



Dynamic acromiohumeral interval changes in baseball players during scaption exercises

Melissa D. Thompson, MEd, ATC*, Dennis Landin, EdD,
Phillip A. Page, PhD, PT, ATC, CSCS

Department of Kinesiology, Louisiana State University, Baton Rouge, LA, USA

Hypothesis: Elevation of the arm during a dynamic scaption exercise will result in a progressive narrowing of the acromiohumeral interval (AHI); however, the addition of a load will not significantly affect the AHI in healthy baseball players.

Materials and methods: Thirteen healthy baseball players performed a seated scaption exercise from 0° to 90°, with and without a normalized additional load. Dynamic AHI intervals were measured using digital fluoroscopic videos with the arm at the side, and at 30°, 45°, 60°, and 75° of humeral elevation.

Results: The mean AHI for unloaded and loaded scaption decreased significantly ($P < .001$) from the arm at the side (12.7 mm) until 45° (4.9 mm), further changes in the mean AHI between 45°, 60°, and 75° were not significantly different. Generally, loaded scaption resulted in smaller AHI values at 45°, 60°, and 75°; however, only the differences at 60° ($P = .005$) and 75° ($P = .003$) were significant.

Discussion: Narrowing of the AHI during dynamic motion was similar to previous reports of static AHI, with the exception of the trend towards widening of the AHI seen at 75° during both conditions. The additional AHI narrowing observed at 60° and 75° during the loaded exercise may indicate that scapular positioning is more influential in this range.

Conclusion: An additional AHI narrowing of 11% during loaded scaption, did not result in any clinical impingement during the exercise, but may have more serious implications in other healthy and pathologic populations.

Level of evidence: Basic Science Study.

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Although the mechanisms behind the development of subacromial impingement syndrome (SIS) are debated, the functional theory proposes that narrowing of the subacromial space may be injurious to the supraspinatus as it passes through the coracoacromial arch and inserts on the greater tuberosity of the humerus.^{4,8,31,36} Development of SIS has been related to overuse in the overhead arm

position,³⁹ with increased incidence in overhead athletes^{7,29} and those who participate in frequent overhead work-related tasks, such as construction workers.⁵ Cadaver analysis^{8,13} and in vivo magnetic resonance imaging (MRI) studies^{17,18} indicate that as the humerus moves into flexion or abduction, decreases in subacromial space may result in “impingement” of the rotator cuff tendons and subacromial bursa between the humeral head and the acromion.

Previous research has established the acromiohumeral interval (AHI), or distance, as a quantitative method for

*Reprint requests: Melissa D. Thompson, MEd, ATC, LSU, Department of Kinesiology, 112 HPL Fieldhouse, Baton Rouge, LA 70803.

E-mail address: Mhargr2@lsu.edu (M.D. Thompson).

evaluating the size of the subacromial space.^{10,11,15-19,21,45} Narrowing of the AHI has been observed during arm elevation in healthy individuals,^{11,19,21} with even greater narrowing observed during muscle activity in individuals with SIS.¹⁸ Scapular retraction⁴⁸ and adduction muscle activity¹⁹ have both been shown to widen the space, and Desmuelles et al¹¹ reported a strong positive relationship between the reduction of AHI narrowing and functional improvement in SIS patients. Alterations in AHI appear to be related to SIS and may be important in the therapeutic treatment and prevention of this disease, yet little is known about the changes in AHI during dynamic arm motions.

Previous investigations have reported that isometric activity of the abductor muscles appears to decrease AHI approximately 53%,^{19,22} but it is unknown if the AHI is affected differently by static (isometric) or dynamic muscle activity. Based on Neer's³⁹ description of SIS as an "overuse condition" and the increased incidence of SIS in overhead athletes^{7,29} who are engaged in repetitive dynamic arm movements, it seems necessary to study AHI changes during similar types of functional muscle activity. Baseball athletes have demonstrated larger passive AHI values than matched controls at 90° of abduction (frontal plane)⁵³; however, because these results were conducted with passive arm positions, it is difficult to determine how muscle dynamic muscle activity may affect this at-risk population.

