



Original article

Clinical and radiological outcomes of osteoarthritis twenty years after rotator cuff repair



Anthony Herve^{a,*}, Hervé Thomazeau^a, Luc Favard^b, Michel Colmar^c, Pierre Mansat^d, Gilles Walch^e, Michael Betz^f, Jean-François Kempf^g, Philippe Collin^h

^a CHU Pontchaillou, 2, rue Henri le Guilloux, 35033 Rennes Cedex 9, France

^b CHU Tours, 49, boulevard Béranger, 37000 Tours, France

^c Hôpital Privé des Côtes d'Armor, 12, rue François-Jacob, 22190 Plérin, France

^d CHU Toulouse Purpan, 1, place du docteur Baylac, 31300 Toulouse, France

^e Hôpital Privé Jean-Mermoz, 24, avenue Paul Santy, 69008 Lyon, France

^f Uniklinik Balgrist, Blümlisalpstrasse, 65 8006 Zürich, Switzerland

^g Service de chirurgie orthopédique et de la main (CCOM), 10, avenue Achille Baumann 67403 Illkirch-Graffenstaden, France

^h Clinique Privé Saint-Grégoire 6, boulevard de la Boutière, 35768 Saint-Grégoire, France

ARTICLE INFO

Article history:

Received 6 April 2018

Accepted 7 February 2019

Keywords:

Rotator cuff repair

Long term

Glenohumeral osteoarthritis

ABSTRACT

Purpose: Outcomes of open or arthroscopic rotator cuff repairs are well reported in the literature. The purpose of the study was to evaluate the prevalence and clinical impact of osteoarthritis 20 years following rotator cuff repair. The hypothesis was that, at long follow-up, most shoulders would have developed gleno-humeral osteoarthritis.

Methods: The authors retrospectively recalled all 322 patients, operated for rotator cuff tears in 1994 at 6 different centres, for clinical and radiographic assessment. At 20 years of follow-up, 24 were re-operated (5 arthroplasty) and 53.4% were lost to follow-up. This left 126 patients, had been clinically assessed, had Magnetic Resonance Images (MRI) that allowed anatomic assessment of tendon healing (Sugaya), fatty infiltration (Goutallier), and X rays in order to analyse arthritis without head migration (Samilson) and with head migration (Hamada and Fukuda). Only patients with complete data were selected.

Results: Mean aged was 52.3 years (25.3–68.6) at index operation. The Constant score was 45.3 ± 19.6 preoperatively to 67.4 ± 18.7 points at 20 years. The SSV was 73.5 ± 21 postoperatively. The rate of osteoarthritis was 29%. Osteoarthritis was associated with a significant inferior Constant score compared to the non-arthritic group (61 versus 71 points, $p = 0.02$), mainly due to a significant lower strength (5.4 versus 8.7 points, $p = 0.007$). Massive rotator cuff tears were significantly associated with a higher rate of osteoarthritis. Only 4.8% patients after cuff repair needed a reverse shoulder arthroplasty. Significantly less osteoarthritis was observed when the rotator cuff repair remained intact. Supraspinatus retear had a significant influence on fatty infiltration of the infraspinatus muscle and on the progression towards osteoarthritis.

Conclusion: Twenty years after open rotator cuff repair, the rate of osteoarthritis was 29%. Massive rotator cuff tears were significantly associated with a higher rate of osteoarthritis. Less osteoarthritis was observed when supraspinatus healed.

Level of evidence: IV.

© 2019 Elsevier Masson SAS. All rights reserved.

1. Introduction

Rotator cuff tears are among the most frequent shoulder pathologies causing pain and functional impairment. It is estimated

that rotator cuff tears are responsible for 4.5 million annual patient visits in the United States and of nearly 250,000 operative repairs [1,2]. Numerous authors reported considerable improvement in clinical and radiographic outcome following rotator cuff tears using various surgical techniques, though most studies have limitations due to small cohort sizes or short follow-up (FU) [3–14]. Until now, true long-term clinical and structural results after operative rotator cuff repair are missing.

* Corresponding author.

E-mail address: kost41@hotmail.com (A. Herve).

