Review

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Radiofrequency in arthroscopic shoulder surgery: a systematic review

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Background: Radiofrequency has seen an increase in use in orthopedics including cartilage lesion debridement in the hip and knee as well as many applications in arthroscopic shoulder surgery. The purpose of this systematic review is to evaluate the safety and usage of radiofrequency in the shoulder.
Methods: This systematic review was registered with PROSPERO (international registry) and followed the preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) guidelines. Embase and PubMed were searched using: "shoulder," "rotator cuff," "biceps," "acromion" AND "monopolar," "bipolar," "ablation," "coblation," and "radiofrequency ablation." The title and abstract review were performed independently. Any discrepancies were addressed through open discussion.
Results: A total of 63 studies were included. Radiofrequency is currently utilized in impingement syndrome, fracture fixation, instability, nerve injury, adhesive capsulitis, postoperative stiffness, and rotator cuff disease. Adverse events, namely superficial burns, are limited to case reports and case series, with higher-level evidence demonstrating safe use when used below the temperature threshold. Bipolar radiofrequency may decrease operative time and decrease the cost per case.
Conclusions: Shoulder radiofrequency has a wide scope of application in various shoulder pathologies. Shoulder radiofrequency is safe; however, requires practitioners to be cognizant of the potential for thermal burn injuries. Bipolar radiofrequency may represent a more efficacious and economic treatment modality. Safety precautions have been executed by institutions to cut down patient complications from shoulder radiofrequency. Future research is required to determine what measures can be taken to further minimize the risk of thermal burns.

Keywords: Radiofrequency; Plasma energy; Arthroscopic shoulder surgery; Safety; Efficiency

INTRODUCTION

Radiofrequency (RF) refers to application of thermal energy to reorganize tissue on a molecular level and restore normal structure and function [1]. Traditional RF or electrocauterization refers to the use of thermal energy to treat surgical pathology by passing electrical current directly through tissue [1]. RF can be delivered through a monopolar or bipolar device [1-3]. Bipolar RF represents a safer alternative at lower temperatures, voltages, contact pressures, and contact times [1]. These devices create high-energy free radicals that can break molecular bonds and excise soft tissue at relatively low temperatures (40°C–70°C) [2]. RF systems are widely used in arthroscopic orthopedic procedures for ablation, resection, and coagulation of soft tissues [3]. RF en-

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ergy is not without its risks and does exhibit time-dependent effects that need to be considered by surgeons [4]. Next-generation RF devices utilize plasma energy fields to deliver thermal energy to minimize damage to the surrounding soft tissues [1,5].

The safety profile of RF has been studied in the knee in the context of low-grade cartilage lesions [2]. The safety of RF has also been well-studied in the hip for ablating soft tissues [6]. In the glenohumeral joint, RF was first studied in the context of instability but resulted in overtreatment [7], permanent tissue damage [7], and high failure rates necessitating capsular plication [8,9]. However, there are limited reports on the temperature profile and complications in shoulder joint RF.

In recent years, there have been many studies published regarding the use of RF energy in the surgical treatment of many shoulder pathologies. In the existing publications regarding RF use in the shoulder, the purpose of the equipment is to split and partially remove soft tissues [10-20]. However, the safety and complications of RF use to debride soft tissue have not been established. The purpose of this investigation is to conduct a systematic review of the currently available literature to evaluate the safety and complication profile of RF devices for use in the shoulder.

METHODS

General

This systematic review was registered in an international prospective register of systematic reviews (PROSPERO No. CRD 42021288444.) The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA-P) guidelines were followed.

Literature Search

The literature search was performed using Embase and PubMed with the keywords displayed in Table 1. The initial literature search revealed 1,531 studies. After removal of duplicate articles, title and abstract screening was performed on 1,374 studies. Of these, 537 studies did not pertain to the use of RF in arthroscopic shoulder surgery. Finally, the full-text of 837 studies was screened (Fig. 1).

Study Selection

Studies were selected according to the inclusion and exclusion criteria presented in Table 2. Of note, studies related to shoulder capsulorrhaphy usage were excluded, given the high complication rates of axillary nerve dysfunction, articular cartilage damage, and capsular necrosis [21]. Application of our inclusion and exclusion criteria resulted in a total of 63 studies.

