Review article
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Scaphoid nonunion and SNAC treatment

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Abstract

Introduction Scaphoid nonunion can result in progressive scaphoid nonunion advanced collapse (SNAC) and have an impact on the quality of life in younger patients. The social significance of the pathological condition induces original research and literature analysis.

The **objective** was to identify methods for preventing scaphoid nonunion and improving treatment outcomes for SNAC patients based on the literature on etiology, diagnosis and treatment of the disease.

Material and methods The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru) and the National Library of Medicine (www.pubmed.org) and using the keywords: scaphoid nonunion, scaphoid, bone grafting, scaphoid nonunion, vascularized bone graft. The search yielded 355 results. Literature searches included both Russian and English studies published between 1984 and 2024. Inclusion criteria included original articles, systematic reviews, meta-analyses relevant to the search topic. Non-inclusion criteria included a case report, case/control, and articles available only on a fee-paying basis. There were 67 articles identified.

Results and discussion The topography of the scaphoid is associated with a high incidence of avascular necrosis, delayed healing and fracture nonunion. Clinical testing and imaging are essential for diagnosis of scaphoid fractures in the acute period of injury, and fracture instability would be important for surgical indications. There is a classification of scaphoid nonunions that is practical for the choice of a surgical treatment (osteosynthesis with compression screws, debridement and bone grafts or “salvage” operations). Scaphoid nonunions treated with the Ilizarov method employing no open approaches or grafts was reported in a few publications. Treatment of SNAC patients is traditionally based on the stage of the disease: 1 — scaphoid reconstruction, resection of the styloid process of the radius; 2–3 — 4-corner arthrodesis or the proximal row carpectomy. Meta-analyses highlight the need for the research into the effectiveness of various treatments. Arthroscopic techniques are common in wrist surgery improving diagnostic capabilities and minimally invasive interventions.

Conclusion Timely healing of a scaphoid fracture is essential for preventing carpal instability and SNAC. The choice of SNAC treatment is associated with the stage of the disease and functional needs of the patient.

Keywords: scaphoid nonunion, scaphoid, percutaneous fixation, bone graft, vascularized bone graft, SNAC

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INTRODUCTION

Wrist injury often results in metaepiphyseal distal radius fractures in elderly patients. Fractures of the carpals (scaphoid, triquetrum and hamate) or the styloid process of the ulna are common for younger individuals. The fractures can be associated with injury to the ligaments, disturbed anatomy and biomechanics of the wrist complicating the diagnosis [1], and the choice of treatment strategy [2]. The scaphoid is the largest bone in the wrist and is critical for the stabilization. Scaphoid fractures are common in athletes and military personnel [3]. Nonunion of scaphoid fractures is a common complication that can lead to the scaphoid nonunion advanced collapse, arthrosis of the wrist joint. Recent reviews indicate problems of choosing treatment methods for patients with scaphoid nonunion and arthrosis of the wrist joint [4, 5]. The social significance of the pathological condition induces original research and literature analysis. The objective was to identify methods for preventing scaphoid nonunion and improving treatment outcomes for SNAC patients based on the literature on etiology, diagnosis and treatment of the disease.

MATERIAL AND METHODS

The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru) and the National Library of Medicine (www.pubmed.org) and using the keywords: scaphoid nonunion, scaphoid, bone grafting, scaphoid nonunion, vascularized bone graft. The search yielded 355 results. Literature searches included both Russian and English studies published between 1984 and 2024. Inclusion criteria included original articles, systematic reviews, meta-analyses relevant to the search topic. Non-inclusion criteria included a case report, case/control, and articles available only on a fee-paying basis.

RESULTS

Epidemiology of scaphoid fractures

The incidence of scaphoid fractures is 2–7 % of all fractures and almost 90 % of carpal fractures [6]. Scaphoid fractures are more common for young men aged 10 to 29 years [7, 8]., The fractures are rare in elderly individuals [9]. Epidemiology of scaphoid fractures and nonunions is heterogeneous [10].

