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Original article

Rotator cuff tears reparability index based on pre-operative MRI: our experience

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Summary. *Background and aim of the work:* It is recognised that a significant percetage of large and massive rotator cuff tears (RCT) cannot be anatomically repaired and this correlates with a worste outcome in terms of pain, active range of motion, increased incidence of retair. The aim of our work is to find reliable index on pre-operative MRI shoulder image to assist orthopaedist in surgical planning of rotatator cuff tears repair. *Methods:* We performed a retrospective study on a population on 131 patients undergoing arthroscopic cuff repair by a single expert surgeon. Pre-operative MRI images were evaluated by a single orthopaedist, trained on MRI shoulder images ad blinded to surgical outcome. For each magnetic resonance we evaluated the following 9 parameters: fatty Infiltration (FI), Patte Stage (PS), tear size measured in medial-lateral (ML) and anterior-posterior (AP) dimension, Tangent Sign (TS), Occupation Grade (OG), Acromion-Humeral Distance (AHD), Inferior Gleno-Humeral Distance (IGHD), Glenoid Version Angle (GVA). We divided population into two groups: patients who obtained a complete repair of RCT (n=110) and patients who obtained only a partial repair of RCT (n=21). For each MRI index we conducted statistical analysis (Student's t test, Mann-Whitney U test, Shapiro-Wilk test, Chi-square test, Fisher exact test, ROC curves and maximum Youden index) to find a Cut Off value useful to predict partial repair. *Results:* We have found statistical significance in predicting partial repair on MRI mesurements of Fatty Infiltration (FI grade ≥3; test di Fisher p<0.001), Patte Stage (grade= 3; test di Fisher p<0.001), Tear size measured in ML (>36 mm; Mann-Whitney p<0.001), Positive Tangent Sign (Chi-quadro p<0.001; sensitivity 95,3%, specificity 83,6%), Occupation Grade (OG <0,46; t-test p<0.001). Acromion-Humeral Distance (AHD <7 mm), Inferior Gleno-Humeral Distance (IGHD >5 mm). Tear size measured in AP (>21 mm; Mann-Whitney p<0.001) seems to be dependent on the contextual size of the lesion in ML. We haven't found statistical significance in predicting partial repair of Glenoid Version Angle. *Conclusions:* A systematic observation of seven independent MRI parameters (FI, PS, tear size ML, TS, OG, AHD, IGHD) can help the surgeon to predict the impossibility to obtain complete repair of RCT and to consider different surgical approach. (www.actabiomedica.it)

Key words: rotator cuff tear, magnetic resonance shoulder, partial repair, tangent sign, occupation grade

Introduction

When orthopaedists evaluate rotator cuff tears on MRI imaging, always have a concreat idea about the grade of reparability that artroscopic treatment would lead to, due to personal experience. It is recognised that a significant percentage of large and massive rotator cuff tears (RCT) undergo a partial repair and this correlates with a worse outcome in terms of pain, range of motion, increased incidence of retear (1, 2, 6, 31). We would like to clarify some definitions first: by the term "Partial repair" we consider a surgical repair that obtain <50% footprint coverage (1, 3, 4); referring to De Orio-Colfield Classification (8), tears >50 mm, mesured in

any direction, are traditionally classificated as "massive", tears between 30 and 50 mm are classificated as "large" (1, 2, 8, 9). In the last fifteen years lots of study have analyzed MRI parameters linked to large and massive tears. Some correlation are already widely know and shared: the role of rotator cuff atrophy, increased muscolar fatty infiltration, grade of muscolar retraction (Patte Stage). Other parameters (Tangent Sign, Occupation Grade, Glenoid version agle) were evaluated less frequently in litterature and substantially in population composed by patients with large and massive tears, lacking of a "control group" of patients with less extensive tears (5). The aim of this study is to evaluate if it was useful or possible to obtain parameters from pre-operative MRI that could provide an index of rotator cuff reparability: thus will assist ortopeadists in surgical planning.

Materials and method

We performed a retrospective study on a population of 131 patients subjected to arthroscopic cuff repair by a single expert surgeon, between January 2016 and September 2017. Population was composed by 53% males and 47% females; 78 patients undergoing arthroscopic treatment of isolated supraspinatus lesions (59,54%), 53 patients undergoing arthroscopic treatment of combined lesions of supra and infraspinatus (40,46%). We have excluded from the study patients who had an associated subscapularis lesion or shoulder instability or patients who have undergone previous shoulder surgery.

Pre-operative MRI images came from 4 different centres, including our hospital: two radiological centres had 0,4 Tesla MRI's, olthers had 1,5 Tesla MRI's.