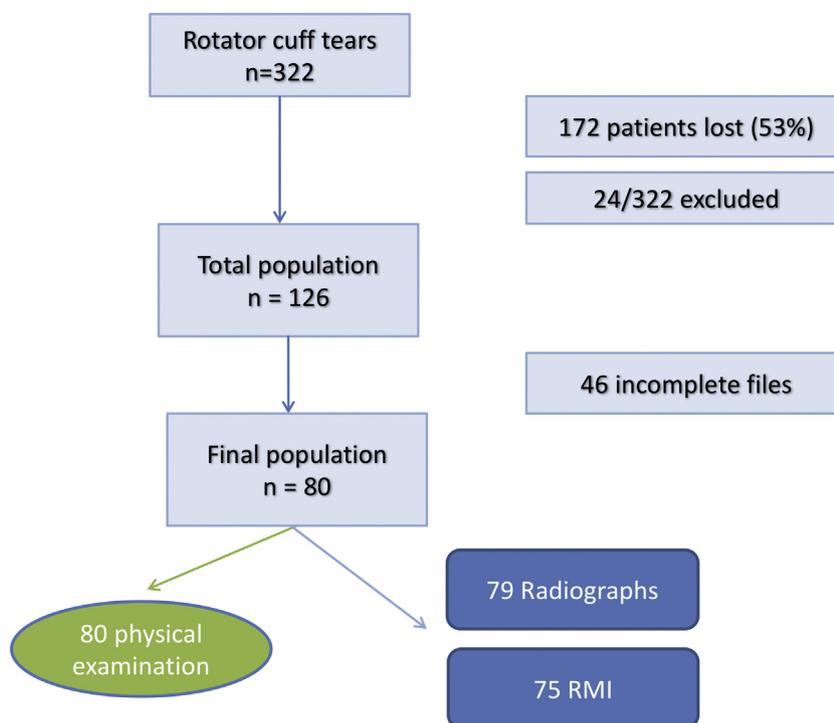


Fig. 1. Flow chart.

Table 1
Etiologies of surgical reoperation.

Iterative suture	N = 10
Total shoulder arthroplasty	N = 5
Lavage-synovectomy	N = 4
Tenotomy-tenodesis	N = 3
Arthrolysis	N = 2
Other	N = 1

The purpose of the present study was to evaluate the prevalence and clinical impact of osteoarthritis 20 years following rotator cuff repair. The hypothesis was that, at long follow-up, most shoulders would have developed glenohumeral osteoarthritis with the need of shoulder arthroplasty implantation.

1.1. Study design

The authors retrospectively studied the records of all patients that underwent surgical repair of rotator cuff tears by 6 surgeons in 6 different centres in the year 1994. To be included in the study the patients had to be adult patients with rotator cuff tears, which were treated with an open operative repair. Patients were excluded if they had muscle transfers, history of previous ipsilateral shoulder surgery, partial tendon repair or concomitant shoulder pathologies. A total of 322 patients fulfilled these criteria and were recalled in 2014 for evaluation at a follow-up of 20 years (Fig. 1). One hundred and seventy-two patients (53.0%) were lost to follow-up corresponding to a 2.5% loss per year. Among them, thirty-four patients died. Twenty-four (7.5%) patients were re-operated before the 20 year FU and not included in the final functional analysis (Table 1). Among this reoperated patients, 5 patients had total shoulder arthroplasty. These 126 patients have been examined by the authors. The authors rigorously selected files with complete clinical exams and imaging data. Files with missing data were not included. This left a cohort of eighty patients (26% of the initial population).

Out of this study cohort 80 patients were analyzed (35 women, 45 men), mean aged was 51,9 years ($\pm 6,5$ years) at time of surgery consented to standard radiographs ($n = 79$) and Magnetic Resonance Imaging ($n = 75$) at 20 years FU. Patient's characteristics are described in Table 2. All patients provided informed consent for this IRB approved study (IRB 2013-A01788-37). For clinical assessment, we used the Constant score (CS), the subjective shoulder value (SSV) and the simple shoulder test (SST).

We analyzed on standard X-rays the rate of glenohumeral osteoarthritis (OA) with the Samilson-Prieto classification [15]. We considered stage 0, 1 and 2 as non-arthritic and 3 and 4 as arthritic. Cranial head migration was analysed on true antero-posterior radiographs taken in neutral rotation using the Hamada and Fukuda classification [16,17] as modified by Walch [18].