Functional anatomy and blood supply to the scaphoid bone

The scaphoid is the largest bone of the wrist, which articulates with five neighboring bones through a predominantly cartilaginous surface and has a complex network of ligamentous attachments; these specific features predetermine a variety of disturbances in the wrist kinematics after fractures and play a significant role in the development of carpal instability syndrome [11]. The shape, size, location of the scaphoid bone and radiological density of its different parts are individually variable [12]. Narrowing of the scaphoid at the waist combined with reduced bone density, predetermines a high incidence of fractures (75 %) in this particular location [13]. The scaphoid bone participates in the kinematics of the proximal and distal rows of the bones of the wrist; palmar flexion of the scaphoid bone occurs with a longitudinal load; sharp extension and ulnar deviation of the wrist combined with a longitudinal load predispose to fractures, with ligament ruptures, in particular; fractures proximal to the waist contribute to displacement and ischemia of the proximal fragment [14]. The main mechanism of scaphoid fractures is a fall on an outstretched arm. Forced dorsiflexion or ulnar deviation of the wrist under axial load leads to dorsal subluxation of the midcarpal joints and increased stress on the scaphoid cortex on the palmar side [15]. Scaphoid

fractures are associated with compromised blood supply [16]. They are characterized by a high rate of complications including avascular necrosis, delayed fusion and nonunion, osteoarthritis, which significantly reduce the quality of life of patients. The peculiarities of the blood supply to the scaphoid bone are that the palmar branch of the radial artery supplies blood to the distal pole, and the branch of the dorsal carpal branch of the radial artery also enters the scaphoid bone distally (Fig. 1), being the only source of blood supply to the proximal pole through retrograde intraosseous blood flow [17].

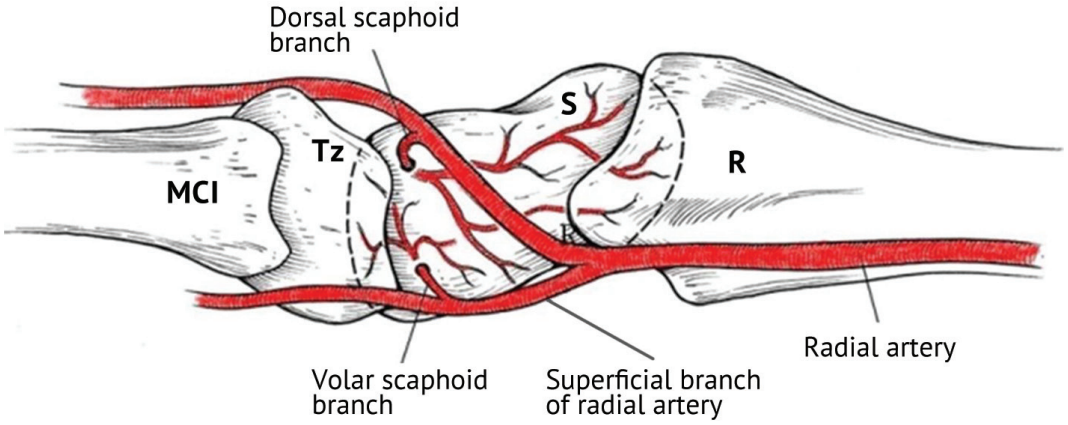

Fig. 1 Diagram showing blood supply of the scaphoid: MCI, first metacarpal bone; Tz, trapezium; S, scaphoid bone, R, radius. Reproduced from T. E. Trumble et al. [18] with changes

