reported that the distance was 6.8 mm for the internal rotated arm with flexion, and 8.7 mm with adduction. Bonutti *et al*.[11] and Friedman *et al*.[12] measured CHD with MRI and found that it was less than 11 mm in patients with shoulder pain. On the other hand, Giaroli *et al*.[6] concluded that the diagnostic role of CHD in subcoracoid impingement was limited, although CHD measured with axial MR images showed a significant difference between surgically confirmed subcoracoid impingement patients and controls. Cetinkaya *et al*.[13] also suggested the limitation of CHD in predicting potential subcoracoid impingement. All these authors adopted two-dimensional (2D) measurement method using a single-plane image. Since, however, both coracoid process and the lessor tuberosity are not always placed on the same plane when their interval was the narrowest, it could be more precise to use three-dimensional (3D) images for the CHD measurement.

There have been no studies investigating the measurement of CHD using 3D images (3D-CHD). The purpose of this study was to compare the CHD among four arm positions using *in vivo* 3D motion analysis.[14-18]

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Key words: Coracohumeral distance; 3D motion analysis; Subcoracoid impingement; Coracoplasty.

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Materials and Methods

Four healthy subjects participated in the present study. All subjects were males and their mean age was 36 years (28-53 years). The subjects had no history of major disorders involving their shoulders. Among 8 shoulders, 2 shoulders from 2 subjects were excluded for this study, because of a bony cyst in the greater tuberosity or arthritic change in the acromioclavicular joint. The ranges of motion among 6 shoulders were measured as follows: 167°±4° (mean±standard deviation) in abduction, 165°±7° in flexion, 80°±15° in external rotation at 0° of abduction, and 31°±8° in horizontal adduction at 90° of flexion. This study was approved by our Institutional Review Board. All of the subjects agreed with the testing protocol and gave their consent for participation in accordance with the Ethical Committee procedures of our institution.

Acquisition of three-dimensional-magnetic resonance imaging

MR images of the scapula and the humerus were obtained using a 3.0-T system (MAGNETOM Verio; Siemens Medical Solutions, Munich, Germany). According to the previous studies,[15,19] a 3D-FLASH method was employed with repetition time/echo time of 12/5.8 ms, 0.8 mm slice thickness. Flip angle was 20° with 240×240 mm^2 field-of-view, and 450×512 in plane acquisition matrix. All subjects lied in supine position with a loop coil around the shoulder. MRI was performed with the arm in four different arm positions: (A) 0° of flexion, (B) 45° of flexion, and (C) 90° of flexion, and (D) 90° of flexion with maximal horizontal adduction as shown in Figure 1. In each position, the arm was internally rotated at 90°. The arm position was confirmed by measuring the angle with a goniometer, and held with the custom-made device. MRI data were saved in Digital Imaging and Communications in Medicine (DICOM) format, which were imported to a computer workstation for further image processing such as segmentation and volume registration using software, Virtual Place M (AZE Inc., Tokyo, Japan).

Segmentation of scapula and humerus

As shown in the previous studies, segmentation was defined as extracting the scapula and humerus required for processing.[14-18] Contours of cortical bones of the scapula and humerus with the arm in 0° of flexion were semi-automatically segmented from 3D MRI using intensity thresholding technique for each shoulder.

Volume registration

Volume registration was defined to calculate, by a unit of voxel, a registration matrix which is expressed as 4 by 4 when an object moves from a position to another position. By using these methods, four registration matrices were obtained for each humerus and scapula; 0° to 30° of abduction, 0° to 45° of flexion, 0° to 90° of flexion, and 0° to 90° of flexion with horizontal flexion. Previous study has verified the accuracy of this method; the mean absolute rotational error of 0.24°-0.43°, and the mean absolute translational error of 0.41-0.52 mm.[20]

Assessment of the three-dimensional-coracohumeral distance and localization in coracoid process

The distance between the coracoid process and the proximal humerus among the four arm positions were calculated using software, Visualization Toolkit (Kitware Inc., New York, NY, USA). The surface model of coracoid process was created by removing the scapula except the level of its base, as shown in Figure 2. The surface model of the proximal humerus was also created. The distance between these two components was measured (3D-CHD) to compare among four arm positions. In addition, the part on coracoid surface that located closest to the proximal humerus in each arm position was identified using the same software program. In order to determine the closest points to the proximal humerus in each subjects, the coracoid surface was divided into 6 parts (M1-3 and L1-3, Figure 2). The part that included the closest point in each arm position was recorded.

