Rotator Cuff Healing

A cicatrização do manguito rotador

Ildeu Afonso de Almeida Filho[1,2] Daniel Andrade Coelho[2,3]

[1] Department of Orthopedics, Hospital Felício Rocho, Belo Horizonte, MG, Brazil
[2] Hospital Vera Cruz, Belo Horizonte, MG, Brazil
[3] Hospital Semper, Belo Horizonte, MG, Brazil

Address for correspondence Ildeu Afonso de Almeida Filho, Department of Orthopedics, Hospital Felício Rocho, Av. do Contorno, 9530, Barro Preto, Belo Horizonte, MG, 30190-130, Brazil (e-mail: ildeu1968@gmail.com).

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Abstract

The present article broadly addresses the aspects that interfere with the healing process of the rotator cuff. Life habits, such as smoking and alcoholism, are considered, systemic factors such as diabetes mellitus, hypertension, and obesity, as well as local factors, among which are those related to the pre, peri, and postoperative periods. From an extensive literature review, with the citation of 60 scientific articles from both Western and Eastern literature, the authors intend to deepen the theme by bringing to medical practice conducts based on new established concepts.

Keywords
- rotator cuff injuries/diagnosis
- rotator cuff injuries/epidemiology
- rotator cuff injuries/surgery
- wound healing

Resumo

O presente artigo aborda de forma ampla os aspectos que interferem no processo de cicatrização do manguito rotador. São considerados hábitos de vida como tabagismo e alcoolismo, fatores sistêmicos como diabetes mellitus, hipertensão arterial e obesidade bem como fatores locais, dentre os quais aqueles relacionados ao pré, per e pós operatório. A partir de uma extensa revisão da literatura, com a citação de 60 artigos científicos tanto da literatura ocidental como oriental, os autores pretendem aprofundar no tema trazendo para a prática médica condutas embasadas em novos conceitos estabelecidos.

Palavras-chave
- lesões do manguito rotador/diagnóstico
- lesões do manguito rotador/epidemiologia
- lesões do manguito rotador/cirurgia
- cicatrização

Introduction

The incidence of rotator cuff injuries has grown exponentially as the life expectancy of the population increases. Several technical explanations have been given to justify this increase. The issue revolves around the degenerative aspects related to the aging process of the organism, associated with some life habits, such as sports practice, profession, diet, use of medications, and the presence of associated diseases in addition to genetic issues, which has not received

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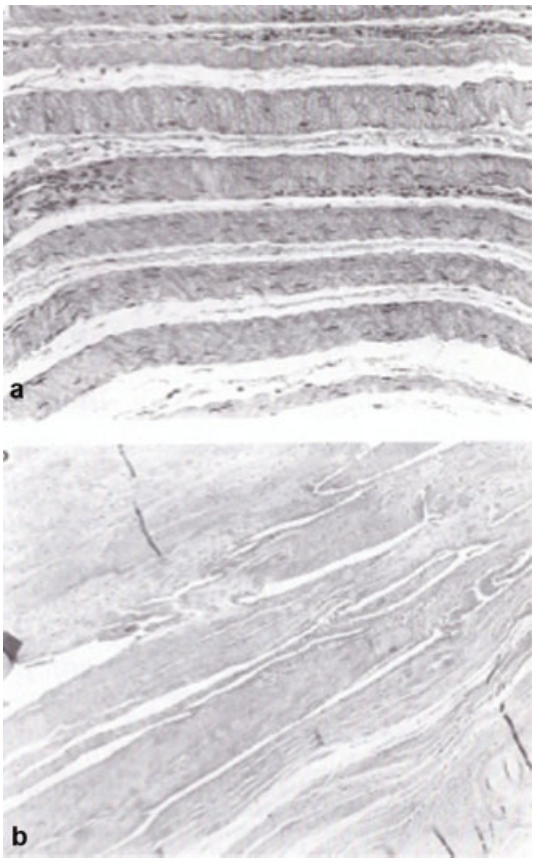

Fig. 1 In the young, the tendon insertion is organized in distinct layers (a) in the elderly, there is disorganization (b).

much attention in publications to date. Anatomical variations also participate in this process. Therefore, there are many factors that may influence the development of rotator cuff tendon injuries.

Hamada et al.[1] studied the histology of the human supraspinatus tendon, subdividing it into portions and observed that, in the youth, the tendon is organized into wavy layers and that in the older patients, this pattern changes to homogeneous, emaciated, and with hyaline degeneration (►**Figure 1**).

Uthoff and Ishii[2] analyzed the histology of tendinous insertion in the larger tubercle and observed, in the youth, the existence of a layered organization pattern. In the elderly, a disorganization occurs that is considered a degenerative process (►**Figure 2**). The author described the inflammatory reaction in the partial lesion of the rotator cuff as an attempt by the organism itself to heal it. However, Yamaguchi et al.[3] histologically studied the natural evolution of these lesions in a series of 58 cases and, in none of them, it was possible to observe the reduction of the size of the lesion. This fact shows that spontaneous healing of the rotator cuff is something that should not be expected by patients, let alone by surgeons.