Waiting times between the execution of the MRI and surgery were on average 3 months. Pre-operative MRI images were evaluated by a single orthopaedist, trained on MRI shoulder images ad blinded to surgical outcome. For each MRI we evaluated the following 9 parameters: Patte stage (PS), tear size measured in medial-lateral (ML) and anterior-posterior (AP) dimension, Fatty Infiltration (FI), Tangent Sign (TS), Occupation Grade (OG), Acromion-Humeral Distance (AHD), Inferior Gleno-humeral distance (IGHD), Glenoid Version Angle (GVA). All measurements were calculated using O3 Reporting Workstation (ORWS Insiel FVG Version 3.2.2) with an accuracy up to 0,01 mm. Than we divided population into two groups: patients that obtained a complete repair of RCT (n=110; 83,97%) and patients that obtained only a partial repair of RCT (n=21; 16,03%). For each MRI parameter we conducted statistical analyses (Student's t test, Mann-Whitney U test, Shapiro-Wilk test, Chi-square test, Fisher exact test, ROC curves and maximum Youden index) to find a Cut Off value to predict partial repair.

MRI parameters

Patte Stage (PS)

Patte stage was evaluated on coronal T1 (Figure 1). Patte Classification divides tendon retraction degree into 3 stages. Stage 1: sovraspinatus tendon retraction remain lateral to the humeral head cartilage; Stage 2: sovraspinatus tendon edge is located between the humeal head and the glenoid margin; Stage 3: sovraspinatus tendon edge is located to the glenoid or beyond the glenoid (16).

Medial-lateral tear size (ML)

Tear size was measured on the same Coronal T1 image in which we had evaluated Patte Stage. Measure was taken drawing a straight line from the most lateral part of humeral tendon footprint to the edge of

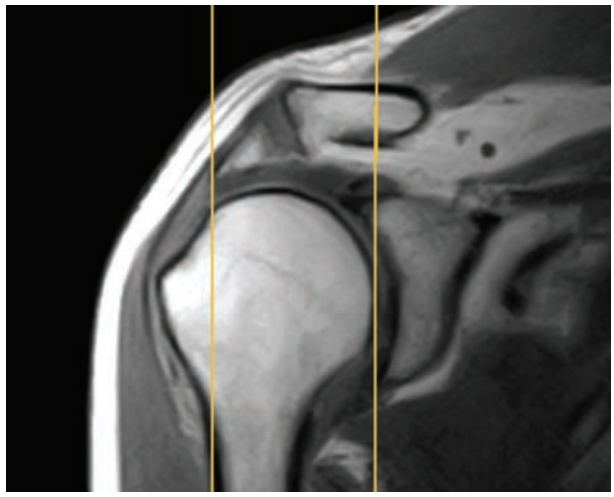


Figure 1. Patte Stage 3; Coronal Sequence T1

retracted sovraspinatus tendon (5, 9). If this sequence was not avaible, measures were taken on T2 sequences (Figure 2).

Antero-Posterior tear size (AP)

Tear size was measured on Sagittal T2 sequences, drawing a straight line form anterior edge of lesion to the intact cuff tendon, thus comprising the lesion of the supra and infraspinatus (5, 9). If this sequence was not avaible, measures were taken on T1 sequences (Figure 3).

Fatty Infiltration (FI)

The assessment of degree of fatty infiltration was obtained using MRI re-adaptation of the Goutallier Fatty index (7, 10). The most useful MRI image to classified Fatty infiltration is the first lateral T1 sagittal image where scapula is "Y-shaped": the scapular spine is seen in contact with scapular body, defining a Y bone image (11). Fatty infiltration was defined as Grade 0: no fatty infiltration; Grade 1: some fatty streacks; Grade 2: more muscle than fat; Grade 3: same proportion of muscle and fat; Grade 4: more fat than muscle (Figure 4).

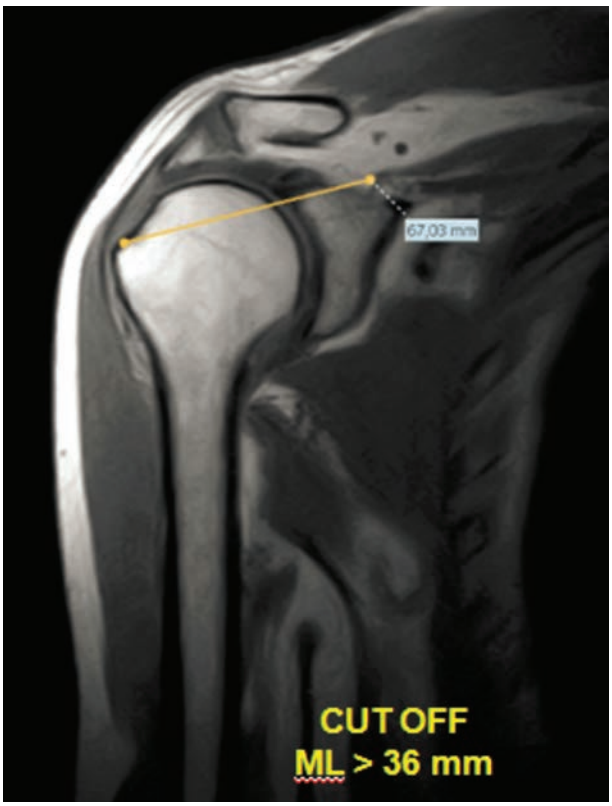


Figure 2. Tear ML dimension; Coronal Sequence T1. Cut off Value ML is 36 mm: it means that tear size >36 mm is associated with the inability to obtain a complete cuff repair