Statistical analysis

Statistical analyses were performed using the softwares, GraphPad Prism (version 5.0, San Diego, CA, USA). The Friedman test was used to determine the significance of differences for the values of 3D-CHD among the four positions (0°, 45°, and 90° flexion, and 90° flexion with horizontal flexion). The level of significance was set at P=0.05.

Results

Change of three-dimensional-coracohumeral distance

Mean 3D-CHD from six shoulders was 14.0 mm with the arm at 0° of flexion, 10.7 mm at 45° flexion, 9.7 mm at 90° flexion, and 9.6 mm at 90° flexion with horizontal

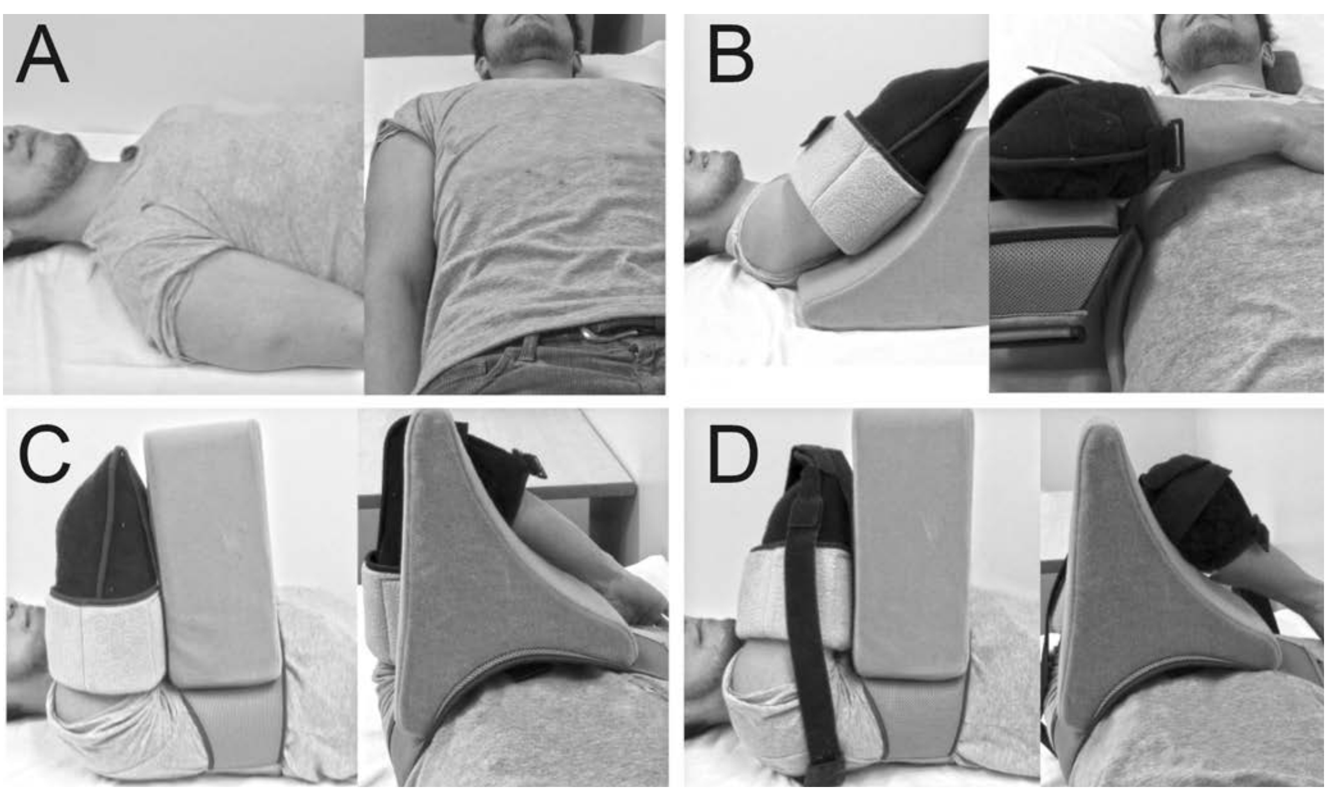

Figure 1. The arm was held in four arm positions: (A) 0° of flexion, (B) 45° of flexion, (C) 90° of flexion, and (D) 90° of flexion with maximum horizontal adduction. In each position, the arm was internally rotated at 90°.

adduction (Figure 3). Statistically significant differences were found among the arm positions: both the arm at 90° flexion and at 90° flexion with horizontal adduction showed significantly shorter 3D-CHD than that at 0° flexion (P<0.05). The arm position that showed the shortest 3D-CHD was 90° flexion in three shoulders, 45° flexion in two shoulders, and 90° flexion with maximum horizontal adduction in one shoulder.

Localization of the closest part of the coracoid process to the proximal humerus

In each arm position, the point closest to the humerus was not always seen in the same part of coracoid process. The arm position that provided the shortest 3D-CHD also varied among 6 shoulders (2 shoulders: 45° of flexion, 3 shoulders: 90° of flexion, and 1 shoulder: 90° of flexion with maximum horizontal adduction). However, in all 6 shoulders, the point serving the shortest 3D-CHD among 4 arm positions located in the lateral aspect of the coracoid process (L3 in 4, and L2 in 2 subjects, Table 1).

Discussion

Previous studies indicated that the impingement could be caused between the proximal humerus and the coracoid process, particularly in the shoulder motion of flexion with internal rotation.[3,10] In addition, passive maneuver of flexion with horizontal abduction has been clinically used as the provocative test for subcoracoid impingement, namely coracoid impingement test[5] or modified Kennedy-Hawkins test.