Does the progressive increase in the incidence of injuries in the general population lead us to ask about what is considered normal for a determined age? How many carriers of cuff injury are asymptomatic? Milgron et al.[4] stated that the prevalence of lesions increases significantly in the population after 70 years

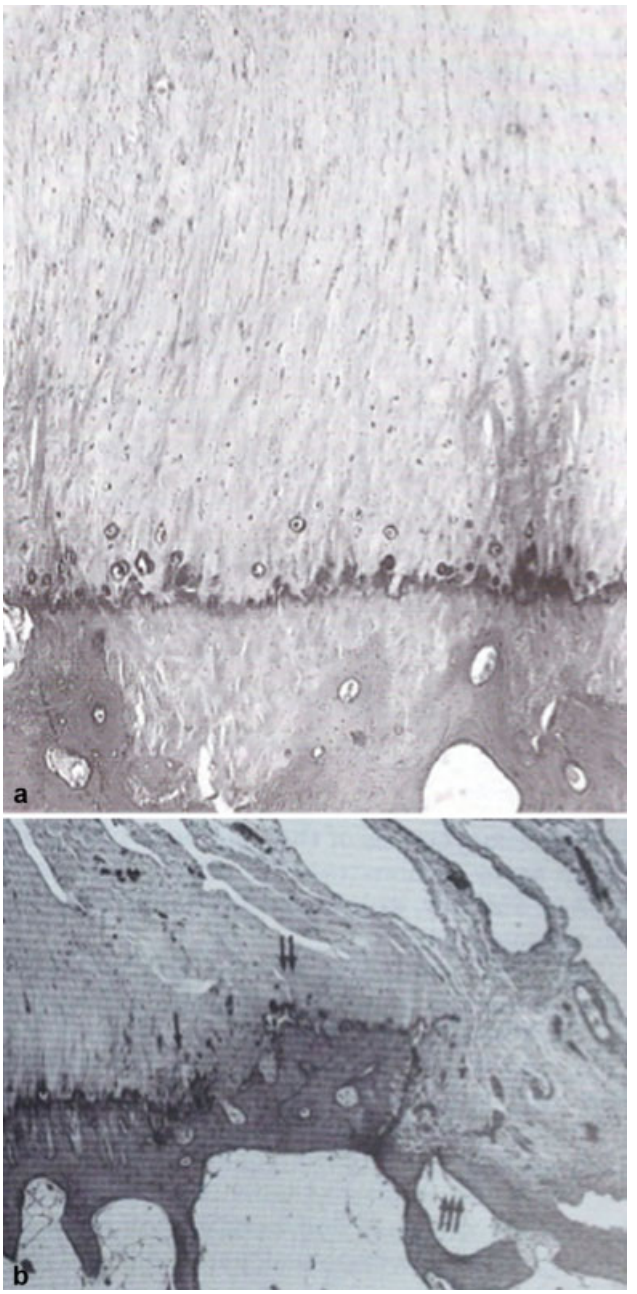

Fig. 2 Organization of the fibers of the supraspinatus tendon in layers in the young, and its progressive disorganization in the adult.

of age, and it is more frequent on the dominant side, a fact that has been proven by other authors.[5] In the seventh decade of life, this incidence increases to more than 80%.

During the last two decades, methods of treatment of cuff injuries have evolved substantially. The surgeries, which have previously been done openly, have started, in most reference centers, to be done arthroscopicly. Different types of sutures emerged, and high-strength threads began to be used routinely.

Local Factors

The main factors associated with rotator cuff healing are injury size, muscle quality (atrophy and fatty degeneration), tendon quality, presence of delamination, and shoulder morphology.

Injury Size

The first characteristic evaluated by most surgeons is the size of the lesion. The analysis, however, should be performed by evaluating the size of the lesion in the sagittal plane and coronal plane (medial retraction or tendon shortening), since they are independent characteristics with respect to the healing rate. From a general point of view, the increase in lesion size negatively influences healing rates, ranging from 97%, for small lesions, to only 6%, for large or massive lesions, in some series. [6–10]

Size Evaluated in the Sagittal Plan

Wylie et al.,[11] when evaluating the healing rate in this plan, showed that lesions $\geq$ 2.2 cm had a healing rate of 49%, and in lesions $\leq$ 2.2 cm the rate rose to 71%. Considering this cutoff value, the hypothesis was postulated that an injury exceeding 2 cm already presents significant involvement of the infraspinal,[12] which alters the kinematics of the humean head, generating unbalance in the forces.[13] This fact would put the repair at risk, thus justifying the increased risk of healing failure in lesions larger than 2.0 cm.

Evaluated Size in Coronal Plan (Shortening)

Myotendinous shortening is considered a direct result of muscle retraction. However, Meyer et al.[14] showed that, although the shortening is predominantly of muscle mass, retraction is also caused by shortening of the tendon itself, both due to the remaining substance in the tubercule after the initial injury and, in advanced stages, the resorption of the tendon itself. In a subsequent analysis, Tashjian et al.,[6] showed that patients with lesions in which the myotendinous junction (MTJ) is lateral to the face of the glenoid, the healing rate was 93%, while in patients with preoperative MTJ medial to the glenoid face, the healing rate was 55%. The analysis then concluded that the position of MTJ is an independent factor in healing. From the point of view of the size of the retraction itself, Wylie et al.[11] showed that lesions with shortening in relation to the footprint $\geq$ 2 cm presented a healing rate of 47%, as opposed to 76% healing in lesions with retraction $\leq$ 2 cm.