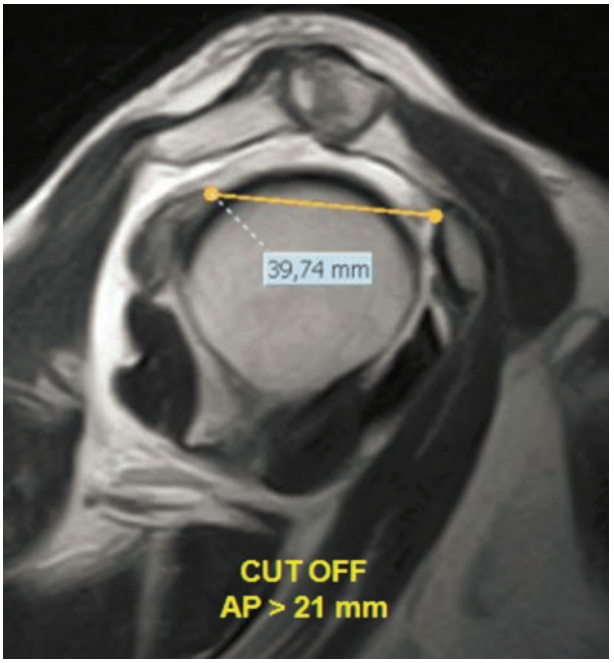


Figure 3. Tear AP dimension; Sagittal Sequence T2. Cut Off value AP is 21 mm

Tangent Sign (TS)

Tangent Sign was measured on the same Sagittal T1 image in which we had evaluated Fatty Infiltration. On the Y shaped section, a straight line is drawn to join the upper portion of the coracoid with the upper portion of the scapular spine: TS is considered positive if the supraspinatus muscle does not cross the tangent, lying under the tangent line (Figure 5).

Occupation Grade (OG)

Occupation grade was measured on the same Sagittal T1 image in which we had evaluated Fatty Infiltration and Tangent Sign: it's calculated as ratio between the cross sectional area of supraspinatus muscle and area of supraspinatus fossa under the Tangent Sign line (Figure 6) (5, 17).

Figure 4. Fatty Infiltration Grade 4; Sagittal Sequence T1

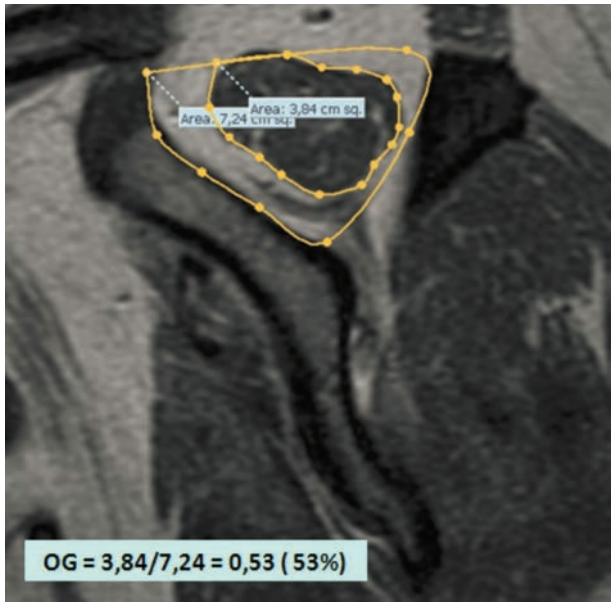


Figure 6. Occupation Grade (OG) is calculated as ratio between the cross sectional area of supraspinatus muscle and area of supraspinatus fossa under the Tangent Sign line

Acromion-Humeral Distance (AHD) and Inferior Gleno-Humeral Distance (IGHD)

AHD and IGHD were measured on the same Coronal T1 image in which we had evaluated Patte Stage and ML tear dimension (Figure 7). AHD was measured with arm in neutral position, drawing a straight line from the middle point of anterior acromion to superior humeral cortex (20). IGHD was measured with arm in neutral position, drawing a straight line from the inferior humeral cortex to the inferior glenoid apex.