Patients were divided in two groups:

- group 1: no OA (Samilson grade 0, 1 and 2, and Hamada and Fukuda grade 1, 2 and 3);
- group 2: OA (Samilson grade 3 and 4 and Hamada and Fukuda grade 4 and 5)

The MRI protocol included T2-weighted fat-suppression sequences (non-proton density weighted) in the oblique coronal, oblique sagittal, and transverse planes, including the entire scapula, to analyze tendon healing, and T1-weighted sequences in the transverse and sagittal planes, to analyze fatty infiltration and muscle conditions. Fatty infiltration was analyzed according to Goutalier/Fuchs [19]. We grouped stages 0/1 and 2 as functional muscles and stages 3 and 4 as non-functional muscles. Rotator cuff tendon healing was analyzed with the Sugaya classification [20]: We defined types I/II and III as healed and types IV and V as return tendons. (We analyzed muscle atrophy with the tangent sign described by Zanetti and al. [21]).

Table 2
Patient's characteristics.

Variable	Global (n=80)	No Arthritis (n=57)	Arthritis (n=23)	p
Sex				p=0.6
Female	35 (43.8%)	24 (42.1%)	11 (47.8%)	
Male	45 (56.3%)	33 (57.9%)	12 (52.2%)	
Active smoker	42 (76.4%)	27 (71.1%)	15 (88.2%)	p=0.3
Pre op infiltration	32 (50%)	24 (53.3%)	8 (42.1%)	p=0.4
Mean age	51.9±6.5	51.2±6.8	53.7±5.3	p=0.1
Profession				
Soft manuel	16 (22.5%)	11 (22.0%)	5 (23.8%)	p=0.6
Heavy manuel	32 (45.1%)	24 (48.0%)	8 (38.1%)	
Sedentary	11 (15.5%)	6 (12.0%)	5 (23.8%)	
Repetitive work	12 (16.9%)	9 (18.0%)	3 (14.3%)	
Side				
Dominant	63 (78.8%)	43 (75.4%)	20 (87.0%)	p=0.4
None dominant	17 (21.3%)	14 (24.6%)	3 (13.0%)	
Traumatic cases	38 (53.5%)	25 (51.0%)	13 (59.1%)	p=0.5
Work accident/Occupational disease	18 (32.1%)	12 (32.4%)	6 (31.6%)	p=0.9
Beginning of symptoms (months)	23±40.7	25.6±47.4	16.8±17	p=0.9
Follow-up (years)	20.8±0.8	20.8±0.9	21±0.7	p=0.4

Qualitative parameters: Effectif (%); χ^2 or Fisher tests. Quantitative parameters: Mean ± standard deviation; Student or Mann–Whitney Wilcoxon tests.

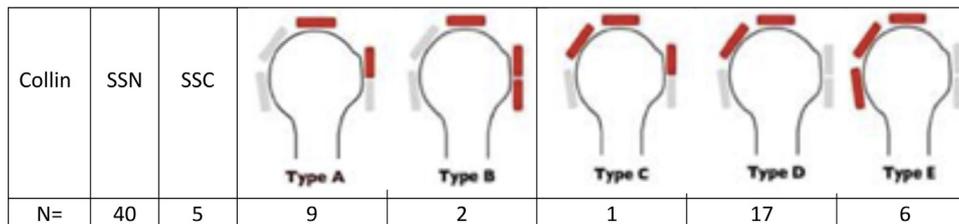


Fig. 2. Lesions according to Collin's classification.

1.2. Surgical technique

The repairs were carried out with the patient in a beach chair position using an open, deltopectoral approach with the use of non-absorbable transosseous sutures [22]. All repairs were watertight at the end of the operation. An adjuvant anterior acromioplasty was performed in all shoulders.

Forty patients were originally operated for an isolated SSN tear, five patients had an isolated subscapular tear (SSC) and 35 patients had a massive RCT classified according to Collin et al. [22], with 2 or more tendons torn (Fig. 2).

1.3. Post-operative rehabilitation

Following surgery, the arm was supported in a sling or an abduction splint for 5 weeks. Passive-motion exercises were initiated on the first post-operative day, and when possible, hydrotherapy was initiated after skin healing. Active shoulder motion was allowed after 6 weeks. Patients were not allowed to perform any strengthening or strenuous work for six months after surgery. Low-demanding sports and activities were allowed after six months.

1.4. Statistical Analysis

Statistical analyses were performed using SAS software, version 9.4. For non-gaussian quantitative data, inter-group differences were evaluated using Wilcoxon rank sum tests (Mann–Whitney U–test). Qualitative data were analyzed using Fisher's exact tests or nonparametric tests. Logistic regression was performed to explain the relationship between osteoarthritis and FI.

