Introduction

Rotator cuff disease has been recognized as one common cause of shoulder pain and functional disability in the adult population. Its definitive etiologies remain controversial and are regarded as multifactorial. These factors can be divided into extrinsic and intrinsic factors. Intrinsic factors originate within the tendon itself. These manifest as degenerative processes, hypovascularity, inflammation, and oxidative stress. Extrinsic factors are either external compression on or shearing of the rotator cuff. This is also known as impingement syndrome of the shoulder.1–4 Previous reports observed frequent incidence of hypertrophic acromial edges and noted its association with rotator cuff tears. The proliferative spurs and ridges on the anterior lip and on the undersurface of the anterior process of the acromion are signs of subacromial impingement and rotator cuff syndrome. Anterior acromioplasty can enhance the subacromial space and decompress the rotator cuff.1–4 Numerous studies contribute to Neer’s principle of external mechanical compression to the rotator cuff.1–4

There are several classifications of acromial morphology. Bigliani et al.3 proposed a flat (type I), curved (type II), and hooked
(type III) acromion on outlet view radiographs. A type III acromion was commonly found with subacromial impingement and rotator cuff syndrome. Tucker et al. describes an experience with an unusual type of acromial spur, a keeled acromion on the Rockwood caudal tilt view (RW), which was associated with bursal-sided and full-thickness rotator cuff tears. Oh et al. classified acromial spurs into six types, according to their morphologies, and stated that the most common heel-type spur is a risk factor for full-thickness rotator cuff tears.

Although a supraspinatus outlet radiograph (SOL) can classify the acromial morphology, there have been reports on its poor reliability and poor reproducibility. When comparing with two-dimensional computer tomography, SOL views show a higher rate of underestimation.

The main purpose of this study is to determine the morphology of acromion and acromial spurs in the supraspinatus outlet (SOL) and Rockwood caudal tilt (RW) views using three-dimensional computed tomography scans (3D-CT) of the shoulders. We hypothesize that the combination of acromial morphology from SOL and RW views of the shoulder from 3D-CT reconstruction yields good reproducibility and reliability in classifying acromial types in patients with shoulder disorders.

Materials and methods

Inclusion and exclusion criteria

This study was conducted with the official approval of the human ethical committee of Thammasat University No.MTU-EC-OT-0-164/57. We included all patients who fulfilled indications for 3D-CT shoulder reconstruction. Exclusion criteria were patients with a history of shoulder surgery (e.g. rotator cuff repair) and patients with marked deformity of the acromion (e.g. rotator cuff tear arthropathy and Charcot joint disease).

Study design

This study is a descriptive analytic study of 108 shoulders in 91 patients who met the inclusion criteria. The 3D-CT of the shoulders were performed at Thammasat University Hospital from January of 2012 to June of 2014. The shoulder conditions were classified as: Normal Shoulder (contralateral shoulders of bilateral CT scan ordered for planning of shoulder replacement, CT scans with proximal humerus fracture without significant scapular or acromial pathology, CT scans with shoulder instability and normal appearance of the acromion). Osteoarthritic (OA) Shoulder (consists of both primary and secondary osteoarthritis). Irreparable Rotator Cuff (RC) Tear Shoulder (includes CT scans with RC tears but without significant arthropathy that were sent pre-operatively for planned reverse total shoulder replacement). We excluded two rotator cuff tear arthropathy shoulders.

Attainment and reconstruction of patient anatomical data

A spiral, Philips 256-slice, Brilliance iCT scanner with 0.625 mm slice thickness (Cleveland, Ohio, U.S.A.) was used to achieve the anatomical topology of the shoulder. Data from the 3D-CT was saved in Digital Imaging and Communications in Medicine (DICOM) format and subsequently processed into three-dimensional software (3D-Slicer, version 4.3.1) to provide three-dimensional geometric models of the shoulder. The three-dimensional models created were adjusted manually in the 3D software program to provide proper supraspinatus outlet and Rockwood caudal tilt views by two orthopaedic surgeons analyzing the results as independent observers.

We collected and classified the acromial morphology from SOL 3D-CT view into 5 types as follows: type I - flat, type II - curved, type III - hooked, type IV - curved with anterior traction, and type V - others (such as gull-wing appearance) as shown in Fig. 1. The prevalence and reliability of the classifications were assessed.

The acromial morphology from RW 3D-CT were also collected and categorized into 4 types: type I - flat to small, type II - keeled, type III - keeled, and type IV - irregular spur. This is seen in Fig. 2. The prevalence and reliability of the classifications were evaluated.