Muscle Quality (Fatty Atrophy and Degeneration)

When one thinks of rotator cuff healing, one goal to be achieved is the healing of the tendon-bone interface. Given this fact, most studies focus on methods to strengthen or positively interfere with this interface. However, analyzing large lesions, Jeong et al.[15] observed that muscle quality is more important than tendon quality in the new rupture index. According to the authors, the occupancy rate of the supraspinatus below 43% in relation to the totality of the supraspinatus fossa and a degree of fatty infiltration $\geq$ 2 according to Goutallier are independent risk factors for further rupture of the rotator cuff, with sensitivity of 98% and specificity of 83.6%. A systematic review by Khair et al.,[16] corroborates this fact, indicating that the quality of the preoperative muscle plays an important role in the rate of tendon healing. Low stages of Goutallier (0–1) are associated with low rates of new rupture (25%); in contrast, high stages (2–4) have high rates of rupture (59%).

Histological and Macroscopic Tendon Quality

Regarding the analysis of the histological and macroscopic quality of the tendon, it has been suggested that a worse quality tendon would lead to worse healing rates. However, Mazzoca et al.[17] showed that there is no correlation between the macroscopic appearance of the tendon in the arthroscopy, or in the histological analysis, and healing. Furthermore, they showed that the macroscopic appearance is not correlated with the histological quality of the tendon, and there is no association between the degree of histological tendinopathy, the macroscopic appearance and the healing index or clinical results of the repair. Therefore, the abnormal appearance should not influence negatively the stress or technique of repair.

Delamination

A chronic complete lesion is considered delaminated when there is a horizontal cleavage area in the ruptured tendon. The rotator cuff is composed of five layers, namely: the most superficial is composed of coracoumeral ligament fibers; the second layer is composed of parallel fibers between the supra and infraspinal; the third is composed of small fascicles that intersect the cuff tendons at an angle of 45 degrees; the fourth is composed of extracapsular loose connective tissue that previously connects with the deep portion of the coracoumeral ligament; and, finally, the fifth layer is basically composed of a joint capsule. The second and third layers are thicker, presenting different directions of collagen fibers.[18] It is precisely between these layers that tendon delamination occurs. In a recent study, Boileau et al.[19] showed a prevalence of 32% delamination, all of which involved a posterior component of the deep layer. This study showed that, in general, delamination has a deleterious effect on the healing rate, especially in large lesions. Kwon et al.,[20] in a study with 1,043 patients, confirmed the significantly lower healing rate in delaminated tendons, if the analysis is performed using a single variable. However, when performing multivariate analysis, it was noticed that delamination is not an independent risk factor for healing failure.

Shoulder Morphology

Heuberer et al.[21] analyzed the morphology of the acronym and correlated it with the chance of developing subacromial impact, impacto rotator cuff injury and arthropathy. There were three ways to evaluate acromial morphology, namely: critical shoulder angle (CSA), acromial index (AI) and lateral acromion angle (LAA). The authors concluded that the best way to predict the appearance of cuff-related lesions or the development of osteoarthrosis is through the CSA. This angle, which was described by Moor et al.,[22] has great benefit for combining the lateral extension of the acromion with glenoid angulation. It is calculated on anteroposterior radiography by the angle between the line of the lower edge to the upper edge of the glenoid and the line of the lower edge of the glenoid to the most inferolateral point of the acromion (►**Figure 3**). In the referred study, the authors demonstrated an association between rotator cuff injury for CSA $>$ 35° and

Fig. 3 Critical shoulder angle.

glenohumeral arthrosis in CSA < 30°. This fact has been demonstrated by other authors.[23]

A biomechanical study conducted by Gerber et al.[24] deepened the subject, demonstrating that CSA > 38° requires an increase of up to 33% in supraspinatus activity for shoulder stabilization during 6°-61° abduction. This fact could explain the findings of Moor et al.[22] and predict probable change in the healing rates of these patients. In fact, Garcia et al.[25] found a 14-fold vezes higher risk of rerupture ruptura in patients with CSA > 38°. A recent systematic review on the subject also confirmed the hypothesis, showing that CSA > 38° is associated with lower healing rate.[26] However, due to the heterogeneity of the relevant literature in the review in question, the strength of this finding is considered limited.

Systemic Factors

We will discuss here the various systemic factors that can influence tendon-bone or tendon-tendon healing.

Chronic alcohol use is an important factor regarding the increased incidence of injury as well as the severity of rotator cuff injury in both genders. The association between alcohol consumption and rotator cuff injuries showed that, in wine drinkers, there was more massive lesions than small lesions.[27]

In relation to smoking, it is known that nicotine acts in the expression of the so-called MMP-9, which is an enzyme involved in the degradation of the extracellular matrix, in tenocytes. This factor leads to the modification of the modulus of elasticity of the tendon and, according to Park et al.,[28] is an important risk factor for the spread of the lesion.