1.5. Source of Funding

This study was financed by the *Soci t  fran aise de chirurgie orthop dique et traumatologique* (SoFCOT).

2. Results

At 20 years FU, osteoarthritis was observed in 23 (28.8%) cases (= group 1: Samilson grade 3 in 5 cases (21.7%), Hamada and Fukuda grade 4A in 10 cases (43.5%), and Hamada and Fukuda grade 4B in 8 cases (34.8%) (Fig. 3). No osteoarthritis was observed in 57 (71.2%) cases (= group 2: Samilson grade 0 in 37 cases, Samilson grade 1 in 6 cases, Samilson grade 2 in 5 cases, Hamada and Fukuda grade 1 in 4 and grade 2 in 3 and grade 3 in 2 cases).

In the 80 shoulders evaluated clinically and radiographically, the Constant score improved from 45.3 ± 19.6 preoperatively to 67.4 ± 18.7 points at 20 years; from 6.8 ± 3.1 to 12.5 ± 3.5 points for pain (15 points = freedom from pain; 0 = worst imaginable pain), from 6.1 ± 5.4 to 7.8 ± 5.1 points for strength (1 point representing one pound of strength at 90 degrees of scapular plane abduction). Osteoarthritis was associated with a significant inferior Constant score compared to the non-arthritic group (61 versus 71 points, p=0.02), mainly due to a significant lower strength (5.4 versus 8.7 points, p=0.007) (Table 3). The SSV at 20 years of FU was 73.5 ± 21.4% and the SST was 9.4 ± 2.7 (Table 4). There was no significant difference between the two groups regarding SSV and SST.

The tendon retear rate was 43.8%. SSN tendon integrity (Sugaya type 1, 2 and 3) was significantly associated with less osteoarthritis (37 versus 3 cases, p=<0.0001) (Table 5). SSN tendon repair failure (Sugaya type 4 and 5) was significantly more frequent in the osteoarthritis group. Massive cuff tear with 3 tendons torn was significantly more frequently observed in the osteoarthritis group (26.1% versus 5.3%, p=0.04) (Table 6). SSN tendon repair integrity was statistically significant associated with less FI of the

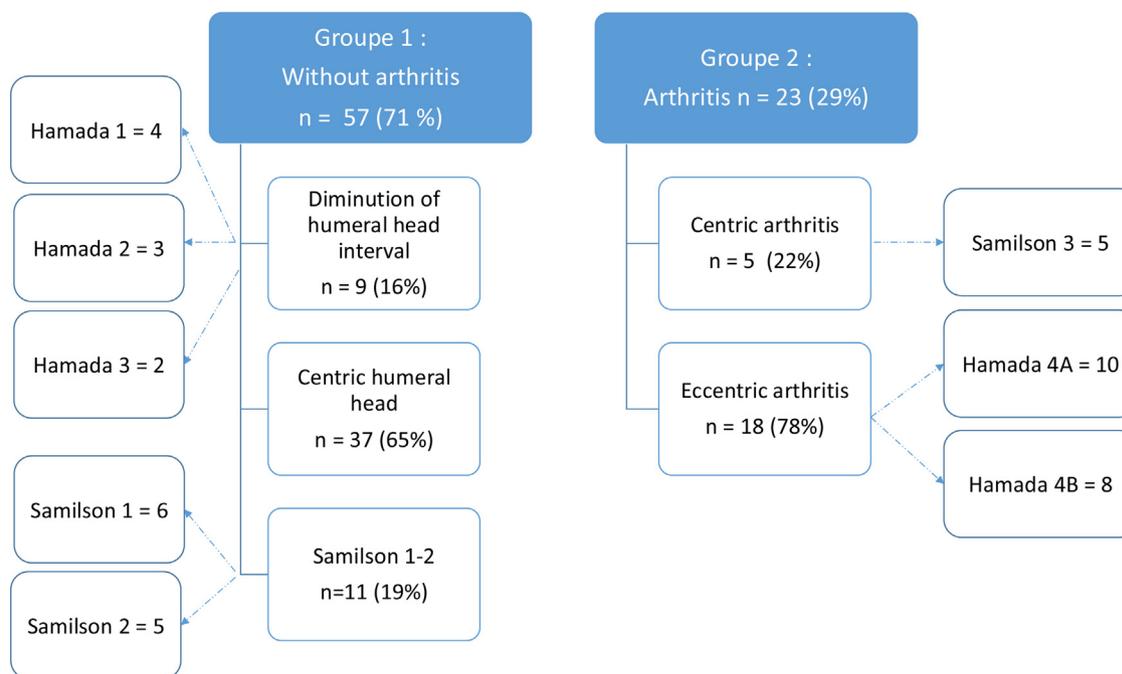


Fig. 3. Groups details.