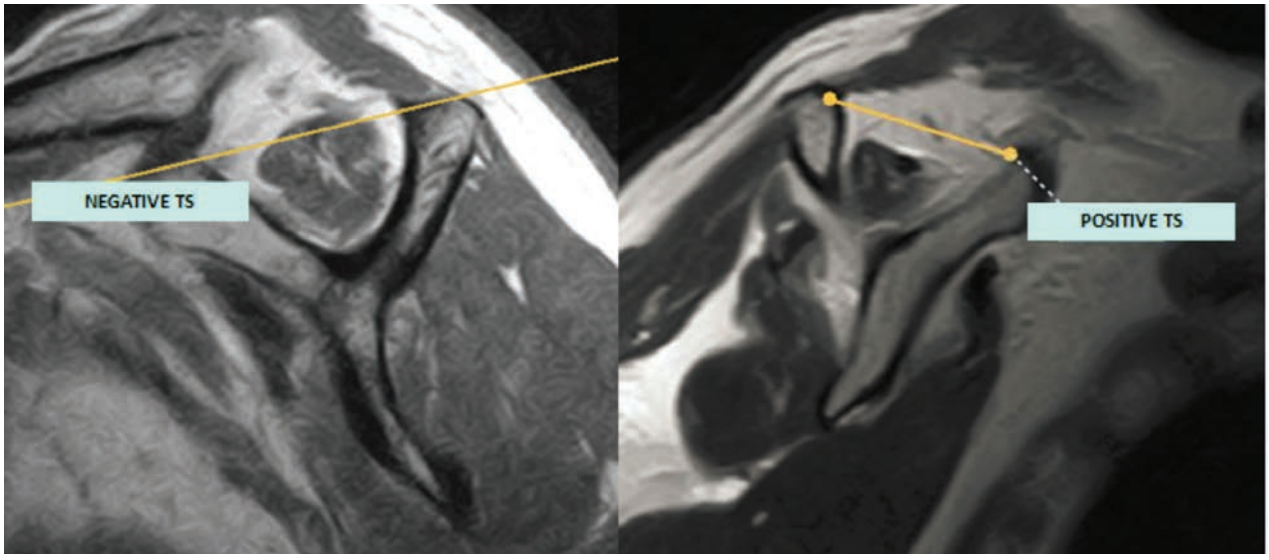


Figure 5. Example of Negative and Positive Tangent Sign (TS)

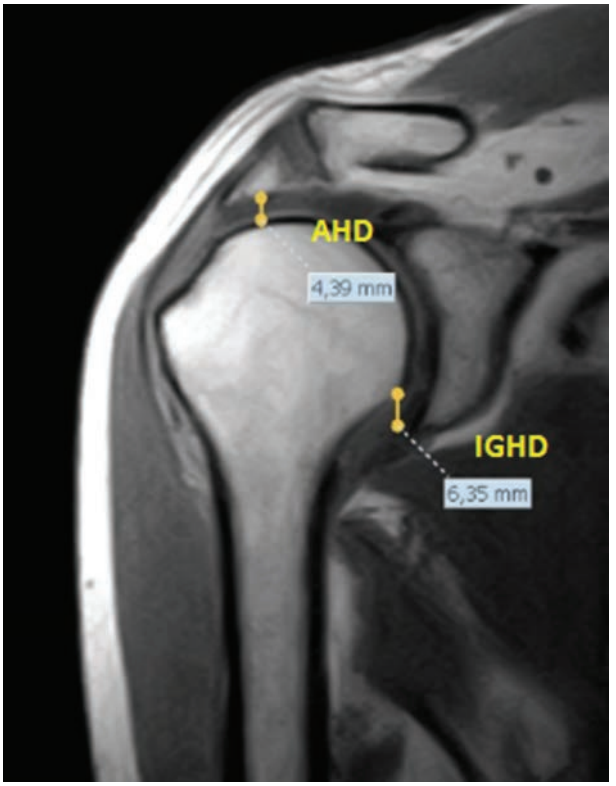


Figure 7. Acromion-Humeral Distance (AHD) and Inferior Gleno-Humeral Distance (IGHD); Coronal Sequence T1. Cut Off value for AHD is 7 mm; Cut Off value for IGHD is 5 mm

Glenoid version Angle (GVA)

Mesure for GVA were obtained on axial sequences, on the first cut immediately beneath sovraspinatus muscle where posterior border of glenoid neck is clearly visible (Figure 8): the sovraspinatus fossa axis was draw by joining the posterior glenoid neck to the point of conjunction of scapular spine to scapular body; than axis of glenoid osseus surface was draw (26). Angle α was the angle in the posterior medial quadrant of the intersection of these two lines. GVA was calculated by subtracting 90° from α angle (GVA=α -90°): glenoid anteversion was indicate as positive GVA values, while retroversion as negative GVA values (27).

Statistical Analysis

Descriptive statistics were used to report continuous variables (mean±standard deviation or median with range, depending on normal vs non-normal distribution of the data). The Shapiro-Wilk test was used to assess whether data were normally distributed. Categorical variables were reported as frequencies and percentages. For categorical variables, Chi-square test or Fisher exact test were conducted in order to detect