Qualitative Synthesis

Due to a limited number of high-level clinical studies on the topic and heterogeneous reporting of data, the included studies were qualitatively synthesized. The included studies were grouped into those that contained data regarding the performance profile of RF and those that did not. The performance profile was defined as any mention of the temperature profile, safety profile and

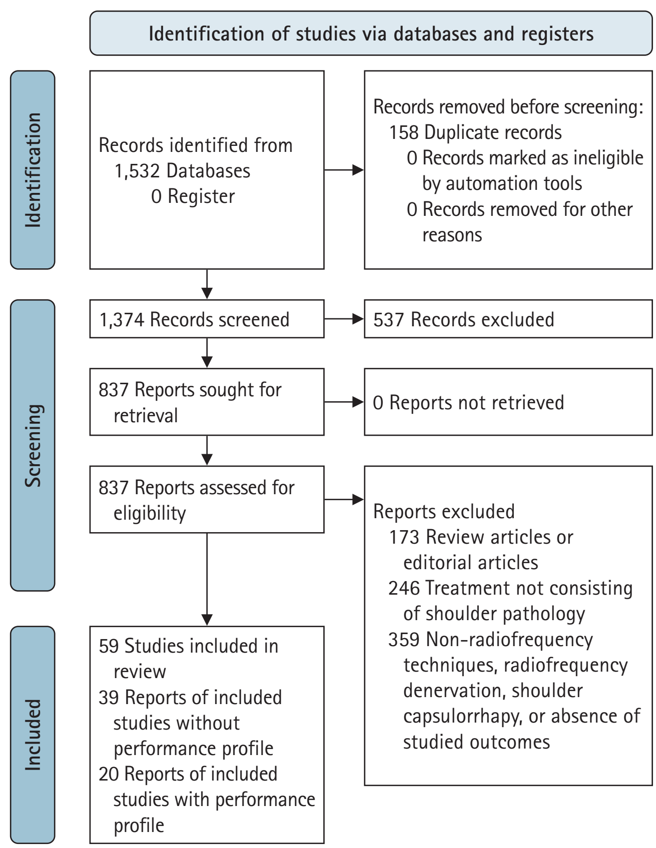

Fig. 1. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA-P) flow diagram for our study.

Table 1. Search keywords used in the literature search

Search term category	Keywords used
Anatomic location	'shoulder,' 'rotator cuff,' 'biceps,' 'acromion'
Radiofrequency modality	'monopolar,' 'bipolar,' 'ablation,' 'coblation,' 'turbovac,' 'radiofrequency ablation'

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Table 2. Inclusion and exclusion criteria utilized for the identification of relevant studies

Inclusion criteria	Exclusion criteria
Treatment regarding radiofrequency usage in during arthroscopic shoulder surgery	Non-radiofrequency techniques, radiofrequency denervation or shoulder capsulorrhaphy
Clinical, cadaveric, or animal studies	Other review articles or editorial articles
Inclusion of data regarding the temperature profile or the safety and complication rate	Treatment not consisting of orthopedic pathology or upper extremity

complication rate, or clinical outcomes. These studies were grouped accordingly and descriptively summarized in the tables.

RESULTS

General

Of our 59 included articles, 39 did not include RF performance in terms of temperature profile or complications. The remaining 20 studies did include at least one of these measures. The studies in this review that discuss RF for shoulder arthroscopic orthopedic procedures without data on performance profile do provide insight regarding the breadth of shoulder RF use and are summarized in Table 3 [10,12-19,22-51]. Table 3 revealed bipolar RF as the most commonly used modality. Of the 39 studies depicted in Table 3, only 17 (43.6%) specified the RF modality, all of which were bipolar. The remaining 22 studies (56.4%) were unspecified.

Performance Profile

Studies that disclosed the performance profile of RF usage in the shoulder were further analyzed. These studies were grouped by temperature profile (Table 4) [3,20,52-62] and complications (Table 5) [21,63-68].

Temperature Profile

Our literature review identified two randomized controlled trials, two prospective cohort studies, two case series, three cadaveric studies, two animal studies, and two basic science studies exploring the temperature profile of RF ablation devices in the shoulder (Table 4).