Table 3
Comparison of post operative Constant score between the two groups.

Variable	Global (n = 80)	No Arthritis (n = 57)	Arthritis (n = 23)	p
Constant score	67.8 ± 18.8	70.6 ± 17.6	60.9 ± 20.4	p = 0.02
Adjusted Constant score	91.3 ± 26.6	95.4 ± 21.2	77.4 ± 37.2	p = 0.1
Pain	12.5 ± 3.5	12.8 ± 3.2	11.5 ± 4.3	p = 0.2
Activity	5.6 ± 5.8	15.9 ± 5.3	4.7 ± 6.9	p = 0.5
Mobility	31.9 ± 9.4	32.8 ± 8.6	29.6 ± 11	p = 0.1
Strength	7.8 ± 5.1	8.7 ± 5.2	5.4 ± 4.1	p = 0.01

Quantitative parameters: Mean ± standard deviation; Wilcoxon signed rank test.

Table 4
SSV and SST comparison between the two groups.

Variable	Global (n = 80)	No Arthritis (n = 57)	Arthritis (n = 23)	p
SSV	73.5 ± 21.4	73.7 ± 21.2	72.9 ± 22.3	0.97
SST	9.4 ± 2.7	9.3 ± 2.8	9.6 ± 2.4	0.8

Quantitative parameters: Mean ± standard deviation, Mann-Whitney Wilcoxon test.

Table 5
Arthritis depending on Sugaya.

Variable	Noarthritis	Arthritis	p
SSN healed	37 (92.5%)	3 (7.5%)	p < 0.0001

Qualitative parameters: number (%); χ^2 or Fisher tests.

ISN ($p = 0.001$) (Table 7). SSN retear had a significant influence on FI of the ISN muscle and so on the progression towards osteoarthritis (Tables 7 and 8).

3. Discussion

Twenty years after rotator cuff repair the rate of OA was 29%. Only 4.8% patients underwent total shoulder arthroplasty. Patients presenting osteoarthritis had a significant inferior Constant Score compared to the non-OA population.

Only few studies have examined the prevalence of gleno-humeral osteoarthritis and its impact on clinical outcome after rotator cuff repair. Neer [23] observed a prevalence of 4% in a population of 19 patients at 4 years FU, Yamagushi [24] found a progression to OA in 16.7% and upward migration of the humeral head in 20.8% at 3.6 years FU. Bartl [25] presented the results of 25 patients at 6 years FU. Fatty infiltration of the infraspinatus (ISN) was significantly correlated with poor clinical outcomes. The acromio-humeral distance decreased significantly and the severity of osteoarthritis increased. Zumstein [14] examined a population

Table 6

Lesion's comparison between the two groups.

Variable	Global (n = 80)	No Arthritis (n = 57)	Arthritis (n = 23)	P
<i>Lesions</i>				
A	9 (11.3%)	6 (10.5%)	3 (13.0%)	<i>p</i> = 0.06
B	2 (2.5%)	0	2 (8.7%)	
C	1 (1.3%)	1 (1.8%)	0	
D	17 (21.3%)	13 (22.8%)	4 (17.4%)	
E	6 (7.5%)	2 (3.5%)	4 (17.4%)	
SSC	5 (6.3%)	3 (5.3%)	2 (8.7%)	
SSN	40 (50.0%)	32 (56.1%)	8 (34.8%)	
<i>Lesions</i>				
Massive tear	40 (50.0%)	25 (43.9%)	15 (65.2%)	<i>p</i> = 0.08
SSN	40 (50.0%)	32 (56.1%)	8 (34.8%)	
<i>Lesions</i>				
2 tendons A/D	26 (32.5%)	19 (33.3%)	7 (30.4%)	<i>p</i> = 0.04
3 tendons B/C/E	9 (11.3%)	3 (5.3%)	6 (26.1%)	
SSC	5 (6.3%)	3 (5.3%)	2 (8.7%)	
SSN	40 (50.0%)	32 (56.1%)	8 (34.8%)	

Qualitative parameters: Effectif (%); χ^2 or Fisher tests.**Table 7**

Comparison of FI ISN depending on Sugaya.