[21] The present study clearly demonstrated that 3D-CHD significantly altered in association with shoulder flexion with horizontal adduction, which simulated the coracoid impingement test. These results might support the feasibility of this test, as a series of motion to bring the proximal humerus closer to the coracoid process. Three-dimensional analysis also revealed that the arm position with the shortest CHD varied among six shoulders. To date, most studies have adopted the clinical use of CHD from MRI which examined with the patients' arm held in adduction with or without internal rotation (Table 2).[4-13] However, Giaroli *et al.*[6] and Cetinkaya *et al.*[13] suggested that CHD is poorly predictive for the diagnosis of subcoracoid impingement syndrome when acquired via routinely performed MRI. We believed that 3D measurements of the CHD could be a better tool for the clinical diagnosis of subcoracoid impingement syndrome, which might also contribute to elucidate its true pathogenesis.

This study showed that with the arm in flexion or flexion/horizontal adduction caused the CHD shorter than the other positions. These findings were observed in normal healthy volunteers without any shoulder complaint. In other words, these findings are thought to be physiological findings, not pathological findings. When we see the narrowing of CHD in patients with shoulder pain, we must be careful in interpreting the narrowing phenomenon, whether it is pathologic or physiologic.

The present study also investigated the localization of the closest part of coracoid process to the proximal humerus among four arm positions. Interestingly, all 6

Table 1. Distribution of projected parts of the coracoid process closest to the proximal humerus under the four types of arm positions (unit: number of subjects).

Part	Arm position			
	A	B	C	D
M1	1 (0)			
M2				
M3	1 (0)			1 (0)
L1	2 (0)			
L2		1 (0)	1 (1)	1 (1)
L3	2 (0)	5 (2)	5 (2)	4 (0)

A, 0° of flexion; B, 45° of flexion; C, 90° of flexion; D, 90° of flexion with maximum horizontal adduction; M, medial part of the coracoid process (M1=upper, M2=middle, M3=lower); L, lateral part of the coracoid process (L1=upper, L2=middle, L3=lower). Numbers in brackets represent the number of subjects who represented shortest three-dimensional-coracohumeral distance throughout the four positions.