While comparing RF instruments, Huynh et al. [3] found few differences in temperature characteristics. The peak temperature during RF usage in subacromial decompression was 32.0°C (range, 29.3 °C–43.1°C) [55]. The mean peak temperature of outflow fluid was 71.6°C, assumed to mimic wand tip temperature, which should be between 40 and 70°C [55]. During the study, Barker et al. [55] found the most crucial factor in subacromial temperature to be fluid irrigation temperature. For this reason, they recommended against the use of warmed irrigation fluid in RF. Davies et al. [56] also suggested that irrigation fluid be cooled before RF usage. In their case series of 30 patients, subacromial bursa temperature during RF with a monopolar device was assessed. Mean (27.8°C) and maximum (41.8°C) temperatures were observed well below the chondrocyte damage threshold temperature. The authors explained the isolated reading of 41.8°C to be due to blockage of the RF suction probe [56].

Good et al. [58] performed a cadaveric study regarding intraarticular temperatures during shoulder RF use. Intraarticular temperatures increased above 45°C in each trial. The highest peak temperatures were observed when the fluid flow rate was 0%, while the lowest peak temperatures were observed when the fluid flow rate was 100% [58]. No statistical differences in mean temperature were observed whether the device was immersed in fluid or in direct contact with tissue [58]. Zoric et al. [57] demonstrated three factors that were critical for maintaining safe intra-articular temperature: rate of flow, distance of device application, and duration of usage. This study also suggested that maximization of irrigation flow, shorter duration of device use, and adequate suction techniques further prevent temperature-related patient complications and injuries.

Safety and Complications

Overall, reports of postoperative complications following RF methods were lacking (Table 5). Our literature search revealed one prospective controlled trial, one case series, and five case reports that provided significant complication rates or commented on the safety profile. The small number of reported complications from RF usage within the literature was related to increased irrigation fluid temperature and was limited to case reports [55] and case series [65]. Four cases of second-degree burns were reported by Troxell et al. [65] due to a bipolar RF device being used in an unreported number of patients over 4 years. The authors [65] attributed these four cases to lack of outflow tubing. Since changing their practice, further burn cases have not occurred.

The most common adverse events of RF use are thermal injuries due to high temperature of the fluid and surrounding tissue [3]. Many studies involve novel arthroscopic techniques with RF devices, yet parameters of its use such as safety, complications, and outcome profiles are poorly detailed within the majority of

Table 3. Studies included within this review article where RF device usage occurred without performance outcome disclosure by authors

Study	Use	Study purpose	Device used	Radiofrequency mode	Amount of radiofrequency use
Baumgarten et al. [22]	Acromioclavicular joint reconstruction	To propose a novel technique for the reconstruction of acromioclavicular joint	Unspecified	Unspecified	Minor
Cvetanovich et al. [10]	Adhesive capsulitis	To report outcomes after 360° arthroscopic capsular release for glenohumeral adhesive capsulitis performed in the lateral decubitus position	Super Turbovac 90 (Arthrocare; Smith & Nephew, Austin, TX, USA)	Coblation	Major
Cvetanovich et al. [14]	Adhesive capsulitis	Description of an arthroscopic 360° capsular release method	Super Turbovac 90 (Arthrocare)	Coblation	Major
Arce et al. [13]	Adhesive capsulitis	To detail an arthroscopic capsular release for primary frozen shoulder syndrome	VAPR III (DePuy Mitek, Raynham, MA, USA)	Bipolar	Major
Katthagen et al. [23]	Anterior instability	Presentation of a novel technique in open Latarjet procedure along with an arthroscopic Hills-Sachs remplissage	Super Turbovac 90 (Arthrocare)	Coblation	Minor
Ganokroj et al. [24]	Anterior instability	To propose a novel arthroscopic technique called the "double row-double pulley" in the restoration of a bony Bankart lesion	Super Turbovac 90 (Arthrocare)	Coblation	Minor
Lewington et al. [25]	Anterior shoulder instability	To present a method for shoulder instability using lateral decubitus arthroscopic Latarjet procedure	StarVac 90 (Arthrocare)	Coblation	Minor
Gomes et al. [26]	Anterior shoulder instability	To present a Marfan's Syndrome patient with recurrent anterior shoulder dislocation due to hyperlaxity requiring arthroscopic treatment	Unspecified	Unspecified	Major
Saithna et al. [17]	Biceps pathology	Description of a novel technique to transilluminate the bicipital groove and identify long head biceps tendon	Unspecified	Unspecified	Minor
Shih et al. [27]	Biceps pathology	Introduction of a novel technique for arthroscopic suprapectoral biceps tenodesis utilizing an all suture method	Unspecified	Unspecified	Minor
Valenti et al. [19]	Biceps pathology	To present a novel technique for arthroscopic biceps tenodesis	VAPR Coolpulse 90 (DePuy Mitek)	Bipolar	Major
Daggett et al. [28]	Biceps pathology	To describe a novel arthroscopic technique for bicep tenodesis, the "loop lock" technique	Unspecified	Unspecified	Minor
Saithna et al. [29]	Biceps pathology	To present a novel method to identify the long head biceps tendon within the subacromial space	Unspecified	Unspecified	Major
Su et al. [18]	Biceps pathology	To introduce a novel technique utilizing a double knotless screw for tenodesis of the long head of the biceps	Unspecified	Unspecified	Minor