Variable	SSN healed (n = 40)	SSN retear (n = 35)	<i>p</i>
<i>FI ISN</i>			
0/1/2	28 (70.0%)	11 (32.4%)	0.001
3/4	12 (30.0%)	23 (67.6%)	

Qualitative parameters: number (%); test of χ^2 .**Table 8**

Comparison between FI et Sugaya in each group.

Variable	SSN healed	SSN retear	<i>p</i>
<i>FI SSN (arthritis group)</i>			
0/1/2	3 (75.0%)	6 (37.5%)	0.3
3/4	1 (25.0%)	10 (62.5%)	
<i>FI SSN (no arthritis group)</i>			
0/1/2	29 (80.6%)	10 (58.8%)	0.1
3/4	7 (19.4%)	7 (41.2%)	

Qualitative parameters: number (%); Fisher's test.

of 23 patients after massive rotator cuff repair with a follow-up of 9.9 years. The prevalence of osteoarthritis (Samilson grade 3 and 4) was 39.1%. Supraspinatus (SSN) retear as well as fatty infiltration (FI) > 2 of the infraspinatus (ISN) were significantly associated with proximal humeral head migration.

Flurin et al. [26] described a prevalence of OA in 5.2% at ten-year follow-up. Tendon integrity was associated with a lower risk of OA and massive tears with the development of OA. The study with the longest follow-up is Borgmästars's study [27] with a 19% prevalence of OA at 16 years follow-up. Paxton et al. [28] studied the clinical and radiographic outcomes of failed repairs of large or massive RCT at 10 years FU. They found clinical improvements despite early repair failure with however a high rate of progression of radiographic signs. Those results are in line with our study: SSN retear ($p < 0.0001$) and massive rotator cuff tears ($p = 0.04$) were significantly associated with osteoarthritis. Recently, Matsuba [29] confirmed that progression of osteoarthritis was related to SSN healing. Plachel and al. [30] put in evidence that these results were also observed after arthroscopic transosseous repair at a mean follow-up of 15 years \pm 2.

Gladstone and al. [31] showed that FI of the ISN muscle was the most important prognostic factor for the outcome of arthroscopic or surgical repair. The major impact of the ISN muscle to center the humeral head was demonstrated by Nove Josserand [32] and Edwards [5]. Many studies have shown the irreversible evolution of fatty infiltration and the influence on clinical and anatomical

outcome [33]. We noted that, SSN retear had a significant influence on FI of the ISN muscle and on the progression towards osteoarthritis. Contrary to FI of the ISN, there may be tears of the SSN without severe DG as shown in photographs 1 and 2.

A major strength of this study is the availability of clinical and imaging results which were specifically collected and evaluated in a very standardized fashion 20 years after surgery for the purpose of this study. Our data therefore allow for analysis of tendon repair integrity, correlation between structural and clinical results as well as information about longevity of the results. This is the longest study about outcomes of rotator cuff repair and occurrence of arthritis.

The study has limitations: First its retrospective design without a control group makes it a level 4 observational study. Nonetheless it provides previously unavailable information on a well-defined patient group with a well-defined pathology treated in a homogeneous and analyzed in also a highly standardized fashion. Second, the patients lost to follow-up (56%) is regrettable but at 20 years inevitable in the environment of 6 centers. It should be considered that a yearly loss of follow-up of 2.5% over twenty years represents an at least very good value. Only 26% of initial population could be completely analyzed (clinical and imaging datas). Third, we would certainly have preferred to obtain imaging studies in all patients but had to accept the refusal of the respective patients who for very various reasons denied imaging studies mostly because they felt it would not change anything for them.

4. Conclusion

At twenty years after open rotator cuff repair, osteoarthritis rate was 29%. Massive rotator cuff tears were significantly associated with a higher rate of osteoarthritis. Only 1.5% of patients need a reverse shoulder arthroplasty. Significantly less osteoarthritis was observed when rotator cuff repair remains intact.

Arthroscopic rotator cuff repair seems to show similar results in terms of tendon healing effect on clinical outcomes.

Disclosure of interest

LF, GW: Tornier Wright.

The other authors declare that they have no competing interest.