The only dynamic *in vivo* study of AHI was performed on the contralateral shoulder of rotator cuff repair patients.² Biplane radiographs and reconstructed computed tomography (CT) images showed the subacromial space ranged from 1.2 to 7.1 mm during loaded, active arm elevation in the frontal plane between 0° and 120°. An AHI of 1.2 mm at approximately 120° represents the smallest reported AHI; however, most AHI analysis has been performed in the more functional scapular plane.

Recent advances in the image quality of digital fluoroscopic video (DFV) have made it attractive for imaging the shoulder joint during static and dynamic motion. DFVs have been used to study subacromial spurs,³³ scapulohumeral rhythm,³⁴ subtle glenohumeral joint instabilities,⁴³ and superior migration of the humeral head.⁵⁰ Teyhen et al⁵⁰ demonstrated excellent reliability when using DFV during dynamic arm elevation in the scapular plane. DFV exposes the individual to significantly less radiation than conventional radiographs, without a reduction in diagnostic accuracy.²⁴ In addition to the enhanced safety for participants, DFV allows for dynamic analysis during functional and upright positions and may provide a more viable method for capturing *in vivo* AHI.

Clinicians also have limited knowledge of the direct effect of rehabilitation exercises on AHI. Scaption is a commonly prescribed shoulder exercise that has been used for assessment of scapular dysfunction²⁵ and for strengthening of the rotator cuff musculature.^{12,37} The scaption exercise is often performed as part of a shoulder

strengthening and maintenance program in overhead athletes, yet little is known about the affect of this exercise on the AHI in this population. Scaption involves raising the arm from the resting position to approximately 90° in the plane of the scapula, which is 30° to 40° anterior to the frontal plane. The addition of external loads during the scaption exercise is commonly prescribed for strengthening purposes, but appears to increase scapular protraction,⁴⁴ which has been linked to decreases in AHI.⁴⁸ However, loaded scaption increases the activity of the rotator cuff muscles,¹ which should lead to increased stability of the humeral head on the glenoid during abduction and thus better maintenance of subacromial space.

Because clinicians often prescribe this exercise for healthy and pathologic patients, it is important to understand how AHI is directly affected during loaded and unloaded conditions. Therefore, this study used digital fluoroscopy to examine changes to AHI during an unloaded and loaded scaption exercise in healthy baseball athletes. We hypothesize a gradual decrease in the AHI during arm elevation, and we expect 60° to be the smallest AHI value. We do not believe that the addition of the load will result in any significant changes in AHI in baseball players.

Materials and methods

This study received approval from Louisiana State University Institutional Review Board (IRB # 2778). Each participant signed an informed consent form approved by the Louisiana State University IRB.

We recruited 16 healthy National Collegiate Athletic Association (NCAA) division I baseball players from a southeastern university. Inclusion criteria included no history of shoulder disorders and no current shoulder, arm, neck, or back pathology. To ensure that study participants were currently without pathology, we administered a screening questionnaire and consulted with the team's certified athletic trainer. We also screened all participants for hooked acromion morphology according to the Bigliani criteria³ using a standard outlet fluoroscopic radiograph.⁴⁰ All participants had either a flat (type 1) or slightly curved (type 2) acromion; none of the participants exhibited hooked (type 3) acromions or bony osteophytes within the subacromial region. All participants were right hand dominant. One participant was excluded because he was unable to fit within the C-arm, and two participants were excluded because of improper image recording, resulting in data from 13 participants.

Instrumentation

We obtained all DFV sequences with the Orthoscan HD Mini C-Arm (Orthoscan, Scottsdale, AZ), which had a resolution of 1000 × 1000 pixels per image. The images were collected at 30 Hz and recorded using a digital video recorder. Videos were transferred to a laptop computer and analyzed using OsiriX 3.6.1 open source imaging software for MacOS X (Apple Computer Corp, Cupertino, CA), which converted all DFVs into sequences of still frames. Pixel width calibration was determined during pilot