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Table 3. Continued

Study	Use	Study purpose	Device used	Radiofrequency mode	Amount of radiofrequency use
Armangil et al. [30]	Brachial plexopathy	To describe a recollection of obstetrical brachial plexus palsy released with arthroscopic technique	Unspecified	Unspecified	Minor
Li et al. [31]	Coracoclavicular ligament repair	Description of a novel technique for coracoclavicular ligament repair arthroscopically	Unspecified	Unspecified	Major
Yalizis et al. [32]	Impingement syndrome	To describe the acquisition of a panoramic view of the subacromial space arthroscopically	Unspecified device	Unspecified	Major
Pagán Conesa et al. [33]	Impingement syndrome	Presentation of intramuscular lipoma of supraspinatus muscle causing impingement syndrome treated arthroscopically	Unspecified device	Unspecified	Minor
O'Brien et al. [34]	Impingement syndrome	To introduce a novel technique of the "subdeltoid approach" for anterior shoulder arthroscopy	Unspecified "radiofrequency ablation device"	Unspecified	Minor
Mellano et al. [35]	Impingement syndrome	To propose an optimized technique for arthroscopic acromioplasty	Unspecified	Unspecified	Minor
Valenti et al. [36]	Impingement syndrome	To describe a novel technique in arthroscopic subscapularis assessment after removal of the coracoid process for shoulder impingement prophylaxis	VAPR (DePuy Mitek)	Bipolar	Minor
Hendrix et al. [37]	Other	To describe a novel arthroscopic technique for Pec Minor release to treat shoulder pain and dysfunction	Unspecified	Unspecified	Minor
Theopold et al. [38]	Other	To evaluate the accuracy of arthroscopic placement versus conventional placement of coracoclavicular tunnels	Unspecified	Unspecified	Minor
Scheibel et al. [39]	Other	To present cases of gracilis tendon transclavicular-transcoracoid loop technique via arthroscopic Tight-Rope	Unspecified	Unspecified	Minor
Almazan et al. [40]	Other	To compare and detail the results of the indirect bursal technique with the direct superior approach (the arthroscopic trans-articular distal clavicle resection)	VAPR 2 Side Effect (DePuy Mitek)	Bipolar	Minor
Boileau et al. [41]	Posterior instability	To introduce data from a novel arthroscopic posterior bone block technique	Unspecified	Unspecified	Minor
Parada et al. [15]	Posterior instability	Description of novel graft transfer technique during arthroscopic posterior glenoid reconstruction	Super Turbovac (Arthrocare)	Coblation	Minor
Rausch et al. [42]	Postoperative stiffness	To describe a novel arthroscopic method for restoration of shoulder mobility treatment of scapula neck fractures	Ambient Super TurboVac 90 (Arthrocare)	Coblation	Major
Bhatia et al. [43]	Proximal humerus fracture	Introduction of proximal humeral plate removal via arthroscopy	Unspecified	Unspecified	Minor