Problems in diagnosing scaphoid fractures

There are problems in diagnosing scaphoid fractures which are radiographically missed in 40 % of patients in the acute period of injury [19]. Clinical tests that have high sensitivity and low specificity are essential. Anatomic snuffbox tenderness or tenderness of the scaphoid tubercle and axial load on the first metacarpal have 100 % sensitivity for scaphoid fractures. However, their specificity is only 9 %, 30 % and 48 %, respectively. Thumb limitation has a sensitivity of 69 % and specificity of 66 %, and a combination of symptoms is important for clinical diagnosis [20]. Grover reported pain in the scaphoid and swelling of the wrist as the most important symptoms that can be more pronounced with fractures than with soft tissue injuries [21]. Attempts are being made to develop a prognostic formula that would include five parameters: male gender, anatomical snuffbox swelling, anatomical snuffbox tenderness, ulnar deviation tenderness, and thumb compression tenderness. This method of predicting fracture has a sensitivity of 97 % and a specificity of only 20 % [22]. According to the authors, the use of the prognostic formula reduces the likelihood of underdiagnosis of scaphoid fractures. Four radiological views of the wrist bones can be practical if a fracture of the scaphoid is suspected; an anteroposterior ulnar deviation radiograph is performed in addition to the three standard projections for the hand [23]. The authors report that 21.5 % of scaphoid fractures are missed with this type of radiography, but with 81.5 % sensitivity of computed tomography (CT) the sensitivity of four radiographic views appears to be similar to that with CT. The diagnostic algorithm developed by the authors (Fig. 2), along with radiography in four projections, includes CT and magnetic resonance imaging (MRI).

Four radiological views of both wrists were offered previously to improve the information content of the radiography in identifying unstable scaphoid fractures, with both AP views produced with deviated ulna and radius [24].

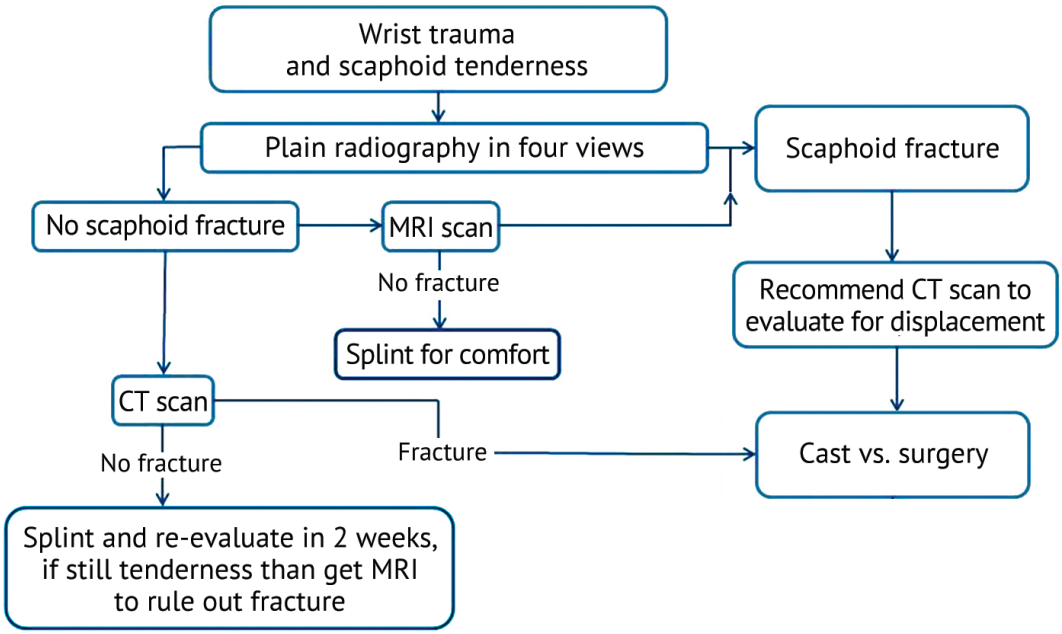

Fig. 2 Algorithm for diagnosing scaphoid fractures as reported by H.C. Bäcker, C.H. Wu, R.J. Strauch [23]

Classifications of scaphoid fractures

Thirteen different (sub)classification systems are found in literature based on (1) fracture location, (2) fracture plane orientation, and (3) fracture stability/displacement. Looking at citations numbers, the Herbert classification appeared to be most popular. According to this classification, most scaphoid fractures are unstable; only type A fractures are stable (Fig. 3).