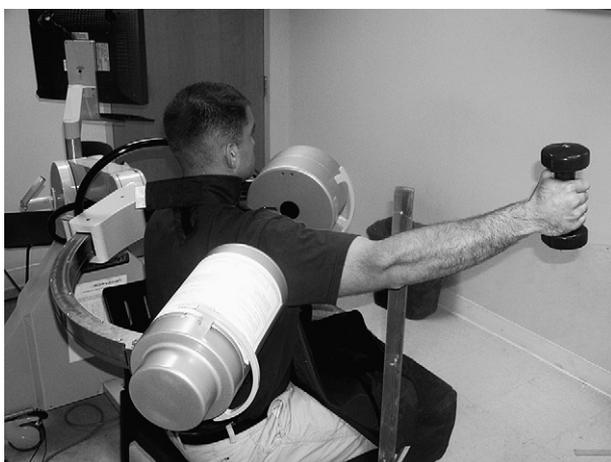


Figure 1 Setup and participant positioning.

testing using a radiopaque calibration device on the image intensifier of the C-arm. Based on data from pilot testing, a consistent pixel width calibration value was obtained and used for all subsequent data.

Imaging protocol

The DFVs were obtained in a manner similar to that described by Poppen and Walker⁴⁶ and Teyhen et al.⁵⁰ Owing to limitations in positioning of the C-arm, participants were seated with the elbow fully extended, palm facing forward, and the thumb towards the ceiling (Figure 1). The C-arm was rotated 30° from the frontal plane, such that the x-ray beam was perpendicular with the plane of the scapula and adjusted for each participant until a single glenoid rim was present on the image. The posterior shoulder was placed in direct contact with the image intensifier to minimize image distortion. The height of the C-arm was adjusted for each participant so that the acromion and humeral shaft were adequately visible.

A board was placed in the participant's scapular plane to ensure that the participants moved in a consistent scapular plane during all trials. A device was placed on the board to prevent scaption past 90° during each trial. The participants were instructed to remain in the same comfortable, upright posture during the trials. One researcher monitored arm elevation during the trials as well as any compensatory trunk, shoulder, or arm movements.

Participants performed dynamic arm elevations in the scapular plane from the arm positioned at the side to 90°, with and without resistance. The hand remained in neutral position, with the palm facing forward and thumb towards the ceiling. The amount of resistance was adjusted for each participant based on limb anthropometrics^{27,28} calculated using body weight, height, and arm length. The formula used to determine resistance was modified from one previously used in research with upper²⁷ and lower²⁸



Figure 2 Radiographic analysis image of humeral angle and acromiohumeral interval.

extremity muscles. This formula ensured a comparable level of effort across the participants on the loaded trials. Average resistance used was 3.6 kg (range, 2.6-4.4 kg).

The participants were instructed to perform 3 consecutive trials of unloaded and loaded scaption, with approximately 3 minutes between the unloaded and loaded conditions. Each arm elevation trial, from the arm at the side up to 90°, was performed at a speed of 3 seconds and was controlled using visual and auditory cues. DFVs were only captured on the last 2 trials of each condition to minimize radiation exposure to the participants.

Radiographic analysis

The best sequence of images out of 2 captured trials for each condition was used to calculate AHI and humeral angle. AHI was calculated in a method similar to Petersson and Redlund-Johnell,⁴⁵ which was defined as the smallest vertical distance between the dense cortical line of the acromion and the most superior aspect of the humerus. Humeral angle was defined as the angle between a line drawn on the shaft of the humerus and a line drawn vertically, representing the axis of the body (Figure 2). One blinded researcher (M.T.) reviewed all frames and performed all measurements. A musculoskeletal radiologist, who reviewed images for 4 of 13 randomly selected participants, verified measurement accuracy.

AHI was only measured on the image frames that corresponded to the following humeral angles: arm at the side (as close to 0° as possible for each participant) and at 30°, 45°, 60°, and 75°. A relatively small 15.24-cm viewing

window on the C-arm did not allow for adequate view of the acromion past a 75° humeral angle; therefore, although elevation was continued to 90°, data could be reliably captured only to 75°. Humeral angle values were selected to allow comparisons with the results from previous studies.^{18,19}