Regarding the influence of diabetes mellitus on the prognosis of cuff repair, it is known that the persistence of hyperglycemia in the postoperative period increases the possibility of non-healing of reconstructed the tendons. Therefore, blood glucose control after surgery becomes fundamental.[29]

The association between arterial hypertension and cuff injuries showed that, in relation to normotensive patients, hypertensive patients have twice as many large lesions and four times as many massive lesions.[30]

Cholesterol also influences the prognosis by increasing tendon stiffness through changes in its modulus of elasticity.[31]

Obese patients, those with increased body mass index, also present increased incidence and severity of rotator cuff injuries.[32]

Immunobiological factors, by interfering with the mechanisms associated with muscle homeostasis, aggravate the process of fatty degeneration, which, in sua turn, determines the worsening of the prognosis of tendon healing.[33]

Finally, age, which is an inexorable factor, also influences through the natural process of tendon degeneration, the modulus of elasticity in the rotator cuff.

Chung et al.[34] analyzed the main prognostic factors associated with poor results after surgical reconstruction of the rotator cuff. The mean age of the patients evaluated was 63.7 years. The authors observed the incidence of 39.8% of failure in the repair of rotator cuff lesions. The worst prognostic factors considered were fatty degeneration of the infraspinal muscle and reduction of subacromial space by cephalic migration of the humeral head.

Cho et al.[35] studied the factors that affect the integrity of rotator cuff reconstruction. The patients were divided into three groups, namely: < 50 years of age group I), between 51 and 60 years of age (group II), and > 60 years of age (group III). They observed that the older the age, the lower the incidence of healing (►**Table 1**). Nevertheless, the study recommends the reconstruction of lesions in elderly patients due to clinical improvement.

Deer et al.[36] evaluated the integrity of the repair and its relationship with the function on the shoulders of patients submitted to arthroscopic reconstruction after 65 years of age. For the study, the authors used the same sonographer to perform all imaging tests and found an incidence of 75% of tendon integrity with the University of California Los Angeles Shoulder Score (UCLA) improvement from 17 points to 32 points, which represents 85% of good and excellent results. There was also a significant reduction in the level of pain when the visual analog scale was used.

Table 1 Increased healing in younger patients

Groups:	< 50	51–60	> 60 years
N	49	68	52 patients
Healing	87.8%	79.4%	65.4%
N-healing	12.2%	20.6%	34.6%

Dezaly et al.[37] conducted a prospective, comparative, randomized study of two groups of patients. Group I underwent rotator cuff reconstruction, acromioplasty, and tenotomy of the long portion of the brachial biceps. Group II underwent biceps tenotomy and acromioplasty, without cuff reconstruction. There were 103 patients evaluated and, although the postoperative recovery time was shorter in group II, as expected, both the functional result by the Constant score (82 in group I and 73 in group II) and the subacromial distance measured in the imaging exams were favorable to group I. Interestingly, the best results were observed in the reconstructions of the most retracted lesions, suggesting that elderly patients with small lesions should be treated conservatively.

Many studies[38] have suggested that increasing age is related to a reduction in the potential for tendon healing, while biomechanical studies suggest that the reason for this should be due to an unfavorable environment, such as low-tissue perfusion and the reduction in the number of undifferentiated cells.

Perioperative Factors

The systemic and local factors mentioned above are inherent to the patient, and, therefore, in general, difficult to control on the part of the surgeon. For this reason, factors related to surgical techniques are of crucial importance in the results, since at this point the surgeon can actively act in the improvement of healing. Here, a good choice, focused on technical knowledge, can increase healing rates.

Single Row x Double Row

Apreleva et al.[39] showed that rotator cuff repair with single row (SR) anchors can restore only 67% of normal footprint, which could be an explanation for healing failures. Considering this, Lo and Burkhart[40] created the double row (DR) of anchors technique. This technique consists of using a row of medial anchors, next to the joint margin, and another row in the lateral aspect of the footprint. In this way, the width from medial to lateral is reestablished in an attempt to recreate the insertion of the rotator cuff and thus optimize the healing potential. From a biomechanical point of view, the addition of a second row of anchors increases the number of attachment points, increasing the initial strength of the construction, decreasing the load that each knot/anchor needs to resist and decreasing stress at the point of contact between each suture in the cuff. Biomechanical studies supported the technique, demonstrating a significant decrease in gap interval formation and strain deformation, associated with increased strength and initial stiffness, when compared to the single row technique.[41]

Despite demonstrating a biomechanical advantage, the clinical value of the technique is controversial, with an important part of the trials stating that there are no improvements in quality of life or clinical scores, despite an advantage in the healing rate of DR over SR.[42] A recent Brazilian study, with results of 1 to 4 years of the double row technique corroborates this fact, demonstrating no statistically significant difference in UCLA and American Shoulder and Elbow Score (ASES) scores between the two techniques.[43]