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Table 3. Continued

Study	Use	Study purpose	Device used	Radiofrequency mode	Amount of radiofrequency use
Park et al. [44]	Rotator cuff disease	Introduction of a novel technique within arthroscopic rotator cuff repair	Unspecified	Unspecified	Minor
Shon et al. [45]	Rotator cuff disease	To describe a novel tenodesis performed via an arthroscopic suture anchor technique	Bisector Arthro Wand (Arthrocare)	Coblation	Minor
Petri et al. [46]	Rotator cuff disease	To describe a novel technique for open reduction internal fixation for posterosuperior rotator cuff repair and latissimus dorsi transfer	Super TurboVac 90 (Arthrocare)	Coblation	Minor
Laskovski et al. [47]	Rotator cuff disease	To introduce a novel technique in arthroscopic augmentation of rotator cuff repair with an acellular human dermal allograft	Unspecified	Unspecified	Minor
Cabarcas et al. [48]	Rotator cuff disease	To describe the surgical technique of a "double-row "arthroscopic subscapularis repair	Super TurboVac 90 (Arthrocare)	Coblation	Minor
Chernchujit et al. [49]	Rotator cuff disease	To present a novel arthroscopic technique for the management of high graded bursal sided rotator cuff tears	Super TurboVac 90 (Arthrocare)	Coblation	Minor
Boutsiadis et al. [16]	Rotator cuff disease	To propose a modification of superior capsular reconstruction with a long head bicep autograft	Super TurboVac 90 (Arthrocare)	Coblation	Minor
Warth et al. [50]	Sternoclavicular joint disease	To describe a novel technique for arthroscopic sternoclavicular joint resection	Unspecified	Unspecified	Minor
Yamakado et al. [51]	Suprascapular nerve entrapment	To quantify the learning curve using the log-linear model for arthroscopic suprascapular nerve decompression	Unspecified	Unspecified	Minor
Thompson et al. [12]	Adhesive capsulitis	To propose a novel technique for performing an arthroscopic capsular release	DYONICS EFLEX (Arthrocare)	Monopolar	Major

studies [16,44-49,69]. All four studies reporting these adverse events specify second-degree burns as related to direct contact of the irrigation fluid from outflow tubing rather than from contiguous, elevated intraarticular temperatures [65-68]. Dermal burns have been reported during subacromial decompression [66]. Surgeons, however, plugged fluid outflow to increase the joint tamponade effect for better visibility, resulting in overheated irrigation fluid that burned the patient [66]. To decrease the burn risk, it is recommended that suction surveillance and high fluid outflow be maintained by surgeons [68].

DISCUSSION

In this systematic review of the literature, 63 studies demonstrated the safety and efficacy of RF devices within the shoulder. Of these, 25 studies explicitly studied the temperature profile, safety profile, or clinical outcomes. Though the temperature and safety profile were reasonably well described, functional or patient-reported outcomes after RF treatment were sparse [10,11,13-19,22,23,25-27,29-33,35,39-45,49-51].

Our study demonstrated that the landscape of shoulder RF has changed significantly since it was originally studied in the context of shoulder instability [1,7,9]. Given the unanimous findings of poor outcomes in this setting, RF is largely used for debriding soft tissue (Table 3). Yasura et al. [70] demonstrated that bipolar RF resulted in significantly less chondrocyte death than unipolar RF in the knee. The results of our systematic review seem to be in concordance with this and demonstrate a general trend toward

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Table 4. Included studies for which the temperature profile was the primary outcome with regards to radiofrequency usage in the shoulder