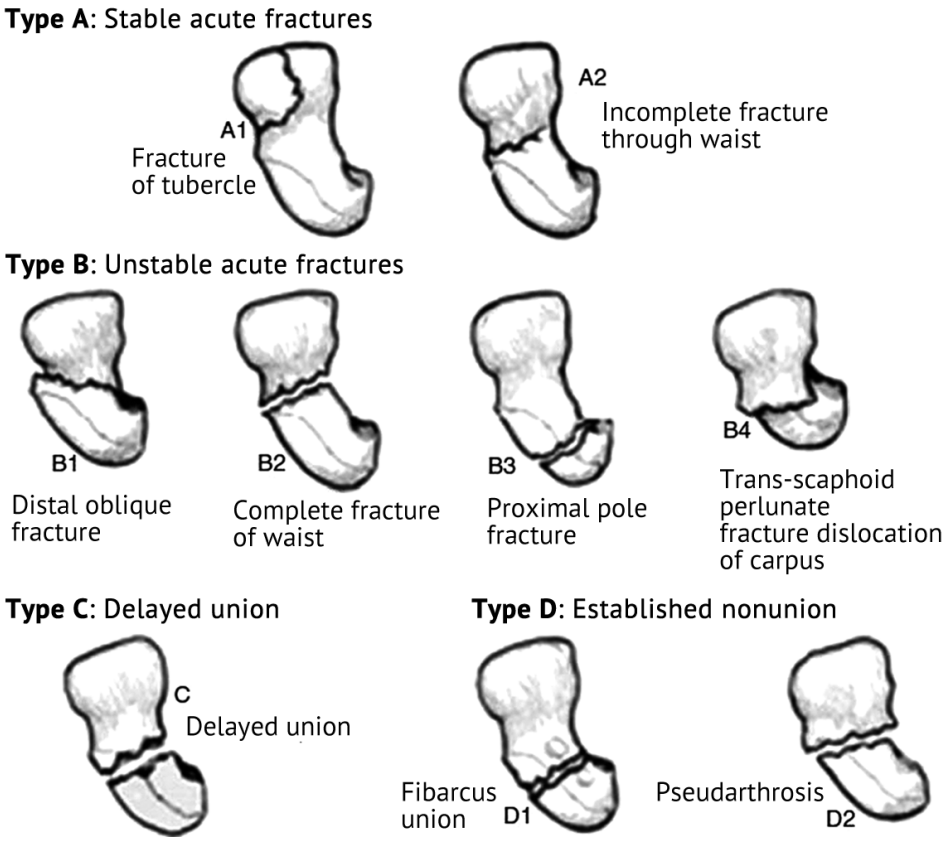

Fig. 3 Herbert's classification scheme for wrist fractures. Reproduced with modifications of T.G. Sommerkamp [8]

A more simplified classification approach of grading scaphoid fractures into proximal, distal and waist fractures is employed in clinical practice indicating the presence and magnitude of displacement and the duration of the injury [17]. Three algorithms for the treatment have been developed in accordance with the simplified classification of the fracture location [26]. Displacements greater than 1 mm are associated with 55 % of nonunion and 50 % of avascular necrosis; displaced fractures that heal spontaneously require long-term immobilization; malunions or nonunions are often accompanied by pain and lead to osteoarthritis of the wrist [27]. Displaced scaphoid fractures are conventionally classified into minimally displaced (⩽ 0.5 mm), moderately displaced (0.5–1.5 mm) and severely displaced (⩾ 1.5 mm) [28]. A displaced fracture is usually a sign of instability, but non-displaced fractures can also be unstable. The main criteria for instability are: displacement of greater than 1 mm, dorsal intercalated segment instability (DISI), a scapholunate angle of greater than 60° and a lateral intrascaphoid angle of greater than 35°, comminuted fractures and scaphoid fractures as part of a perilunate injury [26]. Arthroscopically verified ruptures of the scapholunate ligament are combined with non-displaced scaphoid fractures in about 25 % and are classified as unstable [29].