Given the above, to decide about the real advantage of the technique, and which patient would benefit from it, Xu et al.[44] performed a meta-analysis, with randomized clinical trials of levels 1 and 2 evidence, comparing the two methods. They concluded that, although the DR technique presented a lower rate of new rupture (23.8% DR x 40.2% SR), better ASES and improvement in medial rotation amplitude, there is no difference in the Constant score, UCLA score, anterior elevation, lateral rotation and muscle strength when compared to the SR technique in the overall analysis of the results. However, when analyzing subgroups by lesion size, in large lesions > 3 cm, DR repair showed statistically significant improvement in healing, UCLA and ASES. This result is corroborated by other authors, such as the summary of meta-analyses performed by Spiegl et al.[45] and the meta-analysis produced only with level 1 trials of evidence, conducted by Sheibani-Rad et al.[46]

Arthroscopic x Open

The most used methods for rotator cuff reconstruction are open, mini-open and arthroscopic. Both the mini-open and arthroscopic techniques maintain the integrity of the deltoid origin. In contrast, in the open technique, part of the deltoid is deserted from the edge of the acromion. Theoretically, this would be the main disadvantage of open reconstruction; however, a study by Cho et al.,[47] in postoperative magnetic resonance imaging (MRI) analysis, showed no significant difference between open and arthroscopic techniques regarding complications such as detachment of deltoid origin or muscle changes. Another disadvantage of the open technique would be increased pain in the initial postoperative phase, since it requires greater mobilization of soft tissues. This fact was also not confirmed, as demonstrated in meta-analysis with level 1 randomized controlled studies conducted by Ji et al.[48]

Regarding healing rates, a recent meta-analysis with high-quality studies and 770 patients showed similar healing rates between mini-open and arthroscopic techniques.[49] Moreover, there was no significant difference in clinical scores between the techniques.

Despite the similarity between the clinical results and healing rates, it is worth remembering that the arthroscopic technique offers advantage by providing easy access to glenohumeral joint associated with better cosmetic results.

Postoperative Factors

Chemical Factors: Anti-inflammatory

Healing is a gradual process, composed of overlapping phases, and the inflammatory phase is mandatory. Any factor that slows or alters its progress can affect it. Most studies on the subject are in vitro or with animal models and, as found by Constantinescu et al.,[50] in a systematic review, the current literature does not provide enough evidence for or against the use of nonsteroidal antiinflammatory drugs (NSAIDs). It is worth noting that this review found only one level 1

randomized clinical trial of evidence. The study in question, conducted by Oh et al.,[51] compared the analgesic side effects in the use of celecoxib (selective inhibitor COX-2), ibuprofen (non-selective NSAID), and tramadol (opioid). No significant differences were found between medications. In a second time, retrospectively, the healing rates were evaluated by MRI and ultrasound (US), and an important negative effect was observed with the use of selective COX-2 inhibitor (new rupture: 37% celecoxib $\times$ 7% ibuprofen $\times$ 4% tramadol). Therefore, despite presenting similar analgesia in the postoperative period, when compared with other NSAIDs and opioids, selective COX-2 inhibitors should not be used, since they can act negatively on healing after rotator cuff repair.

Mechanical Factors

The way to conduct the postoperative period may interfere with the healing process of the rotator cuff after a surgical reconstruction. Rehabilitation protocols consider the need for initial protection of reconstruction, associated with the intention of restoring shoulder function, preventing joint stiffness and muscle atrophy. Shoulder joint stiffness still has unclear etiology, but may be related to prolonged immobilization or conservative rehabilitation programs.[52] Biomechanical studies show that early loading is harmful to the organization of collagen fibers, and can generate microdamage at the bone/tendon interface, thus preventing the integration of collagen fibers into the bone or even complete healing failure.[53]

Early Mobilization vs. Late Mobilization

The protocols can be divided basically into two categories: early passive motion (EPM) and immobilization with delayed range motion (DRM).[54] The EPM protocol consists of minimal immobilization with sling, in which commuting movements are allowed plus passive movements of range of motion such as lateral rotation and elevation from the first postoperative day. On the other hand, the DRM protocol imposes the use of sling without passive movements, and only commuting exercises up to 2 to 4 weeks postoperatively are allowed. Performing analysis and review of published meta-analyses, Houck et al.,[55] concluded that the EPM protocol improves the range of motion, but increases the risk of further rupture of the cuff. It is noteworthy that, although shoulder stiffness is an important problem in the postoperative period of rotator cuff surgery, it is considered a complication, different from the recurrence of rupture, which is considered a treatment failure.

Sling Time

One of the first questions of the patients in the preoperative consultation concerns the time of use of the sling. There is a lot of divergence in the literature regarding the minimum time of use associated with better rotator cuff healing. Koh et al.[56] showed, in a level 1 study of evidence, that there are no benefits in healing when comparing immobilization for 4 weeks and immobilization for 8 weeks. Therefore, the literature does not support the use of sling for more than 4 weeks.