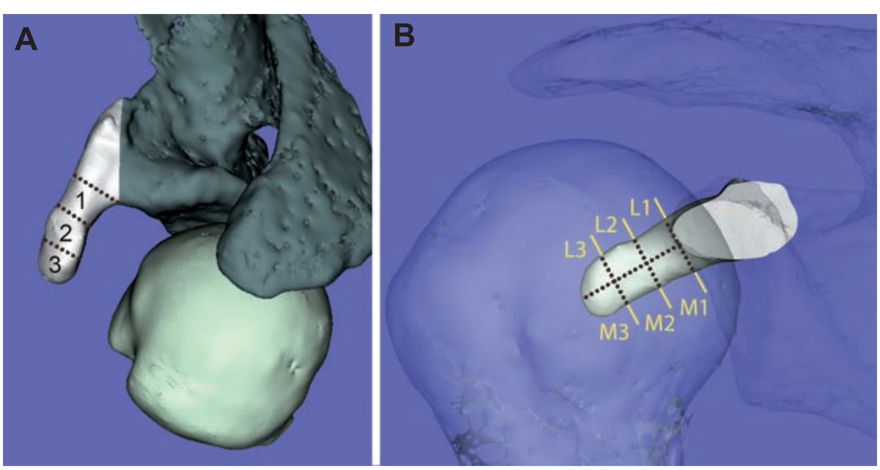

Figure 2. Three-dimensional model of the coracoid process and the proximal humerus created from the MRI data. The surface models of the coracoid process (white) and the proximal humerus (light green) were created using the custom motion analysis system (A). For the assessment of the surface of coracoid process projected closest to the proximal humerus (B), the surface was divided into 6 parts (M1-3 and L1-3) to be applied the closest point to any part.

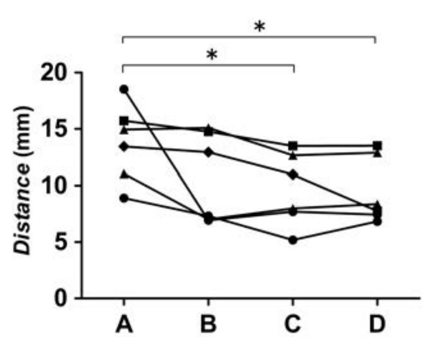

Figure 3. Three-dimensional coracohumeral distance (3D-CHD) with the arm position in 0°, 45°, and 90°of flexion, and 90° of flexion with horizontal abduction. The 3D-CHD at 90° flexion (C) and 90° flexion with horizontal adduction (D) were significantly lesser than those at 0° flexion (A). *P<0.05.

Table 2. Summary of previous literature using coracohumeral distance.