Statistical analysis

During pilot testing, an intraclass correlation coefficient (ICC) model (2,1) was used to measure the test-retest reliability, and the standard error of the measurement (SEM) was calculated to determine variability due to random error.⁵⁴ Short-term test-retest reliability was established during pilot testing of 5 healthy college men by comparing AHI within participants with the arm at the side (ICC = .98, SEM = .01 mm) and at 30° (ICC = .96, SEM = .02 mm), 45° (ICC = .99, SEM = .02 mm), 60° (ICC = .97, SEM = .01 mm), and 75° (ICC = .75, SEM = .03 mm) of elevation from 2 unloaded trials captured approximately 5 minutes apart. Long-term test-retest reliability was determined by retesting the loaded trials of 5 healthy baseball players with 9 months between trials (rest ICC = .96, SEM = .08 mm; 30° ICC = .30, SEM = .24 mm; 45° ICC = .43, SEM = .12 mm; 60° ICC = .82, SEM = .12 mm; 75° ICC = .98, SEM = .06 mm).

The effect of resistance on AHI during scaption was tested with a 2 × 5 repeated measures analysis of variance. The independent variables used were resistance (unloaded and loaded) and arm position (arm at the side and at 30°, 45°, 60°, and 75°). The dependent variable was the AHI, measured in millimeters. The α level was set at .05. Post hoc analysis, when applicable, was performed using paired *t* tests with a Bonferroni correction. Data analysis was accomplished with OsiriX 3.6.1 open source software, Excel Professional Edition 2003 (Microsoft Corp, Redmond, WA), and SPSS 17 software (SPSS Inc, Chicago, IL).

Results

Data were collected on 13 healthy NCAA division I baseball players. Age was 20.1 ± 1.1 years, weight was 85.3 ± 6.7 kg, and height was 179.3 ± 6.8 cm. The mean AHI for both unloaded and loaded scaption decreased significantly ($P < .001$) from the arm at the side (12.7 mm) to 45° (4.9 mm), further changes in the mean AHI between 45°, 60°, and 75° were not significantly different (main effect for arm position, $F = 87.3$, $P < .001$). Generally, loaded scaption resulted in smaller AHI values at 45°, 60°, and 75° but only the differences at 60° ($P = .005$) and 75° ($P = .003$) were significant (main effect for resistance, $F = 6.7$, $P = .024$). The difference between unloaded and loaded at 45° was not significant ($P = .247$); however, the small effect size (.297) for the resistance and position interaction meant we did not

have enough participants to detect whether a true difference existed at this arm position. Mean AHI for the unloaded and loaded scaption exercises at each humeral angle are presented in Table I.

Discussion

Results from the analysis of dynamic AHI during scaption indicate decreases in AHI from the resting position through 60° and are similar to previous passive and static AHI analyses. Arm elevation from 0° to 30° has typically been described as the scapular setting phase,^{23,42} in which the scapula contributes little to total arm elevation. Our findings of large reductions in the AHI between the arm at rest and at 30° support the concept that initial humeral elevation with little or no scapular upward rotation results in significant narrowing of the AHI during early arm elevation. Although we observed further narrowing of the AHI until 60°, we suspect that increases in scapular upward rotation in this range contributed to relatively less narrowing of the AHI compared with the 0° to 30° range.

Our unloaded scaption findings with the arm at the side (12.8 ± 2.1 mm) are larger than those reported by Wang et al⁵³ (7.8 ± 3.6 mm) and Desmuelles et al¹¹ (9.9 ± 1.5 mm); however, we captured AHI with the arm at the side during transition from eccentric lowering of the arm to concentric raising of the arm, not at rest. Capturing AHI during uninterrupted dynamic motion represents functional arm motion and likely results in a different neuromuscular and kinematic pattern compared with static positioning. In addition, variability in humeral position with the arm at the side, due to anatomic and body type variations, also may contribute to the differences between the studies.

It is possible that differences in AHI exist based on patient positioning (supine, seated, or standing); however, we found similar results between our seated scaption and the supine positioning used in MRI studies with isometric muscle activity^{18,22} at both 30° and 60°. Although the standing position may contribute slightly to scapular stabilization through kinetic chain mechanisms, further research is needed to determine if the seated or standing positions contribute to neuromuscularly related changes in AHI. Only one other study has examined AHI at 45°,¹¹ and our findings are much smaller, but significant differences in methodology exist between the 2 studies, such as plane of movement, ultrasound vs DFV, and static vs dynamic motion. Although not significantly different from the AHI at 60°, a trend towards a widening of the AHI at 75° does occur. Observations during data analysis showed that at a humeral angle of 75°, most of the participant's greater tuberosities appeared to have passed through the sub-acromial space and were no longer directly under the lateral edge of the acromion, leading to a wider AHI interval. No measurements were taken, but the passage of