Velpeau Sling vs. Abduction Sling

Basically, anti-rotational sling keeps the arm close to the body in medial rotation. The abduction sling maintains the shoulder in various abduction and lateral rotation configurations. In the biomechanical analysis, Jackson et al.[57] found the optimal position to create the lowest level of supraspinatus and infraspinatus tension. This position would be with elevation of 21 to 45° and lateral rotation of 18 to 23°. However, in practice, the results do not prove the benefits of this position. Some authors show that there was no significant difference in clinical aspects or in the rate of new rupture. Other studies favorable to the use of abduction slings show advantages from the clinical point of view of pain and function, without evaluation of the the results in healing rates.[58] It is worth mentioning that, in general, studies on sling immobilization are based on the responses of patients' self-assessment in relation to the amount of time of use of the type; however, an important question is whether these patients actually use the sling as reported. Based on this questioning, Grubhofer et al.[59] showed, evaluating the use of abduction slings with digital sensors, that only 48% of patients used the sling in a way they considered satisfactory ($>$ 80% of the time). Moreover, when comparing the data obtained by the sensors and the patient information, the discrepancy was frightening, especially in patients who did not use the sling as recommended. The authors, therefore, suggest caution with the results of studies on type and time of use of slings.

Genetic Factors

Figueiredo et al.,[60] identified genetic factors associated with susceptibility of rotator cuff injury, reinforcing the role of extracellular matrix homeostasis in this context.

Final Considerations

The present review article allowed us to broaden the understanding of the factors that interfere in the healing process of rotator cuff tendons. It was clear that there are many variables, being local, systemic, mechanical, chemical, genetic or associated with life habits. Pre, peri, and postoperative factors have a decisive influence on this process. As a final message, it is suggested that the treatment of rotator cuff lesions be done individually, considering all the factors previously described and, in elderly patients, before the surgical option, that the attempt of conservative treatment should be considered.

Conflict of Interests

The authors declare that there is no conflict of interests.

References

1 Yamanaka K, Fukuda H, Hamada K, Nakajima T. Histology of the supraspinatus tendon with reference to rotator cuff tears. In: Gazielly DF, Gleyze P, Thomas T, editors. The Cuff. New York: Elsevier; 1997:15–18
2 Uthoff HK, Ishii H. Histology of the cuff and pathogenesis of the degenerative tendinopathies. In: Gazielly DF, Gleyze P, Thomas T, editors. The Cuff. New York: Elsevier; 1997:19–23
3 Yamaguchi K, Tetro AM, Blam O, Evanoff BA, Teefey SA, Middleton WD. Natural history of asymptomatic rotator cuff tears: a