Causes of scaphoid nonunion and methods of their treatment

If a scaphoid fracture does not heal within 3 months, it is regarded delayed healing, and if it does not consolidate after 6 months, it is considered as non-union. Scaphoid nonunion can be caused by untimely diagnosis and vascularization disorders [30], inadequate immobilization of the fracture in terms of quality and timing [31]. The causes of scaphoid nonunion include patient related factors (non-compliance), iatrogenic and biological factors [32]. Review of the epidemiology of fracture nonunions in 18 locations of about 300 thousand patients indicate an average nonunion rate of 4.9 % with the rate of scaphoid nonunions being the highest and amounted to 15.5 %; the risk of nonunion was increased with open and multiple fractures, high weight-height ratio, smoking and alcoholism [33]. Treatment of scaphoid fractures with open reduction and internal fixation initiated after 31 days of injury and the volume of the scaphoid bone being less than 38 % of the volume of the bone can result in nonunion [34]. The clinical picture of scaphoid nonunion is characterized by variability; severe pain, manifestations of capsulitis, contractures of the wrist joint, and decreased height of the wrist joint are the most frequently reported symptoms. Pathomorphological changes in the wrist joint include destruction, reparation and inflammation [35]. A strategical classification has been offered for scaphoid nonunion [36] (Table 1).

Table 1

Strategical classification of nonunions reported by J.F. Slade et al., 2005 [36]

Group	Description
I	Fractures treated 4–12 weeks of injury
II	Fibrous fusion: minimal fracture line, no cysts or sclerosis
III	Minimal sclerosis: bone resorption occupies ⩽ 1 mm of the nonunion interface
IV	Cysts and sclerosis: bone resorption > 1 ⩽ 5 mm nonunion interface
V	Deformity and pseudarthrosis: bone resorption > 5 mm interface
VI	Arthrosis of the wrist: nonunion with signs of radiocarpal and midcarpal arthrosis

Osteosynthesis with compression screws is indicated for patients of groups I–III, debridement and bone grafts can be used for patients of groups IV–V and salvage operations are recommended for patients of group VI. There is a paucity of publications reporting the use of compression cortical screws made from human allobone to repair scaphoid fractures and nonunions. Allobone screws provide high fusion rates, low complication rates and do not require removal [37]. Bone grafts used for scaphoid nonunions include traditional non-vascularized grafts, and non-free or free

vascular grafts (on a vascular pedicle). Non-free vascularized grafts are associated with high rate of unions reported in 96.3 % of patients with nonunions and bone defects [38]. However, these data are contradictory: M.A. Chang et al. reported fusion in 68 % of patients [39], C. Hirche reported consolidation in 75 % [40]. Some authors report a lower fusion rate of 27 % due to avascular necrosis of the proximal pole of the scaphoid [41].

A systematic review of 48 publications [42] showed that the incidence of fusion with use of vascularized and non-vascularized grafts did not differ significantly for the condition. Similar fusion rate was achieved with grafts sourced from the distal radius or the iliac crest, but the latter resulted in a greater complication rate. Fixation with screws and Kirschner wires also resulted in similar fusion rates, but patients with screw fixation could ambulate earlier. The results of a meta-analysis of randomised controlled trials and comparative studies from 1500 patients [43] indicated that the postoperative union rate in non-vascularised bone grafts is similar to that in vascularised bone grafts; so, the less invasive procedure could be the first choice of treatment for scaphoid nonunion. Analysis of the treatment results and surgical histological examination of 35 patients with nonunions treated with non-vascularized grafting showed a rare case of "infarction" of the proximal pole, and therefore vascularized grafts were not common [44].