Funding sources

SoFCOT.

Authors' contributions

AH reviews patients, draft the manuscript.

HT, LF, MC, PM, GW operated and reviewed patients.

MB review patients and helped to draft the manuscript.

JFK conceived this study, participated in its design and coordination.

PC conceived this study, participated in its design and coordination and helped to draft the manuscript.

Acknowledgements

The authors thank all member of the *Société française de chirurgie orthopédique et traumatologique* (SoFCOT), especially Arnaud Godeneche, Laurent Lafosse, Laurent Nové-Josserand, Pierre-Henri Flurin, Pascal Boileau, Christian Gerber for their participation in the 2015 SOFCOT symposium about rotator cuff repair at 20 years of follow-up.

The authors thank Mrs ROUSSEAU Chloé for his assistance with the statistical analysis.

References

- [1] Genuario JW, Donegan RP, Hamman D, Bell J-E, Boublik M, Schlegel T, et al. The cost-effectiveness of single-row compared with double-row arthroscopic rotator cuff repair. *J Bone Joint Surg Am* 2012;94(15):1369–77.
- [2] Mather RC, Koenig L, Acevedo D, Dall TM, Gallo P, Romeo A, et al. The societal and economic value of rotator cuff repair. *J Bone Joint Surg Am* 2013;95:1993–2000.
- [3] Burkhart SS, Barth JRH, Richards DP, Zlatkin MB, Larsen M. Arthroscopic repair of massive rotator cuff tears with stage 3 and 4 fatty degeneration. *Arthroscopy* 2007;23:347–54.
- [4] Denard PJ, Jiwani AZ, Lädermann A, Burkhart SS. Long-term outcome of arthroscopic massive rotator cuff repair: the importance of double-row fixation. *Arthroscopy* 2012;28:909–15.
- [5] Gerber C, Fuchs B, Hodler J. The results of repair of massive tears of the rotator cuff^{*}. *J Bone Jt Surg* 2000;82:505.
- [6] Gerber C, Vinh TS, Hertel R, Hess CW. Latissimus dorsi transfer for the treatment of massive tears of the rotator cuff. A preliminary report. *Clin Orthop* 1988;51–61.
- [7] Glanzmann MC, Goldhahn J, Flury M, Schwyzer H-K, Simmen BR. Deltoid flap reconstruction for massive rotator cuff tears: mid- and long-term functional and structural results. *J Shoulder Elbow Surg* 2010;19:439–45.
- [8] Gupta AK, Hug K, Boggess B, Gavigan M, Toth AP. Massive or 2-tendon rotator cuff tears in active patients with minimal glenohumeral arthritis: clinical and radiographic outcomes of reconstruction using dermal tissue matrix xenograft. *Am J Sports Med* 2013;41:872–9.
- [9] Kim JR, Cho YS, Ryu KJ, Kim JH. Clinical and radiographic outcomes after arthroscopic repair of massive rotator cuff tears using a suture bridge technique: assessment of repair integrity on magnetic resonance imaging. *Am J Sports Med* 2012;40:786–93.
- [10] Lädermann A, Denard PJ, Collin P. Massive rotator cuff tears: definition and treatment. *Int Orthop* 2015;39:2403–14.
- [11] Ohzono H, Gotoh M, Nakamura H, Honda H, Mitsui Y, Kakuma T, et al. Effect of preoperative fatty degeneration of the rotator cuff muscles on the clinical outcome of patients with intact tendons after arthroscopic rotator cuff repair of large/massive cuff Tears. *Am J Sports Med* 2017;45:2975–81.
- [12] Rokito AS, Cuomo F, Gallagher MA, Zuckerman JD. Long-term functional outcome of repair of large and massive chronic tears of the rotator cuff. *J Bone Joint Surg Am* 1999;81:991–7.
- [13] Vastamäki M, Lohman M, Borgmästars N. Rotator cuff integrity correlates with clinical and functional results at a minimum 16 years after open repair. *Clin Orthop Relat Res* 2013;471:554–61.
- [14] Zumstein MA, Jost B, Hempel J, Hodler J, Gerber C. The clinical and structural long-term results of open repair of massive tears of the rotator cuff. *J Bone Jt Surg Am* 2008;90:2423–31.