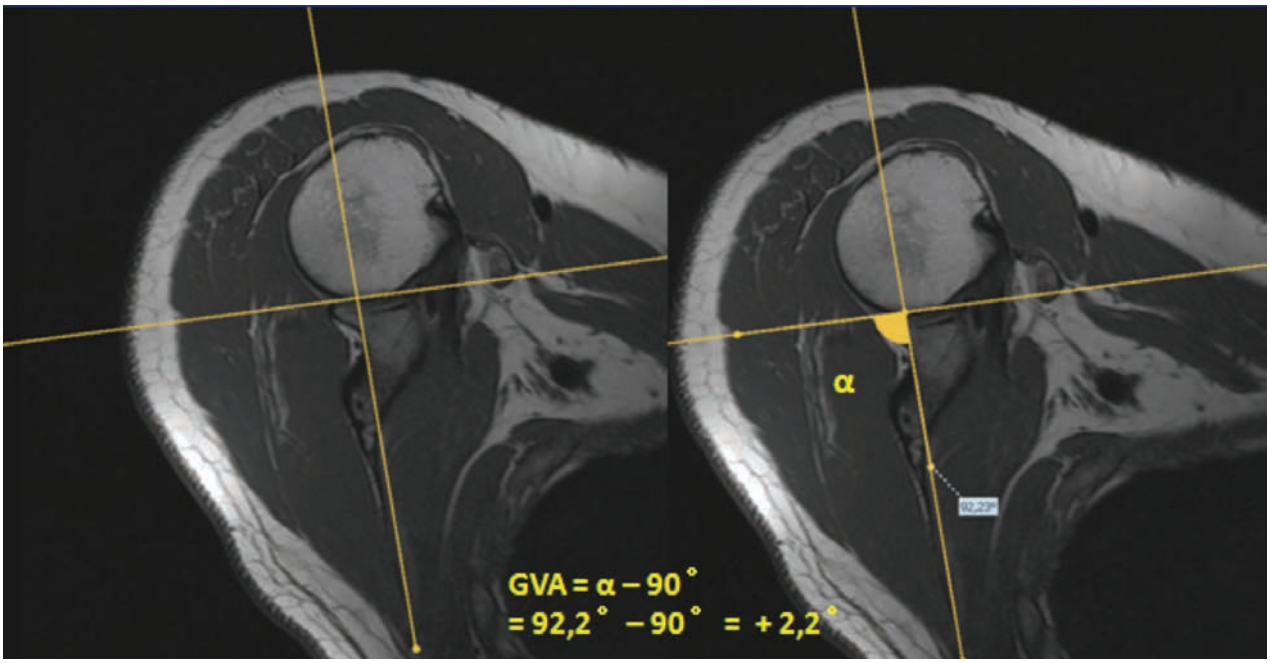


Figure 8. Glenoid Version Angle. Axial Sequence T1

significant differences between the two groups (complete RCT repair vs partial RCT repair), as appropriate. The Student's t test or the Mann-Whitney U test was used to compare continuous variables between the two groups, as appropriate. ROC curves were performed to assess effectiveness of continuous variables in predicting reparation pattern, and maximum Youden index was calculated to identify an empirical optimal Cut-off (maximization of both sensitivity and specificity).

Statistical significance for all tests was set at a p-value of <0.05. All statistical analysis were performed by Stata/IC 13.0 (StataCorp LP, College Station, USA).

Results

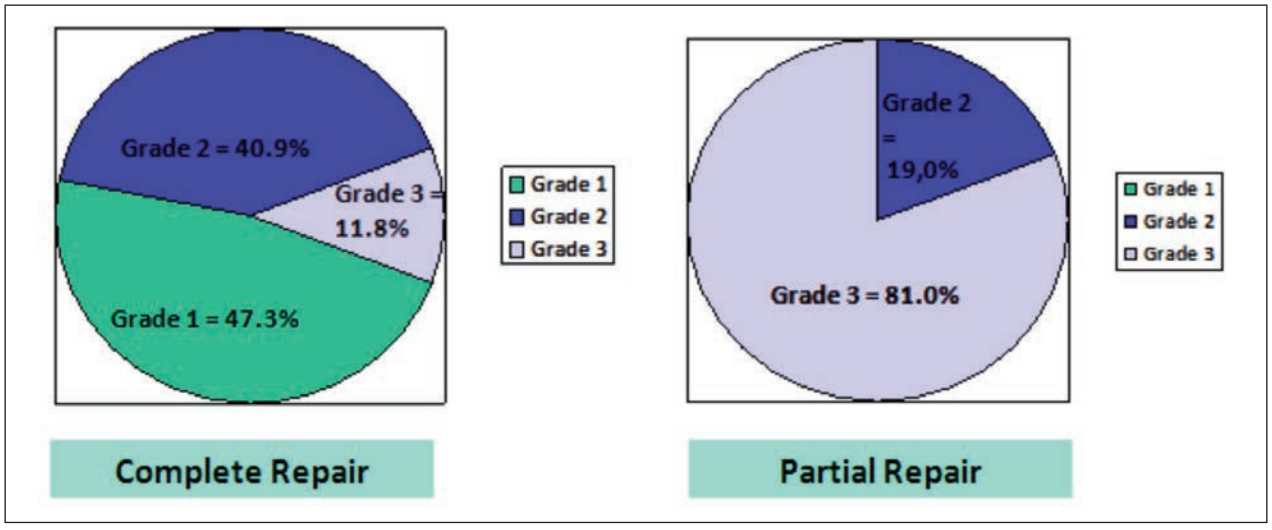
Comparing two groups (Partial Rotator Cuff repair / Complete Rotator Cuff repair) we point out that there is a clear dominance of the male sex in the group that obtained a partial repair (81%; test Chi-quadro p=0.005). We found no evidence of significance in the two groups regarding age differences nor in merit of the presence of a recent trauma (in the previous 6 months) reported in anamnesis.