Study	Radiofrequency device used	Radiofrequency mode	Study type	Level of evidence	Number of patients	Use	Purpose	Main outcome	Conclusion
Faruque et al. [52]	Stryker Endoscopy Radio Frequency Ablation System (SERFAS) (Stryker, Portage, MI, USA) or Super Turbovac 90 (Arthrocare; Smith & Nephew, Austin, TX, USA)	Bipolar and Coblation	Randomized control trial	I	40	Rotator cuff repair	To compare intraarticular temperature profile in standard ablation versus plasma ablation RF devices for arthroscopic rotator cuff repair	Although 7 patients registered temperatures above 45 °C, no significant differences in intraarticular temperature were found between standard and plasma RF devices ($P = 0.433$).	Plasma ablation radiofrequency may be equivalent to standard radiofrequency. Further study is needed to determine the safety profile of plasma radiofrequency.
Gereli et al. [53]	Super Turbovac 90 (Arthrocare)	Coblation	Prospective cohort study	II	41	Subacromial decompression	To investigate the effect of irrigation fluid temperature on joint temperatures during shoulder surgery	The measured maximum temperature between the group receiving irrigation fluid of 34 °C and the group receiving 24 °C irrigation fluid was not statistically significantly different with a mean rise of 7.34 °C ± 0.7 °C with concurrent RF use.	Irrigation fluid temperature may not influence intraarticular temperature during shoulder surgery. New generation coblation devices may have a safe temperature profile.
Chivot et al. [54]	Ambient Super Turbovac 90 (Arthrocare)	Coblation	Prospective cohort study	II	22	Subacromial decompression/rotator cuff surgery	To determine the effect of surgery site, radiofrequency modality, and other surgical details on intraarticular temperature during arthroscopic shoulder surgery	Additional portal sites reduced the temperature elevation by 3.8 °C ($P < 0.05$) when concurrent radiofrequency was used. Arthropump pressure plays a significant role in the intraarticular temperature as well ($P < 0.05$). No significant difference was found regarding radiofrequency modality choice.	It is important to be cognizant of the variables that can affect intraarticular temperature during arthroscopic shoulder surgery. Radiofrequency modality may or may not be as important as other factors.

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Table 4. Continued

Study	Radiofrequency device used	Radiofrequency mode	Study type	Level of evidence	Number of patients	Use	Purpose	Main outcome	Conclusion
Huynh et al. [3]	Super Turbovac 90 (Arthrocare) and VAPR Mitek (DePuy Mitek, Raynham, MA, USA)	Coblation	Prospective controlled trial	II	13	Subacromial decompression	To investigate the temperature profile during arthroscopy within the subacromial space	No difference in temperature profile was demonstrated between VAPR and coblation within the first 40 seconds ($P > 0.05$). After 40 seconds, coblation temperatures were higher than VAPR ($P < 0.05$). All trials displayed temperatures below the chondrocyte threshold damage of 45 °C.	There is minimal concern for temperature violation with both VAPR and coblation.
Barker et al. [55]	Super Turbovac 90 (Arthrocare)	Coblation	Case series	IV	15	Subacromial decompression	To investigate if the bipolar RF ablation wand causes excess heating	The mean peak temperature was 32.0 °C in the subacromial bursa and 71.6 °C in the outflow fluid during arthroscopic subacromial decompression. Baseline temperature of irrigation fluid most influenced bursal temperature	Bipolar RF can be safely used below the temperature threshold in the shoulder.
Davies et al. [56]	Ablator-S (Arthrocare)	Monopolar	Case series	IV	30	Impingement syndrome	To assess subacromial space temperatures during RF ablation of subacromial bursa	Both the mean and maximum temperatures reached in 30 case series patients were below the experimental thresholds for chondrocyte damage.	Radiofrequency can be used safely in the shoulder below the temperature limit.

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Table 4. Continued

Study	Radiofrequency device used	Radiofrequency mode	Study type	Level of evidence	Number of patients	Use	Purpose	Main outcome	Conclusion
Zoric et al. [57]	Super Turbovac (Arthrocare)	Coblation	Cadaveric study (10 cadavers)	NA	NA	NA	To investigate factors that impact joint temperature profiles with RF usage	Three factors are crucial in influencing joint capsule temperature: application duration, application distance, and flow rate, with the flow rate being the most important factor.	Maintaining appropriate joint temperature during shoulder radiofrequency treatment is important. These factors better enable clinicians to do so.
Good et al. [58]	VAPR3 (DePuy Mitek)	Bipolar	Cadaveric study (30 cadavers)	NA	NA	NA	To assess glenohumeral fluid temperature during shoulder arthroscopy and the effect RF energy has upon it	In this cadaveric study using VAPR3, joint temperatures rose above 45 °C in all trials. A flow rate of 100% had reduced temperatures compared to a flow rate of 0%.	Bipolar radiofrequency has the potential to raise the intraarticular temperature, which can be detrimental to chondrocyte viability. Clinicians must keep this in mind while pursuing radiofrequency treatment in the shoulder.
Edwards et al. [59]	ArthroCare System 2000 (Arthrocare) and Vulcan EAS	Monopolar	Animal study	NA	NA	NA	To compare and contrast cartilage matrix temperatures between the monopolar and bipolar RF energy devices	Monopolar RF devices were associated with lower temperatures and at greater depths within the cartilage	Monopolar radiofrequency can be safely used without violating the temperature limit of the shoulder.