- [15] Samilson RL, Prieto V. Dislocation arthropathy of the shoulder. *J Bone Joint Surg Am* 1983;65:456–60.
- [16] Hamada KMD, Fukuda HMD, Mikasa MMD, Kobayashi YMD. Roentgenographic findings in massive rotator cuff tears a long-term observation. *Clin Orthop* 1990;254:92–6.
- [17] Hamada K, Yamanaka K, Uchiyama Y, Mikasa T, Mikasa M. A radiographic classification of massive rotator cuff tear arthritis. *Clin Orthop* 2011;469:2452–60.
- [18] Walch G, Edwards TB, Boulahia A, Nové-Josserand L, Neyton L, Szabo I. Arthroscopic tenotomy of the long head of the biceps in the treatment of rotator cuff tears: clinical and radiographic results of 307 cases. *J Shoulder Elbow Surg* 2005;14:238–46.
- [19] Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C. Fatty degeneration of the muscles of the rotator cuff: assessment by computed tomography versus magnetic resonance imaging. *J Shoulder Elbow Surg* 1999;8:599–605.
- [20] Sugaya H, Maeda K, Matsuki K, Moriishi J. Functional and structural outcome after arthroscopic full-thickness rotator cuff repair: single-row versus dual-row fixation. *Arthroscopy* 2005;21:1307–16.
- [21] Zanetti M, Gerber C, Hodler J. Quantitative assessment of the muscles of the rotator cuff with magnetic resonance imaging. *Invest Radiol* 1998;33:163–70.
- [22] Collin P, Matsumura N, Lädermann A, Denard PJ, Walch G. Relationship between massive chronic rotator cuff tear pattern and loss of active shoulder range of motion. *J Shoulder Elbow Surg* 2014;23:1195–202.
- [23] Neer CS, Craig EV, Fukuda H. Cuff-tear arthropathy. *J Bone Joint Surg Am* 1983;65:1232–44.
- [24] Yamaguchi H, Kanaya F, Suenaga N, Oizumi N, Hosokawa Y. Open repair for massive rotator cuff tear with a modified transosseous-equivalent procedure: preliminary results at short-term follow-up. *J Orthop Sci* 2011;16:398–404.
- [25] Bartl C, Eichhorn S, Kouloumentas P, Holzapfel K, Imhoff A, Salzmann G, et al. Long-term outcome and structural integrity following open repair of massive rotator cuff tears. *Int J Shoulder Surg* 2012;6:1.
- [26] Flurin P-H, Hardy P, Valenti P, Meyer N, Collin P, Kempf J-F. Osteoarthritis after rotator cuff repair: a 10-year follow-up study. *Orthop Traumatol Surg Res* 2017;103:477–81.
- [27] Borgmästars N, Paavola M, Remes V, Lohman M, Vastamäki M. Pain relief, motion, and function after rotator cuff repair or reconstruction may not persist after 16 years. *Clin Orthop* 2010;468:2678–89.
- [28] Paxton ES, Teefey SA, Dahiya N, Keener JD, Yamaguchi K, Galatz LM. Clinical and radiographic outcomes of failed repairs of large or massive rotator cuff tears. *J Bone Jt Surg Am* 2013;95:627–32.
- [29] Matsuba T, Hata Y, Ishigaki N, Nakamura K, Kato H. Osteoarthritis progression of the shoulder: a long-term follow-up after mini-open rotator cuff repair. *PubMed NCBI* 2018 <https://www.ncbi.nlm.nih.gov/pubmed/29635956>.
- [30] Plachel F, Traweger A, Vasvary I, Schanda JE, Resch H, Moroder P. Long-term results after arthroscopic transosseous rotator cuff repair. *J Shoulder Elbow Surg* 2018 [<http://www.sciencedirect.com/science/article/pii/S1058274618306931>].
- [31] Gladstone JN, Bishop JY, Lo IKY, Flatow EL. Fatty infiltration and atrophy of the rotator cuff do not improve after rotator cuff repair and correlate with poor functional outcome. *Am J Sports Med* 2007;35:719–28.
- [32] Nové-Josserand L, Edwards TB, Walch G. The acromioclavicular and coracohumeral intervals are abnormal in rotator cuff tears with muscular fatty degeneration. *Clin Orthop* 2005:90–6.
- [33] Chaudhury S, Dines JS, Delos D, Warren RF, Voigt C, Rodeo SA. Role of fatty infiltration in the pathophysiology and outcomes of rotator cuff tears. *Arthritis Care Res* 2012;64:76–82.