Stage 3 in Patte classification was found in 81% of pre-operative MRIs in patients who subsequently achieved partial cuff repair, compared to the predominance of Stage 1 (47,3%) and Stage 2 (40,9%) in patients who achieved complete cuff repair (Graphic 1). High statistical significance of this data was confirmed by Fisher test (p<0.001).

Tear dimension in Medial-Lateral (ML) was measured on the same Coronal image in which we had evaluated Patte Stage: the statistical median for Partial rotator cuff repairs was 52.8 mm with range [31.0 mm - 67.0 mm], the statistical median for Complete rotator cuff repairs was 19.7 mm with range [8.5 mm - 46.8 mm], with remarkable statistical difference in two groups (Ranksum-test di Mann-Whitney p<0.001). Cut Off value for Tear dimension in Medial-Lateral (ML) was 36 mm (Youden Index 0,818; Sensitivity at cutpoint: 1.00; Specificity at cutpoint: 0.82) (Figure 2).

Tear dimension in Anterior-Posterior the statistical median for Partial Rotator Cuff repairs was 28.0 mm with range [14.6 mm - 48.4 mm], the statistical median for Complete rotator cuff repairs was 12.8 mm with range [8.9 mm - 32.4 mm], with remarkable statistical difference in two groups (Ranksum-test di Mann-Whitney p<0.001). Cut Off value for Tear dimension in Anterior-Posterior (AP) was 21 mm (Youden index 0.823; Sensitivity at cutpoint: 0.90; Specificity at cutpoint: 0.92) (Figure 3).

The degree of fatty infiltration was assessed on the readaptation for MRI of Goutallier Fatty Index, it re-



Graphic 1. Patte Stage measured on pre-operative shoulder MRI in patients who obtained complete Rotator Cuff repair and patients who obtained partial Rotator Cuff repair

Table 1. Muscolar Fatty Infiltration percentage found in pre-operative shoulder MRI

GRADO	FATTY INFILTRATION	COMPLETE REPAIR	PARTIAL REPAIR
0	No fatty deposits	1,1 %	0%
1	Some fatty streacks	33,5 %	14,1%
2	Muscle > Fat	60,0 %	14,3%
3	Muscle = Fat	3,6 %	52,5%
4	Muscle < Fat	1,8%	19,1%

DICOTOMIZED VARIABLE

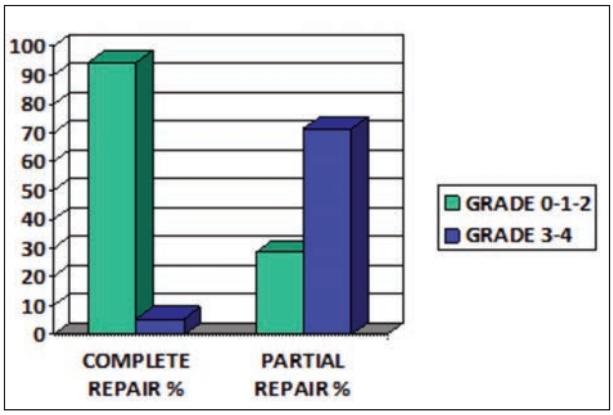
confirms in our study how important a grade 3-4 is in influencing a partial repair (Table 1).

This data is further highlighted by the merging of grades 0-1-2 and 3-4 (Graphic 2): it is possible to notice that 94% of complete repairs the degree of fatty infiltration assessed at the pre-operative MRI was between 0 and 2, while partial repairs showed in 72% of cases 3-4 degrees. High statistical significance of this data was confirmed by Fisher test (p<0.001).

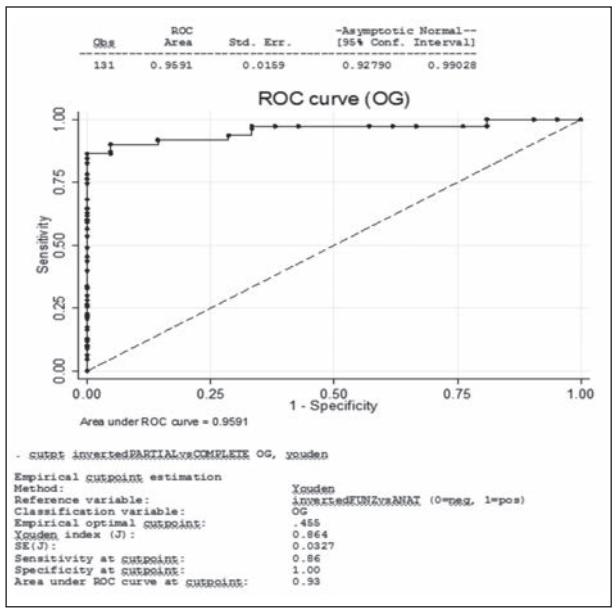
Positive Tangent Sign showed a sensitivity 95,3%, specificity 83,6% (Chi-quadro p<0.001) in predict a Partial cuff repair.

In the evalutation of Occupation Grade, the statistical mean±DS for Partial rotator cuff repairs was 33.0%±7.2%, the statistical median for Complete rotator cuff repairs was 63,2%±16,7%, with remarkable statistical difference in two groups (t-test p<0.001). Cut off value for Occupation Grade was 46% (0,46) (Youden index 0.864; Sensitivity at cutpoint: 0.86; Specificity at cutpoint: 1.00) (Graphic 3).