Authors	Journal	CHD measurements	Subjects (n)	Pertinent findings with CHD
Cetinkaya *et al.*[4] (in press)	Arthroscopy	MR (axial, sagittal)	SSC tear (N=78) and other pathologies (N=141)	Axial CHD was different between groups (mean, 8.2 *vs* 8.7 mm, P<0.05), whereas sagittal CHD was not (8.1 *vs* 8.7 mm, P=0.17). 31% with SSC tear had axial CHD≤7 mm; 41% with other pathologies had P>0.05
Balke *et al.*[13] (2016)	Am J Sports Med	MR (axial)	SSC tear (degenerative N=44, traumatic N=39) and intact SSC (N=20)	CHD with degenerative SSC tear was smaller than that with traumatic tears or intact SSC (mean, 8.6 *vs* 10.2, 10.4 mm, P<0.001)
Lanz *et al.*[7] (2013)	Arthroscopy	MR or CT arthrography (axial)	Patients with arthroscopic repair of SSC tear (N=39)	CHD did not significantly increase from preoperatively (mean, 9.7 mm) to postoperatively (10.1 mm, P=0.09).
Giaroli *et al.*[6] (2006)	Am J Roentgenol	MR (axial, sagittal)	Patients with subcoracoid impingement (N=19) and control subjects (N=41)	Axial CHD was different between individuals with or without subcoracoid impingement (mean, 8.6 *vs* 9.9 mm, P=0.01); whereas, this was poorly predictive (area under the receiver operating characteristic curve, 0.73).
Richards *et al.*[8] (2005)	Arthroscopy	MR (axial)	Patients with arthroscopic repair of SSC tear and control subjects (both, N=35)	CHD in patients with SSC repair was smaller than CHD in control group (mean, 5.0 *vs* 10.0 mm, P≤0.0001).
Tan *et al.*[9] (2002)	Am J Orthop	MR (axial)	Shoulders with routine clinical MR (N=100)	CHD values measured with axial MR was similar to published value using CT
Friedman *et al.*[12] (1998)	Orthopedics	MR (axial)	Symptomatic (N=75) and asymptomatic shoulder (N=75)	In maximal internal rotation, mean CHD in symptomatic and asymptomatic shoulders was 5.5 and 11 mm
Bonutti *et al.*[11] (1993)	J Comput Assist Tomogr	MR (axial)	Symptomatic (N=35) and asymptomatic shoulder (N=24)	Subcoracoid impingement could be identified in maximum internal rotation with distance<11 mm
Gerber *et al.*[10] (1987)	Clin Orthop Relat Res	CT (axial)	Normal shoulder (N=47)	CHD was smaller in flexed arm than in adducted arm (mean, 6.8 *vs* 8.7 mm)
Current study	Orthop Rev	Three-dimensional MR	Normal shoulder (N=6)	-

CHD, coracohumeral distance; MR, magnetic resonance; SSC, subscapularis; CT, computed tomography.

shoulders showed a similar pattern for the closest point on the coracoid process, with some varieties of the arm position; the lateral part on the coracoid process showed closest to the proximal humerus. Recently, several authors reported the arthroscopic coracoplasty as one of the surgical options for the subcoracoid impingement syndrome.[2,22-24] Our findings concerning the localization for closest area on the coracoid process might be of some help for surgeons to consider the extent of resection in this procedure.

There are several limitations in the present study. First, the measurement was done with the subjects in the supine position. There might be some differences in CHD between the supine position and the upright position with the shoulder loaded by gravity or the weight of the arm.[3,17] Second, we analyzed the movement patterns estimated under sequential static conditions: it may not completely reflect the shortest CHD during dynamic motion. From this perspective, 2D-3D registration technique using fluoroscopy might be more precisely evaluated than our method using MRI. In contrast, the fluoroscopic technique has a disadvantage of radiation exposure; moreover, it might be difficult to reproduce accurate joint motions in the technique, especially for the joint with large range of motion, *e.g.* the shoulder joint.[15,24,25] Third, the present study included a small number of the subjects. Although statistically significances were found in the alteration of 3D-CHD among the arm positions, further studies might be required to explain the age- or sex-related changes of the shortest 3D-CHD as well as of the localization on the coracoid process closest to the proximal humerus.

Conclusions

In conclusion, *in vivo* quasi-static motion analysis showed that 3D-CHD shortened in association with the arm position for the coracoid impingement test. We also found the lateral part on the coracoid process became closest to the proximal humerus during the motion.

References

1. Goldthwait JE. An anatomic and mechanical study of the shoulder joint, explaining many of the cases of painful shoulder, many of the recurrent dislocations and many of the cases of brachial neuralgias or neuritis. Am J Orthop Surg 1909;6:579-606.
2. Gaskill TR, Braun S, Millett PJ. Multimedia article. The rotator interval: pathology and management. Arthroscopy 2011;27:556-67.
3. Osti L, Soldati F, Del Buono A, Massari L. Subcoracoid impingement and subscapularis tendon: is there any truth? Muscles Ligaments Tendons J 2013;3:101-5.
4. Cetinkaya M, Ataoglu MB, Ozer M, et al. Subscapularis tendon slip number and coracoid overlap are more related parameters for subcoracoid impingement in subscapularis tears: a magnetic resonance imaging comparison study. Arthroscopy (in press).
5. Dines DM, Warren RF, Inglis AE, Pavlov H. The coracoid impingement syndrome. J Bone Joint Surg Br 1990; 72:314-6.
6. Giaroli EL, Major NM, Lemley DE, Lee J. Coracohumeral interval imaging in subcoracoid impingement syndrome on MRI. Am J Roentgenol 2006;186: 242-6.
7. Lanz U, Fullick R, Bongiorno V, et al. Arthroscopic repair of large subscapularis tendon tears: 2- to 4-year clinical and radiographic outcomes. Arthroscopy 2013;29:1471-8.
8. Richards DP, Burkhart SS, Campbell