longitudinal analysis of asymptomatic tears detected sonographically. J Shoulder Elbow Surg 2001;10(03):199–203
4 Milgrom C, Schaffler M, Gilbert S, van Holsbeeck M. Rotator-cuff changes in asymptomatic adults. The effect of age, hand dominance and gender. J Bone Joint Surg Br 1995;77(02):296–298
5 Carvalho AL, Martinelli F, Tramujas L, Baggio M, Crocetta MS, Martins RO. Lesões do manguito rotador e fatores associados à reoperação. Rev Bras Ortop 2016;51(03):298–302
6 Tashjian RZ, Hung M, Burks RT, Greis PE. Influence of preoperative musculotendinous junction position on rotator cuff healing using single-row technique. Arthroscopy 2013;29(11):1748–1754
7 Boileau P, Brassart N, Watkinson DJ, Carles M, Hatzidakis AM, Krishnan SG. Arthroscopic repair of full-thickness tears of the supraspinatus: does the tendon really heal? J Bone Joint Surg Am 2005;87(06):1229–1240
8 Galatz LM, Ball CM, Teefey SA, Middleton WD, Yamaguchi K. The outcome and repair integrity of completely arthroscopically repaired large and massive rotator cuff tears. J Bone Joint Surg Am 2004;86(02):219–224
9 Ikemoto RY, Murachovsky J, Nascimento LG, et al. Arthroscopic Repair Of Small And Medium Tears Of The Supraspinatus Muscle Tendon: Evaluation Of The Clinical And Functional Outcomes After Two Years Of Follow-Up. Rev Bras Ortop 2012;47(04):436–440
10 Godinho GG, França FO, Freitas JM, et al. Evaluation of anatomical integrity using ultrasound examination, and functional integrity using the constant & murley score, of the rotator cuff following arthroscopic repair. Rev Bras Ortop 2010;45(02):174–180
11 Wylie JD, Baran S, Granger EK, Tashjian RZ. A Comprehensive Evaluation of Factors Affecting Healing, Range of Motion, Strength, and Patient-Reported Outcomes After Arthroscopic Rotator Cuff Repair. Orthop J Sports Med 2018;6(01):2325967117750104
12 Mochizuki T, Sugaya H, Uomizu M, et al. Humeral insertion of the supraspinatus and infraspinatus. New anatomical findings regarding the footprint of the rotator cuff. J Bone Joint Surg Am 2008;90(05):962–969
13 Burkhart SS, Esch JC, Jolson RS. The rotator crescent and rotator cable: an anatomic description of the shoulder's "suspension bridge". Arthroscopy 1993;9(06):611–616
14 Meyer DC, Farshad M, Amacker NA, Gerber C, Wieser K. Quantitative analysis of muscle and tendon retraction in chronic rotator cuff tears. Am J Sports Med 2012;40(03):606–610
15 Jeong HY, Kim HJ, Jeon YS, Rhee YG. Factors Predictive of Healing in Large Rotator Cuff Tears: Is It Possible to Predict Retear Preoperatively? Am J Sports Med 2018;46(07):1693–1700
16 Khair MM, Lehman J, Tsouris N, Gulotta LV. A Systematic Review of Preoperative Fatty Infiltration and Rotator Cuff Outcomes. HSS J 2016;12(02):170–176
17 Sethi PM, Sheth CD, Pauzenberger L, et al. Macroscopic Rotator Cuff Tendinopathy and Histopathology Do Not Predict Repair Outcomes of Rotator Cuff Tears. Am J Sports Med 2018;46(04): 779–785
18 Clark JM, Harryman DT II. Tendons, ligaments, and capsule of the rotator cuff. Gross and microscopic anatomy. J Bone Joint Surg Am 1992;74(05):713–725
19 Boileau P, Andreani O, Schramm M, Baba M, Barret H, Chelli M. The Effect of Tendon Delamination on Rotator Cuff Healing. Am J Sports Med 2019;47(05):1074–1081
20 Kwon J, Lee YH, Kim SH, Ko JH, Park BK, Oh JH. Delamination Does Not Affect Outcomes After Arthroscopic Rotator Cuff Repair as Compared With Nondelaminated Rotator Cuff Tears: A Study of 1043 Consecutive Cases. Am J Sports Med 2019;47(03):674–681
21 Heuberer PR, Plachel F, Willinger L, et al. Critical shoulder angle combined with age predict five shoulder pathologies: a retrospective analysis of 1000 cases. BMC Musculoskelet Disord 2017; 18(01):1–9
22 Moor BK, Bouaicha S, Rothenfluh DA, Sukthankar A, Gerber C. Is there an association between the individual anatomy of the scapula and the development of rotator cuff tears or osteoarthritis of the glenohumeral joint?: A radiological study of the critical shoulder angle Bone Joint J 2013;95-B(07):935–941
23 Gomide LC, Carmo TC, Bergo GH, Oliveira GA, Macedo IS. Associação entre o ângulo crítico do ombro e lesão do manguito rotador: um estudo epidemiológico retrospectivo. Rev Bras Ortop 2017;52(04):423–427
24 Gerber C, Snedeker JG, Baumgartner D, Viehöfer AF. Supraspinatus tendon load during abduction is dependent on the size of the critical shoulder angle: A biomechanical analysis. J Orthop Res 2014;32(07):952–957
25 Garcia GH, Liu JN, Degen RM, et al. Higher critical shoulder angle increases the risk of retear after rotator cuff repair. J Shoulder Elbow Surg 2017;26(02):241–245
26 Scheiderer B, Imhoff FB, Johnson JD, et al. Higher Critical Shoulder Angle and Acromion Index Are Associated With Increased Retear Risk After Isolated Supraspinatus Tendon Repair at Short-Term Follow Up. Arthroscopy 2018;34(10):2748–2754
27 Passaretti D, Candela V, Venditto T, Giannicola G, Gumina S. Association between alcohol consumption and rotator cuff tear. Acta Orthop 2016;87(02):165–168
28 Park JH, Oh KS, Kim TM, et al. Effect of Smoking on Healing Failure After Rotator Cuff Repair. Am J Sports Med 2018;46(12):2960–2968
29 Cho NS, Moon SC, Jeon JW, Rhee YG. The influence of diabetes mellitus on clinical and structural outcomes after arthroscopic rotator cuff repair. Am J Sports Med 2015;43(04):991–997
30 Gumina S, Arceri V, Carbone S, et al. The association between arterial hypertension and rotator cuff tear: the influence on rotator cuff tear sizes. J Shoulder Elbow Surg 2013;22(02):229–232
31 Beason DP, Hsu JE, Marshall SM, et al. Hypercholesterolemia increases supraspinatus tendon stiffness and elastic modulus across multiple species. J Shoulder Elbow Surg 2013;22(05):681–686
32 Gumina S, Candela V, Passaretti D, et al. The association between body fat and rotator cuff tear: the influence on rotator cuff tear sizes. J Shoulder Elbow Surg 2014;23(11):1669–1674
33 Thankam FG, Dilisio MF, Agrawal DK. Immunobiological factors aggravating the fatty infiltration on tendons and muscles in rotator cuff lesions. Mol Cell Biochem 2016;417(1-2):17–33
34 Chung SW, Kim JY, Kim MH, Kim SH, Oh JH. Arthroscopic repair of massive rotator cuff tears: outcome and analysis of factors associated with healing failure or poor postoperative function. Am J Sports Med 2013;41(07):1674–1683
35 Cho NS, Rhee YG. The factors affecting the clinical outcome and integrity of arthroscopically repaired rotator cuff tears of the shoulder. Clin Orthop Surg 2009;1(02):96–104
36 Veado MA, Prata EF, Gomes DC. Lesão do manguito rotador em pacientes maiores de 65 anos: avaliação da função, integridade e força. Rev Bras Ortop 2015;50(03):318–323
37 Dezaly C, Sirveaux F, Philippe R, et al. Arthroscopic treatment of rotator cuff tear in the over-60s: repair is preferable to isolated acromioplasty-tenotomy in the short term. Orthop Traumatol Surg Res 2011;97(6, Suppl)S125–S130
38 Mall NA, Tanaka MJ, Choi LS, Paletta GA Jr. Factors affecting rotator cuff healing. J Bone Joint Surg Am 2014;96(09):778–788
39 Apreleva M, Ozbaydar M, Fitzgibbons PG, Warner JJ. Rotator cuff tears: the effect of the reconstruction method on three-dimensional repair site area. Arthroscopy 2002;18(05):519–526
40 Lo IK, Burkhart SS. Double-row arthroscopic rotator cuff repair: re-establishing the footprint of the rotator cuff. Arthroscopy 2003;19(09):1035–1042
41 Smith CD, Alexander S, Hill AM, et al. A biomechanical comparison of single and double-row fixation in arthroscopic rotator cuff repair. J Bone Joint Surg Am 2006;88(11):2425–2431
42 Charousset C, Grimberg J, Duranthon LD, Bellaiche L, Petrover D. Can a double-row anchorage technique improve tendon healing in arthroscopic rotator cuff repair?: A prospective, nonrandomized, comparative study of double-row and single-row anchorage techniques with computed tomographic arthrography tendon healing assessment Am J Sports Med 2007;35(08):1247–1253