Acromion-Humeral Distance (AHD) showed a statistical mean±DS for Partial rotator cuff repairs of 5.4 mm ± 1.7 mm and a statistical mean±DS for



Graphic 2. In 94% of Complete RCT Repairs fatty infiltration Grade, assessed at the pre-operative MRI, was between 0 and 2, while Partial RCT Repairs showed in 72% of cases Grade 3-4



Graphic 3. ROC Curve for Occupation Grade (OG); Cut Off value is 0,46 (46%), Sensitivity at Cut Point 0,86; specificity at Cut Point 1,00

Complete rotator cuff repairs of 8.0 mm ± 1.4. These differences were statistically significatives at t-test ($p<0.001$). The Cut off value of AHD <7 mm predict a partial reparability of Rotator Cuff lesion (Youden index: 0.630; Sensitivity at cutpoint: 0.77; Specificity at cutpoint: 0.86)

Inferior Gleno-Humeral Distance (IGHD) showed a statistical median for Partial rotator cuff repairs of 6.9 mm with range [4.2 mm -14.8 mm] and a statistical median for Complete rotator cuff repairs of 4.5 mm with a range of [0.0 mm- 9.8 mm]. These differences were statistically significatives at Ranksum-test Mann-Whitney ($p<0.001$), The Cut off value of IGHD >5 mm predict a partial reparability of Rotator Cuff lesion (Youden index: 0.464; Sensitivity at cutpoint: 1.00; Specificity at cutpoint: 0.46)

Glenoid Version Angle (GVA) showed a statistical mean±DS for Partial rotator cuff repairs of -1.0°±4.7° and a statistical mean±DS for Complete rotator cuff repairs of -1.5°±3.7°. These differences weren't statistically significatives at t-test ($p=0.594$).

Discussion

Our study confirms the role of tear size and Patte stage in influencing a rotator cuff's partial repair. This evidence is already largely shared. We have associated the medial-lateral lesion measurement with the evaluation of Patte Stage. Tracing a medial-lateral straight line we clearly have done an approximation and understimation of the real tear size but the aim of this study is to furnish a pratical an rapid method of MRI's evaluation that can be really applied during clinical practice, so, agreeing with previous studies (5, 9), we have choosen this method. More interesting than underlining the absolute mean and median values in the two groups, it seemed practical to indicate a cut-off value to which to refer. The cut of value for medial-lateral tear size in our population is 36 mm: it means that tear size >36 mm is associated with the inability to obtain a complete cuff repair. We found a Cut Off value for anterior-posterior tear size in our population: 21 mm, but we think that this data is influenced by the fact that in our population the larger tears measured in ML were also larger in AP, so the AP size taken as single values is inconsistence in clinical practice (for example a Crescent lesion should be completely reperied also if it is larger than 21 mm in AP because there is little ML lesion size). As Holtby et al. showed (5), AP lesion size should be taken in consideration only combined to ML size, to give an area.

Our study also confirms the role of fatty infiltration (FI) and muscolar atrophy in influencing a rotator cuff's partial repair. Yoo et all. (2) showed how advanced sovraspinatus and infraspinatus fatty involution is associated with inability to obtain a complete repair. Other authors have found that this degeneration is reversible after rotator cuff repair and surgery could prevent the progression of fatty involution (12-14, 19).

Tangent Sign (TS) is a useful, easily performer and reproducible tool to evaluate supraspinatus atrophy. TS showed in our population sensitivity of 95,3%, specificity of 83,6% in predicting a partial repair (18). Considering a Positive TS, due to an evidence of different filling of supraspinosa fossa, an assessment of the Occupation Grade has been proposed by Thomazeu et al. (17). In our population we have found an Occupation Grade Cut off of 0,46 (46%): it means that OG values below 0,46 indicate an impossibility to obtain a complete Rotator Cuff repair.

Moreover, Jeong et al (24) evaluated 112 MRIs executed at 9 months post-operatively in patient who underwent arthroscopic rotator cuff repair for a large sized tear: they demonstrated that Occupation Grade of supraspinatus <0,43 (43%) and grade ≥2 fatty infiltration of the infraspinatus were the strongest predictors of retear, with sensitivity of 98.0%, and specificity of 83.6% (accuracy=90.2%).

Recently Sheean et al. (23) had demonstrate that a positive Tangent Sign and/or high-grade fatty infiltration (Grade ≥3) of the supraspinatus were risk factors for incomplete RCT repair, however, these were not completely predictive of reparability because the majority of massive RC tears with these imaging characteristics were still fully reparable.

Otherwise, in other studies (14, 15) immediate post-operative MRIs shows a significant improvement of fatty degeneration grade (one degree lower) and muscle atrophy (evaluated with Tangent Sign and Occupation Grade): they underline the role of tendon retraction as cause of false positive muscle atro-

phy ("pseudo-artrophy") on pre-operative MRI, found that the conventional Y shape view is distant from the osseus origin of sovraspinatus tendon, at which non attached muscle and tendon can freely retract; in conclusion they support that the immediate post operative MRI should be the baseline study to visualize the real muscolar quality on Y shaped view.