For validating the 3D-CT classification, we delineated the intra- and inter-observer reliability of the system. Two, independent, fellowship-trained sports medicine surgeons (AA and ST) analyzed and labeled images using this classification system, independently. The intra-observer test by the both evaluators were performed and repeated in two-weeks.

Statistical analysis

Inter-observer and intra-observer reliability of the acromial morphology and spurs in the SOL 3D-CT views, RW 3D-CT views, and the combination of both views (SOL & RW) were calculated by Linear Weighted Kappa with 95% CI with Jackknife’s method. The level of agreement based on an intraclass correlation coefficient was graded according to McHugh criteria as: none (0.00–0.19), minimal (0.20–0.39), weak (0.40–0.59), moderate (0.60–0.79), strong (0.80–0.89), and almost perfect (0.90–1.00). Statistical analysis of the results was conducted using STATA version 13.0.

Results

108 shoulders of 91 patients were enrolled in the study. All demographic data are shown in Table 1.

The acromial morphology taken from SOL views concluded that type II-curved is the most common type. In order of prevalence, type II-curved had a percentage of 68.52%, type IV-curved with anterior traction spur comprised of 20.37%, type I-flat holds 6.48%, and type III-hooked holds 3.70%. Morphology in the ‘others’ category, defined as type V, consisted of the gull-wing appearance and was found along with os acromiale. Type V had a frequency and percentage of 0.93%.

The acromial morphology observed from RW views showed that the most common is type I-flat. In order of prevalence, type I-flat

![Type I](image1)

**Fig. 1.** Acromion morphology from the supraspinatus outlet 3D-CT view were classified in 5 types: type I (flat), type II (curved), type III (hooked), type IV (curved with anterior traction spur (red arrow)), and type V (others; gull-wing appearance).
had a percentage of 45.37%, type II-heeled holds 35.18%, type III-keeled holds 16.67%, and type IV-irregular holds 2.78%. The combination of two views (SOL and RW) established that the three most common combined types are the curved/flat (SOL II/RW I), with a percentage of 35.18%, curved/heeled (SOL II/RW II) comprised of 28.70%, and curved with anterior traction spur/keeled (SOL IV/RW III) comprised of 10.18%.

The relationship between shoulder conditions and the acromial types is shown in Table 2. The subgroup analysis reveals that normal shoulders have more curved-type morphologies (type II SOL) than irreparable rotator cuff tear shoulders in SOL [80.95% vs. 48.39%, p-value = 0.001]. However, there was no significant difference between normal and OA shoulders in type II SOL [80.95% vs. 57.14%, p-value = 0.057].

Shoulders with rotator cuff tears have more curved with anterior traction spur morphologies (type IV SOL) than normal shoulders in SOL [41.94% vs. 9.52%, p-value<0.001]. Nonetheless, there was no significant difference between RC tears and the OA shoulder in type IV SOL [41.94% vs. 21.43%, p-value = 0.183].

From the RW views, normal shoulders have more flat-type morphologies (type I RW) than rotator cuff tear shoulders [55.56% vs. 22.58%, p-value = 0.003]. Moreover, rotator cuff tear shoulders have more keeled-type morphologies (type III RW) than normal shoulders in RW [35.48% vs. 6.35%, p-value<0.001]. However, there is no significant difference in type III RW between RC tear and OA shoulders [35.48% vs. 21.43%, p-value = 0.346].

The association between SOL and RW types using the chi-square test reveals that 6 of 7 patients (85.71%), with flat type in SOL (type I SOL), have higher rates of the flat type in RW (type I RW) than the other SOL type (42.57% of 43/101 shoulders, p-value = 0.027). Moreover, there was a significant association between the hooked type in SOL (type III SOL) and the keeled type in RW (type III RW) (p-value<0.001) with 100% (4/4 shoulders), in the hooked SOL, having the keeled type as compared to the other SOL types (13.46% of 14/104 shoulders).