43 Senna LF, Ramos MR, Bergamaschi RF. Reparo artroscópico do manguito rotador: fileira simples versus fileira dupla – Resultados clínicos após um a quatro anos. Rev Bras Ortop 2018;53(04):448–453

44 Xu C, Zhao J, Li D. Meta-analysis comparing single-row and double-row repair techniques in the arthroscopic treatment of rotator cuff tears. J Shoulder Elbow Surg 2014;23(02):182–188

45 Spiegl UJ, Euler SA, Millett PJ, Hepp P. Summary of Meta-Analyses Dealing with Single-Row *versus* Double-Row Repair Techniques for Rotator Cuff Tears. Open Orthop J 2016;10:330–338

46 Sheibani-Rad S, Giveans MR, Arnoczky SP, Bedi A. Arthroscopic single-row versus double-row rotator cuff repair: a meta-analysis of the randomized clinical trials. Arthroscopy 2013;29(02):343–348

47 Cho NS, Cha SW, Rhee YG. Alterations of the Deltoid Muscle After Open Versus Arthroscopic Rotator Cuff Repair. Am J Sports Med 2015;43(12):2927–2934

48 Ji X, Bi C, Wang F, Wang Q. Arthroscopic versus mini-open rotator cuff repair: an up-to-date meta-analysis of randomized controlled trials. Arthroscopy 2015;31(01):118–124

49 Shan L, Fu D, Chen K, Cai Z, Li G. All-arthroscopic versus mini-open repair of small to large sized rotator cuff tears: a meta-analysis of clinical outcomes. PLoS One 2014;9(04):e94421

50 Constantinescu DS, Campbell MP, Moatshe G, Vap AR. Effects of Perioperative Nonsteroidal Anti-inflammatory Drug Administration on Soft Tissue Healing: A Systematic Review of Clinical Outcomes After Sports Medicine Orthopaedic Surgery Procedures. Orthop J Sports Med 2019;7(04):2325967119838873

51 Oh JH, Seo HJ, Lee YH, Choi HY, Joung HY, Kim SH. Do Selective COX-2 Inhibitors Affect Pain Control and Healing After Arthroscopic Rotator Cuff Repair? A Preliminary Study. Am J Sports Med 2018;46(03):679–686

52 Koo SS, Burkhart SS. Rehabilitation following arthroscopic rotator cuff repair. Clin Sports Med 2010;29(02):203–211, vii

53 Gerber C, Schneeberger AG, Perren SM, Nyffeler RW. Experimental rotator cuff repair. A preliminary study. J Bone Joint Surg Am 1999;81(09):1281–1290

54 Bakti N, Antonios T, Phadke A, Singh B. Early versus delayed mobilization following rotator cuff repair. J Clin Orthop Trauma 2019;10(02):257–260

55 Houck DA, Kraeutler MJ, Schuette HB, McCarty EC, Bravman JT. Early Versus Delayed Motion After Rotator Cuff Repair: A Systematic Review of Overlapping Meta-analyses. Am J Sports Med 2017;45(12):2911–2915

56 Koh KH, Lim TK, Shon MS, Park YE, Lee SW, Yoo JC. Effect of immobilization without passive exercise after rotator cuff repair: randomized clinical trial comparing four and eight weeks of immobilization. J Bone Joint Surg Am 2014;96(06):e44

57 Jackson M, Sylvestre É, Bleau J, Allard P, Begon M. Estimating optimal shoulder immobilization postures following surgical repair of massive rotator cuff tears. J Biomech 2013;46(01):179–182

58 Conti M, Garofalo R, Castagna A. Does a brace influence clinical outcomes after arthroscopic rotator cuff repair? Musculoskelet Surg 2015;99(Suppl 1):S31–S35

59 Grubhofer F, Gerber C, Meyer DC, et al. Compliance with wearing an abduction brace after arthroscopic rotator cuff repair: A prospective, sensor-controlled study. Prosthet Orthot Int 2019;43(04):440–446

60 Figueiredo EA, Loyola LC, Belangero PS, et al. Rotator Cuff Tear Susceptibility Is Associated With Variants in Genes Involved in Tendon Extracellular Matrix Homeostasis. J Orthop Res 2020;38(01):192–201