However, on the basis of the evidence found, we confirm that the pre-operative assessment of the degree of atrophy (using TS and OG) and fatty infiltration provides, even taking into account false positives, an excellent pre-operative planning meter. On the other hand, we find less useful to request a MRI in the immediate post-operative period only to obtain a basic value of muscular atrophy.

The cut off value we had found for AHD (<7 mm) are in line with what was found by Flatow at al. (20), Hamada et al (21), Snyder et Al (22). In 1994, Flatow et al. (20) assessed the subacromial space of a normal X-ray, quantifying it as being an average of 10-15 mm, mean acromio-humeral interval was 11.1 mm at 0° of elevation in normal shoulders and 6 mm or less in 50% of patients with rotator cuff tears. In Hamada Classification (21) Grade 1 was defined as an ADH ≥6 mm, Grade 2 as ADH ≤5 mm, Grade 3 as acetabulization (concave deformity of the acromion undersurface) plus an AHI ≤5 mm, Grade 4 as narrowing of the glenohumeral joint plus conditions required for grade 3, and Grade 5 as humeral head collapse. Recently Shim et al. Demonstrated that ADH is an independent risk factors for irreparabile RCT, whereas Critical shoulder Angle and Acromial Index were not: mean AHD of Shim at al. patients was 8.007 mm, range [0.8 mm -18.5 mm] (25).

We found few studies attesting the utility of IGHD (5, 9). In our study we showed that the cut off value of IGHD>5 mm is useful to suggest the impossibility to obtain a complete Rotator Cuff repair and IGHD measurement is easy and rapid to be performed.

The last parameter we have measured was Glenoid Version Angle. Our population showed a small degree of glenoid retroversion but these fact didn't correlate to final Cuff Repair. Tetrault et al. (26) reported that retroversion (mean-5°±4°) was associated with high probability of supraspinatus tendon injury but these study lack of a control group. Thus we agree with previous articles that confirmed that glenoid axis has a great variability and is not related with Rotator Cuff Tears (27, 28). If there are significant anatomical glenoid abnormalities, such as Bankart lesions, it is useful to complete the pre-operative study with evaluation of glenoid bone loss by Multiplanar Reconstruction Curved Computed Tomographic imaging (cMPR – TC) (33).

One limitation of this study was related to different numerosity of two groups esamine (Partial repair n°=21 patients; Complete repair n°=110 patients).

It is also important to consider that choosing these Cut Off values, we had done a compromise between a useful maximization of sensitivity and specificity.

Another limitation was that pre-operative MRI's came from 4 different main Radiological centres: we had examinated MRI with different image quality (0,4 Tesla or 1,5 Tesla) and in a few MRI's arm position was not compliant with the standard position (29), thus influencing some measurements, expecially IGDH if the arm was internally rotated. Moreover, we have not always had the best MRI sequence available to examine specific parameter (29). Moreover, only one trained orthopaedist made each measurements, we didn't verify inter-observer variability: however previous studies showed good inter-observer reliability (4, 5, 9, 14, 30).

Finally, as is know, the presence of subcutaneous implants, such as permanent defibrillators, is an absolute contraindication to the use of MRI. Moreover, MRI is unadvisable in subjects with metallic hardware near the area of study, as artifacts generated by such materials distort image quality: for those patients, Multidetector Computed Tomography Arthrography (Arthro-MDCT) of the shoulder is a safe technique that provides accurate diagnosis in identifying chondral, fibrocartilaginous and intra-articular ligamentous lesions (32).

Conclusion

We found statistical significance in predict partial repair analyzing pre-operative MRI mesurements of seven independents MRI index. For each parameter we have found a cut of value, useful in clinical practice, as summarize in (Table 2).

Table 2. Useful MRI index to evaluate Rotator Cuff Reparability

INDEX	CUT OFF PARTIAL REPAIR
Tear dimension **ML**	**ML > 36,5 mm**
Acromion-Humeral Distance **AHD**	**AHD < 7 mm**
Inferior Gleno-Humeral Distance **IGHD**	**IGHD > 5,7 mm**
Fatty Infiltration **FI**	**FI ≥ GRADO 3**
Patte Stage **PS**	**PS = GRADO 3**
Tangent Sign **TS**	**TS POSITIVE (sens. 95%, spec. 90%)**
Occupation Grade **OG**	**OG <0,43**

Our cut of values predicting parzial repair are: Fatty Infiltration (FI grade ≥3), Patte stage (PS grade= 3), tear size measured in ML (ML>36 mm), Positive Tangent Sign (sensitivity 95,3%, specificity 83,6), Occupation Grade (OG<0,46), Acromion-Humeral Distance (AHD<7 mm), Inferior Gleno-Humeral Distance (IGHD>5 mm).

A systematic observation of seven MRI index can help the ortopeadist, especially when less experienced, to predict the impossibility to obtain complete repair of RCT and to consider and plan different surgical approach.

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