Linear Weighted Kappa analysis was calculated, which concluded that the intra-observer reliability of SOL had a weak-to-

### Table 1: Demographic data of the 3D-CT shoulders.

| Characteristic                          | Value       |
|----------------------------------------|-------------|
| Sex (n = 91)                           |             |
| Male                                   | 48 (52.75%) |
| Female                                 | 43 (47.25%) |
| Age (in years)                         | 57.51 (15–87) |
| Mean (Min–Max)                         | 57.51 (15–87) |
| Side                                   |             |
| Right                                  | 56 (51.85%) |
| Left                                   | 52 (48.15%) |
| Shoulder conditions (n = 108)          |             |
| Normal Shoulder                        | 63 (58.33%) |
| OA Shoulder (primary and secondary)    | 14 (12.96%) |
| Irreparable RC Tear                    | 31 (28.70%) |

Fig. 2. Acromion morphology from the Rockwood 3D-CT view were classified in 4 types; type I (flat to small, flat or less than 2 mm spur), type II (heeled, quadrangular spur like the heel of a shoe), type III (keeled, central downward-facing spur like a sailboat’s keel), and type IV (irregular spur).
strong agreement. Results were 0.828 (95%CI: 0.716–0.945, p-value<0.001), with a 95.33% agreement from evaluator1, and 0.475 (95%CI: 0.288–0.672, p-value<0.001), with an 88.47% agreement from evaluator2. The inter-rater of the SOL has a minimal-to-moderate agreement as the results are 0.782 (95%CI: 0.662–0.907, p-value<0.001), with a 94.08% agreement in the first read, and 0.344 (95%CI: 0.157–0.539, p-value<0.001), with a 85.36% agreement in the second read.

The intra-observer reliability of the RW has a moderate-to-almost-perfect agreement. The results are 0.752 (95%CI: 0.652–0.860, p-value<0.001), with a 93.46% agreement from evaluator1, and 0.903 (95%CI: 0.833–0.974, p-value<0.001), with a 97.20% agreement from evaluator 2. The inter-observer reliability of the RW has a moderate-to-strong agreement as the results are 0.854 (95%CI: 0.777–0.936, p-value<0.001), with a 95.95% agreement in the first read, and 0.737 (95%CI: 0.634–0.847, p-value<0.001), with a 92.83% agreement in the second read. All data on intra- and inter-observer reliability are summarized in Table 3.

### Discussion

Rotator cuff disease is a common cause of shoulder pain and functional disability. Neer's principle of external mechanical compression to the rotator cuff is a widely accepted conceptual theory. Many studies correlate different characteristics of the acromion with rotator cuff tears and impingement syndrome. Acromioplasty is a popular procedure used for surgical treatment of rotator cuff tears and subacromial impingement syndrome. The benefits of acromioplasty in rotator cuff surgery remains controversial. Many comparative studies reported no significant differences in post-operative results of rotator cuff repair between cases, with and without, acromioplasty. However, acromioplasty could improve visualization and expand the working area in the subacromial space in arthroscopic surgery.

The understanding of acromial morphology could guide surgeons to perform adequate subacromial decompression and acromioplasty. Hence, the Rockwood caudal tilt view (RW) and supraspinatus outlet radiographs (SOL) are useful for pre-operative assessment in rotator cuff tear patients. Unfortunately, the disadvantages of the supraspinatus outlet view on plain radiographs are the poor reliability, poor reproducibility, and underestimation when compared to the 2D-computer tomography scans.[10,11]

This study used 3D-CT reconstruction to determine the morphology of the acromion and acromial spurs in the supraspinatus outlet and Rockwood caudal tilt views. This new method may overcome the poor reliability and reproducibility resulting from conventional, plain radiographs.

In the SOL view, we found that rotator cuff tear patients significantly have more curved with anterior traction spur morphologies than patients with normal shoulders, but our findings may be invalid due to the poor intra- and inter-observer reliability. A study[13] described a fair correlation and a moderate correlation of findings in mean intra-observer reliability as 0.35 and 0.55, respectively, by using the Kappa values of six observers that independently evaluated supraspinatus outlet radiographs. In our study, 3D-CT reconstruction SOL view still exhibits poor reliability. Hence, this SOL classification may be inadequate for acromial morphology assessment and a new classification or radiographic view may be essential.

In the 3D-CT RW view, we found that there is a significantly higher amount of keeled-type morphology in rotator cuff tear patients than in patients with normal shoulders [35.48% vs. 6.35%]. The intra-observer reliability has a moderate-to-almost-perfect agreement and the inter-observer reliability has a moderate-to-strong agreement. Therefore, the RW view is useful for acromial spur and morphology assessment for pre-operative acromioplasty in rotator cuff tear patients. A previous study categorized Rockwood tilt radiographs and arthroscopic findings into 5 types. These were flat, bump, heeled, keeled and irregular, with excellent significant intra- and inter-observer reliability. The study noted a high correlation between heeled, keeled, and irregular types with rotator cuff tears.[14] Nonetheless, we excluded the bump type in our study's classification system due to a poor agreement between two evaluators of the bump type with the flat or the heeled types. We modified the bump category to the heeled if the size is more than 2 mm from the inferior edge of distal clavicle and to the flat if the size is less than 2 mm.