Table I Descriptive statistics for acromiohumeral intervals (AHI) at selected humeral angles during unloaded and loaded scaption

Angle	Unloaded AHI	Unloaded	Loaded AHI	Loaded
	(Mean \pm SD)	SEM	(Mean \pm SD)	SEM
0°	12.8 \pm 2.1 mm	.575 mm	12.5 \pm 2.3 mm	.632 mm
30°	6.9 \pm 2.7 mm	.743 mm	7.0 \pm 2.5 mm	.696 mm
45°	5.2 \pm 2.1 mm	.591 mm	4.7 \pm 1.4 mm	.387 mm
60°	5.3 \pm 2.1 mm	.594 mm	4.1 \pm 1.7 mm	.483 mm
75°	6.1 \pm 3.3 mm	.911 mm	4.6 \pm 2.5 mm	.692 mm

SD, standard deviation; SEM, standard error of measurement.

the greater tuberosity through the subacromial space appeared to occur between 60° and 75° for most participants, which is similar to previous analysis using cadaveric specimens.^{6,8}

A slight difference of 6° between humeral angle calculations from radiographs and from clinical and goniometric measurements has been previously reported.⁴⁶ Given possible examiner error in goniometric measurements, the humeral angles we report are likely similar, but not identical, to the arm angles observed by clinicians. Differences in reporting AHI based on calculation of arm range of motion and planes of motion make it difficult to compare our results to the only other dynamic analysis of AHI by Bey et al;² however, the trend in a decreasing AHI from rest through abduction appears to be similar to their results. Our ability to analyze dynamic AHI from the arm at the side to only 75° represents a limitation in our results, because previous investigators have indicated further narrowing of the AHI at 90°.^{16,18,53}

No previous research has studied the effect of loaded vs unloaded on AHI during dynamic shoulder elevation. We found that adding a load to a scaption exercise results in a significantly smaller AHI at 60° and 75° in healthy baseball athletes. The size of the AHI at 75° during unloaded scaption represented 48% of the AHI present with the arm at the side, whereas the size of the AHI during loaded scaption at 75° represents only 37% of the AHI present with the arm at the side. Although loaded scaption appears to result in an additional narrowing of 11% at 75°, no participants reported pain during the exercise, indicating that the additional reduction caused by the weight did not result in acute impingement in these individuals.

Although we did not directly measure any scapular positions or motions, it is possible that narrowing of the AHI during loaded scaption may be related to differences in shoulder kinematics caused by the addition of the load. Similar loading of the arm during elevation has been shown to decrease scapular upward rotation^{26,35} and increase scapular protraction.⁴⁴ Protraction of the scapula may result in a more anterior acromial position and is known to cause narrowing of the subacromial space at rest.^{20,48} Failure of the scapula to upwardly rotate during humeral elevation increases the scapulothoracic rhythm and is believed to result in a more

inferiorly positioned acromion.^{14,25,30,32,49,52} During humeral elevation, the encroachment of the greater tuberosity to the acromion has been found to occur between 48° and 90°,¹³ thus a more anterior or inferior acromion due to scapular kinematic alterations is likely to result in significant narrowing of the AHI in this range.

It is important to note that differences have been documented in the resting scapular posture between dominant and nondominant arms^{41,51} in baseball athletes and controls,³⁸ thus our results may not correspond to individuals outside of the baseball population. Wang et al⁵³ were the only others to present AHI values specific to baseball players, although they used static ultrasound images to measure the AHI. They demonstrated relatively larger passive AHI values at 0° and 90° in the frontal plane for healthy athletes compared with anthropometrically matched controls, yet not in the scapular plane. More dynamic AHI analysis between athletes and nonathletes is warranted.