Successful outcomes of arthroscopic bone grafting and K-wire fixation in treatment of scaphoid nonunion were reported in a retrospective study [45], but the procedure can be used as a surgical treatment for scaphoid non-union of the proximal and middle third without intracarpal deformity or osteoarthritis. Two screws without graft can be used as a first-line treatment for scaphoid nonunion with or without humpback deformity and cyst formation. [30]. Electrical or ultrasound bone stimulation combined with plaster immobilization can be offered for patients who do not agree to surgery for a variety of reasons [46]. Bone grafting procedures, such as arthroscopic fixation with bone grafting and the Fisk-Fernandez approach (iliac crest graft and internal fixation) have excellent outcomes as identified by a search in Embase and Pubmed between 2000 and 2023. Ultrasonic treatment is also needed, but evidence is limited [47]. The use of the Ilizarov method and external fixation device in the treatment of scaphoid nonunions is reported in a few publications. Outcomes were rated as good or excellent (n=14) in a group of 18 patients; the length of immobilization with the device on did not exceed 9 weeks [31]. Similar results were reported by another group of authors who used compression pins with olives; the immobilization period in the series did not exceed 6 weeks [48]. The advantage of this approach is that it does not require open surgical approaches and bone grafts. The patients did not develop humpback deformity, carpal instability, progressive collapse or avascular necrosis. Regardless of the method used to repair scaphoid nonunion a successful outcome suggests preservation of blood supply, stable fixation, bone grafting to replace the defect and stimulate union, which must be achieved before the onset of degenerative changes [49].

Progressive collapse due to scaphoid non-union (SNAC)

Untreated scaphoid nonunions would lead to degenerative changes in the wrist joints. A 30-year observation of patients with scaphoid fractures demonstrated marked radiocarpal osteoarthrosis in only one (2 per cent) of the forty-seven patients who had a healed fracture and it was more common in the group that had a pseudarthrosis, in which the prevalence was five of nine patients [50]. Osteoarthritis of the wrist and midcarpal joints indicates progressive wrist collapse or SNAC wrists affecting the wrist joint at the styloid process, causing a narrowing of the joint space (stage 1). Bone cysts of the scaphoid develop later involving the whole scaphoid fossa (stage 2), midcarpal osteoarthritis and narrowing of the lunate-capitate joint gap (stage 3), and diffuse involvement

of the capitate bone (stage 4) [51]. A low reliability of the classification was reported [52], and no other classifications were available for assessment. The incidence of SNAC depends on the level of the original scaphoid fracture. Obvious degenerative changes occurred in 85.7 %, 40.0 % and 33.3 %, for the six proximal-, eight middle- and two distal-third nonunions, respectively [53].

The choice of surgical treatment method would be determined by the stage of the disease. For SNAC I, scaphoid reconstruction combined with resection of the scaphoid styloid process is a promising method. Denervation procedures, resection of the proximal row of wrist bones and partial arthrodesis are performed to reduce pain and preserve wrist function in more advanced stages. Total arthrodesis and total arthroplasty are used for panarthritis and failures of "salvage operations" [54]. For SNAC I, arthroscopically assisted bone grafting without resection of the styloid process was reported to be highly effective [55]. Successful use of bone grafts in SNAC II and SNAC III can prevent progression of arthrosis, so the method is superior to four-corner arthrodesis [56]. Four-corner arthrodesis with screw fixation and proximal row carpectomy were reported as cost-effective options based on forty studies yielding 1730 scapholunate advanced collapse/scaphoid nonunion advanced collapse wrists [57]. Four-corner arthrodesis with plate fixation and four-corner arthrodesis with Kirschner wire fixation were inferior strategies and therefore not cost-effective. Ten patients with symptomatic grade IV non union of the scaphoid were treated using the four-corner arthrodesis with Kirschner wire fixation. Good results were achieved in 7 patients according to the modified Mayo Wrist Scoring Chart. There were no intraoperative complications [58]. The technique of the four-corner fusion with two retrograde crossed headless screws used in six cases of carpal collapse is reported as a gold standard [59].