In this study, the keeled 3D-CT was significantly associated with rotator cuff tear shoulders but was less in normal shoulders. Regardless, the heeled-type 3D-CT has no significant differences in terms of the association between rotator cuff tear patients and patients with normal shoulders [35.48% vs. 36.51%, p-value = 0.853]. Furthermore, the irregular-type 3D-CT has no

### Table 2

The relationship between shoulder conditions and the acromial types from 3D-CTs of the shoulder in the SOL and RW views.

| Disease       | Acromial Type | Normal (%) | OA shoulder (%) | RC tear (%) | Total (%) |
|---------------|---------------|------------|-----------------|-------------|-----------|
| SOL view      |               |            |                 |             |           |
| Type I (flat) | 4 (6.35)      | 2 (14.29)  | 1 (3.23)        | 7 (6.48)    |           |
| Type II (curved) | 51 (80.95)  | 8 (57.14)  | 15 (48.39)      | 74 (68.52)  |           |
| Type III (hooked) | 2 (3.17)    | 0 (0)      | 2 (6.45)        | 4 (3.70)    |           |
| Type IV (curved with anterior traction spur) | 6 (9.52) | 3 (21.43) | 13 (41.94) | 22 (20.37) |
| Type V (gull-wing) | 0 (0)      | 1 (7.14)   | 0 (0)           | 1 (0.93)    |           |
| Total         | 63 (100)      | 14 (100)   | 31 (100)        | 108 (100)   |           |
| RW view       |               |            |                 |             |           |
| Type I (flat) | 35 (55.56)    | 7 (50)     | 7 (22.58)       | 49 (45.37)  |           |
| Type II (heeled) | 23 (36.51)  | 4 (28.57)  | 11 (35.48)      | 38 (35.19)  |           |
| Type III (keeled) | 4 (6.35)     | 3 (21.43)  | 11 (35.48)      | 18 (16.67)  |           |
| Type IV (irregular) | 1 (1.59)    | 0 (0)      | 2 (6.45)        | 3 (2.78)    |           |
| Total         | 63 (100)      | 14 (100)   | 31 (100)        | 108 (100)   |           |

### Table 3

A summary of Kappa values of intra- and inter-observer reliability in SOL and RW views. (SOL-supraspinatus outlet, RW-Rockwood tilt).

| Reliability (Kappa value) | Intra-observer | Inter-observer |
|---------------------------|----------------|---------------|
|                           | Evaluator1     | Evaluator2     | First read | Second read |
| SOL view                  | 0.828          | 0.475         | 0.782      | 0.344      |
| RW view                   | 0.752          | 0.903         | 0.854      | 0.737      |
significant differences in terms of the association between both groups [6.45% in the RC group vs. 1.59% in the normal group, p-value = 0.320]. However, the validity of the conclusion is questionable due to the low number of the sample size.

The combination of acromial morphology from 3D-CT SOL and RW views had poor reliability and may not be useful in shoulder disorder assessment due to the SOL classification’s poor inter- and intra-observer reliability.

Besides conventional characteristics of the acromion, from the 3D-CT scan of 108 shoulders, we found one patient (0.93%) with os acromiale. This percentage is similar with the value found in a Korean study that found a prevalence of approximately 0.7% from plain radiographs and/or MRI study of shoulders in 1,568 patients. The supraspinatus outlet radiograph of os acromiale may have cortical irregularity with 73.5% of sensitivity. Evaluators in our study identified the same cortical irregularity overlying the remaining portion of the acromion that resembled a gull-wing acromion (Fig. 2).

Limitations of this study include a small sample size (which reduces the study’s statistical power), poor reliability in SOL view (leads to an unreliable association between acromial morphology and the SOL classification), and inadequate representation of the general rotator cuff tear population (3D-CT shoulder scans used were limited to massive irreparable RC tear patients that required CT scans as opposed to patients with RC tears). The strengths of this study include that this is the first study to compare the acromion morphology/spurs in both popular views (SOL and RW views) and the new modified ROL and RW classification were established based on well-aligned 3D-CT imaging. Despite that 3D-CT is not routinely used in investigating rotator cuff tear patients, Rockwood 3D-CT may be developed for rotator cuff evaluation using a plain radiographic classification in the future. Moreover, this study discovered a new morphology of the acromion, gull-wing type in SOL, which may be further developed as a plain radiographic sign or a classification in the shoulders with os acromiale.