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Table 4. Continued

Study	Radiofrequency device used	Radiofrequency mode	Study type	Level of evidence	Number of patients	Use	Purpose	Main outcome	Conclusion
Valet et al. [60]	SuperTurbo Vac 90 (Arthrocare)	Coblation	Basic science study	NA	NA	NA	To determine an optimal technique for prevention of damaging suture material in RF tissue ablation	High-strength ultra-high molecular weight polyethylene sutures were less sensitive to RF treatment than polyester sutures. By maintaining the distance between the probe and suture, damage can be reduced to sutures.	Suture choice can affect the safety of radiofrequency treatment in the shoulder.
Shah et al. [61]	Orthopedic Procedure Electrosurgical System (Arthrex, Naples, FL, USA)	Monopolar	Basic science study	NA	NA	NA	To evaluate different sutures and the effect RF energy exerts on their mechanical properties	This study demonstrates that exposure to electrocautery damages and weakens sutures.	Radiofrequency has the potential to affect the integrity of all sutures tested and should be used with care around sutures.
Lemos et al. [20]	Ambient Super TurboVac 90 (Arthrocare)	Coblation	Cadaveric study (17 specimens)	NA	NA	Biceps tenodesis or tenotomy	To describe a novel technique of outlet biceps tenodesis	In comparison to traditional tenotomy on cadavers, biomechanical testing showed favorable pullout force results from this technique.	Radiofrequency use was used in a novel biceps tenodesis technique that did not result in any adverse effects.
Ficklscherer et al. [62]	OPES CoolCut (Arthrex)	Bipolar	Animal study (189 rats undergoing rotator cuff repair)	NA	NA	NA	To investigate footprint preparations in rotator cuff repair along with their histological and biomechanical outcomes	RF in comparison to spongialisation of the footprint was associated with poorer biomechanical and histological outcomes.	RF cannot be advised in place of spongialisation for rotator cuff repair.

RF: radiofrequency, NA: not applicable.

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Table 5. Studies included within the review article that investigated complications and safety profile of radiofrequency use in the shoulder

Study	Radiofrequency device	Radiofrequency mode	Study type	Level of evidence	Number of patients	Use	Purpose	Main outcome	Conclusion
Nho et al. [21]	VAPR Mitek (DePuy Mitek, Raynham, MA) and OraTec Vulcan EAS (OraTec, Manassas, VA, USA)	Bipolar	Prospective randomized clinical trial	I	50	Varied	To investigate if RF energy devices originally from coagulation and soft tissue ablation cause thermal injury to the bone	With MRI, no cases of osteonecrosis or bone edema occurred with monopolar or bipolar RF devices.	There may not be any injury or insult that is detectable on imaging studies after utilization of radiofrequency in the shoulder.
Jerosch et al. [63]	VAPR (DePuy Mitek)	Bipolar	Case report	IV	1	Capsular release	To present a case of chondrolysis post arthroscopic capsular release for adhesive capsulitis with a bipolar VAPR RF energy probe	Glenohumeral chondrolysis occurred after treatment with the bipolar VAPR RF probe, although rare. A surface replacement was required.	Chondrolysis can occur as a complication of bipolar radiofrequency in the shoulder.
Bonsell et al. [64]	Unspecified device	Bipolar	Case report	IV	1	Subacromial decompression	To present a case of deltoid detachment that occurred during arthroscopic subacromial decompression	Overaggressive use of the bipolar RF was attributed to deltoid detachment by the authors.	Bipolar radiofrequency use is not without its risks. The practicing shoulder surgeon needs to be aware of these risks.
Troxell et al. [65]	SuperTurbo Vac 90 (Arthrocare; Smith & Nephew,Austin, TX, USA)	Coblation	Case series	IV	4	Subacromial decompression	To present reports of shoulder arthroscopy bipolar RF-induced burn injuries within patients	Four patients over 4 years suffered second-degree burns after irrigation fluid from outflow tubing contacted the patients.	Orthopedic surgeons need to be cognization of burn risk during radiofrequency of the shoulder.
Chahar et al. [66]	VAPR (DePuy Mitek)	Bipolar	Case report	IV	1	Rotator cuff repair	To present a dermal burn case that occurred after a radiofrequency procedure	The suction device was removed leading intraarticular fluid temperature to increase. Dermal burns occurred as a consequence of RF subacromial decompression.	Practitioners need to be aware of the complication of thermal burns.