The addition of the load did not affect the AHI between the arm at the side and 45°. Alpert et al¹ reported peak muscle activity for the rotator cuff muscles between 30° and 60° and noted the largest increases in muscle activity with additional loads during this range. Between 0° and 60°, the deltoid produces a significant upward shear force on the humerus, which may result in superior humeral head migration and narrowing of the AHI. The rotator cuff muscles counteract this upward shear force and keep the humeral head centered on the glenoid while the scapular stabilizer muscles affect the relative position of the acromion. Thus, increased rotator cuff or scapular stabilizer muscle activity in the lower arm elevation positions may assist in maintaining AHI in the ranges of 0° to 45°. Further research is necessary to determine the relationship of these two muscle groups in regards to maintenance of AHI during dynamic arm motions.

Supine MRI examinations of 3 patients with rotator cuff tears reported a 3-mm reduction of AHI at 30°, but only a 1-mm reduction at 90°,¹⁸ which provides further support for the influence of the rotator cuff on AHI in lower arm elevation positions. The strength of the rotator cuff muscles, specifically external rotation, has been shown to result in decreased subacromial pressures, measured in vivo

with pressure transducers implanted in the subacromial space.⁵⁵ We presume that our healthy, baseball players who regularly participate in rotator cuff strengthening exercises had strong and functional rotator cuff muscles that were successful in maintaining AHI, despite the added load, during these lower arm elevations. Although we did not measure shoulder strength, all participants were currently engaged in a similar shoulder strength training programs. Fatigue of the rotator cuff muscles has been shown to increase upward migration of the humeral head in healthy individuals.^{9,50} Our participants, however, only performed 3 repetitions of scaption and rested between loaded and unloaded trials, so it is unlikely that fatigue would be a factor in these differences. Further dynamic AHI examinations are necessary to determine exactly how those with untrained or dysfunctional rotator cuff muscles may respond to loaded scaption exercises in the 0° to 60° range of arm elevation.

To our knowledge, we are the first study to directly record dynamic AHI during loaded and unloaded scaption using DFV. Previous studies have used DFV only to capture humeral head migration⁵⁰ during dynamic arm movements. DFV cannot capture of all the kinematic factors involved in defining AHI, but it does allow for dynamic analysis using methods of radiographic image acquisition and measurement frequently used to diagnose rotator cuff injury.^{10,15,45} Although our AHI findings were similar to previous MRI studies with muscle activity,^{17,18,22} limitations due to 2-dimensional viewing and lack of ability to visualize soft tissue structures, such as articular cartilage and the supraspinatus tendon, do exist in this method of AHI analysis. Despite the limitations, the use of DFV adds an important dynamic component to the understanding of subacromial space changes during arm elevation.

Short-term test-retest reliability analysis done during pilot testing indicated excellent reliability between testing sessions performed on the same day. Long-term test-retest reliability revealed that some variability exists in the early phases of arm elevation from 0° to 45°; however, good to excellent reliability occurred during the later phases of arm elevation. The lack of a significant *F* value during ICC analysis and low SEM values indicate that systematic error was not a factor in the poor reliability during the early phases of arm elevation. High intrasubject variability for scapular positioning and shoulder kinematics during the scapular setting phase (0° to 30°) of arm elevation is well accepted in the literature^{23,34,42,47} and may significantly contribute to the variability seen only in the low ranges of arm elevation. Furthermore, the good to excellent reliability observed at humeral angles of 60° and 75° supports the concept of differences in reliability based on range of motion. From these test-retest results, we believe that DFV can provide very reliable intrasubject analysis of dynamic AHI during scapular plane elevation (0° to 75°); however, caution should be exercised when comparing results in the

lower ranges of elevation when significant time exists between sessions.

Conclusions

We found significant reductions in AHI during dynamic scaption exercises with even greater reductions in AHI noted at 60° and 75° during loaded scaption in healthy baseball athletes. Because of the approximately 11% further reduction in AHI with the load, we urge clinicians to be cautious in their use of loaded scaption exercises, especially in cases where AHI may already be narrow or in cases of current subacromial inflammation. We recommend that more research be done during functional arm activities to determine which activities are safe for athletes and patients with SIS. The differences between loaded and unloaded AHI seem to suggest that scapular position may be a key factor in AHI at this position; however, more investigation into the direct relationship of scapular position, rotator cuff muscle activity, and AHI are necessary before any firm conclusions can be made.

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