A comparative meta-analysis of long-term functional results of proximal row carpectomy and four-corner arthrodesis performed on the basis of 7 articles reporting 1059 wrists showed that proximal row carpectomy produced significantly better range of motion and lower complication rate. There was no significant difference in the grip strength and conversion to total wrist arthrodesis [60]. Advanced carpal collapse with osteoarthritis of the midcarpal joint cannot be solely treated with proximal row carpectomy. The procedure should be added by pyrocarbon prosthesis implant to replace the head of the capitate [61]. Partial arthrodesis is used as an alternative to four-corner arthrodesis to stabilize the SNAC wrist with osteoarthritis and pain with intact joints retaining mobility [62]. The authors suggests that this approach reduces complication rates and improves functional outcomes as compared to four-corner arthrodesis. Single-column fusion [63], bicolumn limited intercarpal fusion/lunatocapitate and triquetrohamate arthrodesis [64] were described as less invasive techniques as compared to four-corner arthrodesis. A union rate of 95 % and an acceptable complication rate were achieved in 78 patients with single- or bicolumn limited intercarpal fusion that showed significant improvement in pain and function. Three patients were converted to total wrist fusion and one to total wrist arthroplasty [65]. The patients treated with proximal row carpectomy were reported to have osteoarthritis at follow-up, whereas it was seen in 19 % of patients treated with limited carpal fusion at 31/2 years. The range of motion and the grip strength were comparable in men and were found to be better in women after limited carpal fusion [66]. The authors concluded that further comparative studies on the effectiveness of different treatments are needed.

DISCUSSION

The scaphoid location determines high prevalence of fractures among wrist injuries. The geometry of the scaphoid as it relates to its retrograde blood supply renders it particularly prone to avascular necrosis, delayed healing and nonunion of the fracture. Suspected scaphoid fractures are a diagnostic and therapeutic challenge and up to 40 % of scaphoid fractures can be missed at initial presentation

and radiological investigation. Anatomic snuffbox tenderness or tenderness of the scaphoid tubercle and axial load on the first metacarpal tests are practical to improve the prognosis of the outcome. Prognostic formulas based on several parameters including sex, swelling and tenderness could significantly reduce the incidence of underdiagnosis despite the low specificity of the tests. A multilevel approach with combined clinical data, imaging methods and diagnostic algorithms can help improve the accuracy of diagnosis of scaphoid fractures. At present, established strategical classification has been used to guide the surgical treatment of scaphoid nonunion including osteosynthesis with compression screws, debridement and bone grafts or salvage procedures. Treatment strategy for SNAC patients are traditionally determined depending on the stage of the disease. Radial styloidectomy along with scaphoid nonunion reconstructive surgery is considered an acceptable surgical treatment for stage 1 scaphoid nonunion. Both proximal row carpectomy (PRC) and four-corner arthrodesis (FCA) are motion-sparing surgical procedures commonly used to treat certain painful, degenerative wrist conditions of SNAC 2 and SNAC 3. Arthroscopic wrist surgery has become one of the most common forms of arthroscopy.

CONCLUSION

Multidisciplinary approach and comprehensive care are essential to diagnosing scaphoid fractures improving patient outcomes and reducing the risk of underdiagnosis. SNAC is a condition that have an impact on the quality of life with associated reduced range of motion, grip strength and persistent pain. Imaging techniques are important for evaluation of scaphoid fracture, posttraumatic condition and the SNAC wrist can be finally diagnosed intraoperatively. Appropriate healing time of the scaphoid fracture helps to prevent carpal instability. For this purpose, a variety of surgical treatments have been developed and the strategical classification of nonunions would be practical for the choice of a treatment modality. A nonoperative approach may be the first choice for patients with wrist arthrosis prior to surgical treatment. A surgical treatment of the SNAC wrist would rely on the stage of the disease and functional needs of the patient. Meta-analyses highlight the need for the research into the effectiveness of various treatments. Arthroscopic techniques are common in wrist surgery improving diagnostic capabilities and minimally invasive interventions.

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