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Table 5. Continued

Study	Radiofrequency device	Radiofrequency mode	Study type	Level of evidence	Number of patients	Use	Purpose	Main outcome	Conclusion
Talati et al. [67]	Stryker endoscopy radio Frequency Ablation System (Stryker Endoscopy Radio Frequency Ablation System [SERFAS]; Stryker, Portage, MI, USA)	Bipolar	Case report	IV	1	Impingement syndrome	To describe a report of skin burn from contact with an RF device with a spinal needle during acromioplasty	A patient received skin burns from the contact of the spinal needle with the RF device during an arthroscopic subacromial decompression.	Orthopedic surgeons should use caution when using radiofrequency in order to minimize the risk of superficial dermal burns.
Kouk et al. [68]	SuperTurbo Vac 90 (Arthrocare)	Coblation	Case report	IV	1	Subacromial decompression	To report a case of overheating irrigation fluid from RF causing second-degree burns on the patient's chest wall and shoulder	Author details forgetting to close the valve and place the suction, thus allowing heated irrigation fluid to drip onto the patient and cause second-degree burns.	Bipolar radiofrequency use is not without its risks, which are increased by user error.

RF: radiofrequency, MRI: magnetic resonance imaging.

the use of bipolar RF in recent years. Though a few studies in our literature review demonstrate adverse thermal effect profiles, these are limited to case reports [65-67], case series, and cadaveric studies [58]. Shoulder joint temperature increases with the use of RF technologies [3,55,58]. The flow of irrigation fluid [55,57,58], length of application [55,57], device used [3], and proximity of the thermometer to the RF wand [57,58] all impact the temperature profile.

The incidence of RF complications was appropriately reported [21,63-68,71] and generally comprised superficial burns related to fluid irrigation temperature [65-68]. All of the Level III or higher studies reporting temperature profile demonstrate a favorable profile (Table 5). This is in concordance with the literature on RF use in the knee [1,5] and hip [6]. Maintenance of inflow and outflow circulation, avoidance of plugged arthroscopic fluid outflow, avoidance of excess use of coagulation mode [54], and monitoring overheating of the tubing can be performed to reduce burn complications with RF in the shoulder. It is well known that cartilage is more heat-sensitive than other tissues in the human body, and this must be considered when treating cartilage lesions [1].

It is important to consider economic efficiency when determining the RF modality of choice. Efficiency and cost between monopolar RF and bipolar RF in 40 arthroscopic subacromial decompression patients were investigated by Diab et al. [72]. The mean operative time in the bipolar group was 13 minutes (5–25 minutes), while it was 21 minutes (10–35 minutes) for the monopolar RF device group. Bipolar RF decreased the average procedure time by 8 minutes ($p < 0.0001$), while simultaneously decreasing cost by 83 British Pounds (111 European Euros) per case ($p < 0.003$) in comparison to monopolar RF [72]. Based on these results, the authors recommended bipolar RF when clinical judgment deems it appropriate.

This systematic review is not without its limitations. As a systematic review of level I–level IV evidence, the findings are limited to level IV. Due to heterogeneous data reporting, this is a comprehensive summary of all studies delineating the use of RF in the shoulder as defined by the inclusion and exclusion criteria. However, many of the studies included were limited by unspecified use of RF. Further, our study is unable to comment on the clinical outcomes of RF based on the inclusion criteria regarding temperature profile and safety/complications of shoulder RF. The results pertaining to safety and complication are based on a limited subset of select articles. Thus, the findings of this study may be limited by selection bias.

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CONCLUSIONS

Shoulder RF has a wide scope of application in various shoulder pathologies. Although shoulder RF is safe, it requires practitioners to be cognizant of the potential for thermal burn injuries. Protocols regarding irrigation fluid temperature and outflow rates should be set by individual institutions to further reduce minor patient complications of shoulder RF. Future research is required to determine measures to minimize further the risk of thermal burn injuries.

NOTES

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Author contributions

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Conflict of interest

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