SE. Relation between narrowed coracohumeral distance and subscapularis tears. Arthroscopy 2005;21:1223-8.
9. Tan V, Moore RS Jr, Omarini L, et al. Magnetic resonance imaging analysis of coracoid morphology and its relation to rotator cuff tears. Am J Orthop 2002;31: 329-33.
10. Gerber C, Terrier F, Zehnder R, Ganz R. The subcoracoid space. An anatomic study. Clin Orthop Relat Res 1987;215:132-8.
11. Bonutti PM, Norfray JF, Friedman RJ, Genez BM. Kinematic MRI of the shoulder. J Comput Assist Tomogr 1993;17:666-9.
12. Friedman RJ, Bonutti PM, Genez B. Cine magnetic resonance imaging of the subcoracoid region. Orthopedics 1998;21:545-8.
13. Balke M, Banerjee M, Greshake O, et al. The coracohumeral distance in shoulders with traumatic and degenerative subscapularis tendon tears. Am J Sports Med 2016;44:198-201.
14. Goto A, Moritomo H, Murase T, et al. In vivo elbow biomechanical analysis during flexion: three-dimensional motion analysis using magnetic resonance imaging. J Shoulder Elbow Surg 2004; 13:441-7.
15. Omori Y, Yamamoto N, Koishi H, et al. Measurement of the glenoid track in vivo as investigated by 3-dimensional motion analysis using open MRI. Am J Sports Med 2014;42:1290-5.
16. Sahara W, Sugamoto K, Murai M, et al. The three-dimensional motions of glenohumeral joint under semi-loaded condition during arm abduction using vertically open MRI. Clin Biomech 2007;22:304-12.
17. Sahara W, Sugamoto K, Murai M, Yoshikawa H. Three-dimensional clavicular and acromioclavicular rotations during arm abduction using vertically open MRI. J Orthop Res 2007;25:1243-9.
18. Yang C, Goto A, Sahara W, et al. In vivo threedimensional evaluation of the functional length of glenohumeral ligaments. Clin Biomech 2010;25:137-41.
19. Algin O, Gokalp G, Ocakoglu G. Evaluation of bone cortex and cartilage of spondyloarthropathic sacroiliac joint: efficiency of different fat-saturated MRI sequences (T1-weighted, 3D-FLASH, and 3DDESS). Acad Radiol 2010;17:1292-8.
20. Ishii T, Mukai Y, Hosono N, et al. Kinematics of the upper cervical spine in rotation: in vivo three-dimensional analysis. Spine 2004;29:139-44.
21. Freehill MQ. Coracoid impingement: diagnosis and treatment. J Am Acad Orthop Surg 2011;19:191-7.
22. Lo IK, Burkhart SS. Arthroscopic coracoplasty through the rotator interval. Arthroscopy 2003;19:667-71.
23. Park JY, Lhee SH, Oh KS, et al. Is arthroscopic coracoplasty necessary in subcoracoid impingement syndrome? Arthroscopy 2012;28:1766-75.
24. Moro-oka TA, Shiraishi H, Iwamoto Y, Banks SA. Modified gap-balancing technique in total knee arthroplasty: evaluation of the postoperative coronal laxity. Knee Surg Sports Traumatol Arthrosc 2010;18:375-80.
25. Tamaki M, Tomita T, Watanabe T, et al. In vivo kinematic analysis of a high-flexion, posterior-stabilized, mobile-bearing knee prosthesis in deep knee bending motion. J Arthroplasty 2009; 24:972-8.