Conclusion

The classification of acromion morphology under Three-dimensional computed tomography in the supraspinatus outlet view has poor reliability. The Rockwood caudal tilt view model results in moderate-to-almost-perfect reliability that can be developed to the plain radiographic classification to determine the need for acromioplasty in rotator cuff surgery.

Ethics approval and consent to participate

Approval by the human ethical committee of Thammasat University No.MTU-EC-OT-0-164/57. Consent was waived due to the retrospective analysis.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Authors’ contributions

AA analyzed and interpreted all the data of 3D-CT shoulders, classified the type of acromion, and was a major contributor in writing the manuscript. ST classified the type of acromion and draft of the manuscript. PK collected the data. BC advised for the methodology, acromial classification and manuscript suggestion. All authors read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no competing interests.

Acknowledgements

Thank you, Orthopaedics Department, Faculty of Medicine, Thammasat University and Thammasat University Hospital for the kind support, Mrs. Pimrapat Gebert for statistical analysis, and Miss. Amolint Chiarnpattanadom for English correction.

References

1. Nho SJ, Yadav H, Shindle MK, Macgillivray JD. Rotator cuff degeneration: etiology and pathogenesis. Am J Sports Med. 2008;36(5):987—993.
2. Seitz AL, McClure PW, Finucane S, Boardman 3rd ND, Michener LA. Mechanisms of rotator cuff tendinopathy: intrinsic, extrinsic, or both? Clin Biomech. 2011;26(1):1—12.
3. Neer 2nd CS. Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. J Bone Joint Surg Am. 1972;54(1):41—50.
4. Tucker TJ, Snyder SJ. The keeled acromion: an aggressive acromial variant—a series of 20 patients with associated rotator cuff tears. Arthroscopy. 2004;20(7):744—753.
5. Nicholson G, Indianapolis O, Goodman D, Georgia A, Flatow E, Bigliani L. The acromion: morphology and age-related changes. A study of 420 scapulae. J Shoulder Elbow Surg. 2006;15(2):S77.
6. Natsis K, Tsikaras P, Totlis T, et al. Correlation between the four types of acromion and the existence of enthesisophyseal changes: a study on 423 dried scapulae and review of the literature. Clin Anat. 2007;20(3):267—272.
7. Oh JJ, Kim JY, Lee HK, Choi J-A. Classification and clinical significance of acromial spur in rotator cuff tear: heel-type spur and rotator cuff tear. Clin Orthop Relat Res. 2010;468(6):1542—1550.
8. Morelli KM, Martin BR, Charakla FH, Durmisevic A, Warren GL. Acromion morphology and prevalence of rotator cuff tear: a systematic review and meta-analysis. Clin Anat. 2019;32(1):122—130.
9. Bigliani LU, Ticker JB, Flattow EL, Soslowski LJ, Mow VC. The relationship of acromial architecture to rotator cuff disease. Clin Sports Med. 1991;10(4):823—836.
10. Duralde XA, Gauntt SJ. Troubleshooting the supraspinatus outlet view. J Shoulder Elbow Surg. 1999;8(4):314—319.
11. Feldman V, Marom N, Nyska M, Kitz E, Koh JEJ, Barchilon V. The correlation of the anterior acromial undersurface. Eur J Orthop Surg Traumatol. 2018;28(2):207—212.
12. Sun Z, Fu W, Tang X, Chen G, Li J. Systematic review and Meta-analysis on acromioplasty in arthroscopic repair of full-thickness rotator cuff tears. Acta Orthop Belg. 2018;84(1):54—61.
13. Bright AS, Torpey B, Magid D, Codd T, McFarland EG. Reliability of radiographic evaluation for acromial morphology. Skeletal Radiol. 1997;26(12):718—723.
14. Kongmalai P, Apivatgaroon A, Cherchuiwjit B. Morphological classification of acromial spur: correlation between Rockwood tilt view and arthroscopic finding. SKDFT J. 2017;3:4.
15. Kumar J, Park WH, Kim SH, Lee HJ, Yoo JC. The prevalence of os acromiale in Korean patients visiting shoulder clinic. Clin Orthop Surg. 2013;5(3):202—208.
16. Lee DH, Lee KH, Lopez-Ben R, Bradley EL. The double-density sign: a radiographic finding suggestive of an os acromiale. J Bone Joint Surg Am. 2004;86(12):2666—2670.