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ARTICLE

# A meta-analysis of union rate after proximal scaphoid fractures: terminology matters

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**ABSTRACT**

Heterogeneity in the anatomical definition of 'proximal' affects the comparison of outcomes of these scaphoid fractures. This study aims to review published outcomes of all variants to determine both, differences in terminology, and union rate based upon definition. A literature search was conducted to identify articles that reported descriptions and union rate of all acute (<8 weeks of injury) proximal scaphoid fractures in adult patients (>16 years old). Proximal fractures were grouped as reported ('third', 'pole', 'fifth' or 'undefined'). The data were pooled using a fixed-effects method, and a meta-analysis was conducted to compare relative risk (RR) of non-union against non-proximal fractures. Qualitative analysis of 12 articles included three main definitions: 'proximal' (1 article), 'proximal third' (3 articles), and 'proximal pole' (8 articles). Only 6 articles adopted a specific anatomical or ratio description. In a pooled meta-analysis of union rates (15 articles), 'proximal third' and 'proximal pole' fractures demonstrated a relative risk (RR) of non-union of 2.3 and 3.4 in comparison to non-proximal fractures, respectively. Operative management yielded lower non-union rates than non-operative for all fracture types (6% vs. 18%). In conclusion, non-union risk varies depending on definition, with non-standardised classifications adding heterogeneity to reported outcomes. We recommend an approach utilizing fixed anatomical landmarks on plain radiographs (referencing scaphoid length and scapho-capitate joint) to standardise reporting of proximal fracture union in future studies.

**Abbreviations**: CI: confidence intervals; CT: computer tomography; Df: degrees of freedom; DL: dersimonian and laird estimator; MRI: magnetic resonance imaging; NICE: national institute for health and care excellence; OTA: orthopaedic trauma association; PA: posterior-anterior; PRISMA: preferred reporting items for systematic reviews and meta analyses; RCT: randomised controlled trial; RR: relative risk; SNAC: scaphoid non-union advanced collapse; UK: United Kingdom

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Scaphoid; proximal; fracture; non-union; union rate; classification

## Introduction

The scaphoid is the most commonly fractured carpal bone, particularly in young, active individuals [1]. Estimates of the incidence of scaphoid fractures in the UK range from 12.4 to 29 per 100,000 per year [2,3]. The scaphoid has a predominantly retrograde blood supply originating from branches of the radial artery; dorsal branches enter *via* the middle third and supply the majority (70 to 80%), while palmar branches enter more distally and supply the remaining 20 to 30%. Proximal fractures are therefore at higher risk of non-union and osteonecrosis [4–6].

Anatomically, the scaphoid may be demarcated into a distal pole, tuberosity, waist, and proximal components; however, specific definitions vary. The fracture classifications of Herbert, Russe, and Mayo are generally the most commonly cited in the literature, although numerous others exist based on either specific anatomical parameters, different fracture configurations, stability, or a combination [7]. Coupled with the lack of consensus on anatomical definitions, this heterogeneity makes a comparison of outcomes challenging.

The anatomical definition and boundaries of 'proximal' are particularly problematic, with the distinction between 'proximal', 'proximal third', 'proximal fifth', and 'proximal pole' either inconsistently applied or unspecified [1,8–10]. As proximal scaphoid fractures have the highest risk of adverse sequalae, such inconsistencies impact the comparison of the union rate of different treatments. This review, therefore, aims to evaluate the different definitions used in the published studies reporting outcomes of all variants of 'proximal' scaphoid fractures and to also identify differences in union rate based upon definition.

## Methods

This meta-analysis was performed in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement [11].

### *Search strategy*

The electronic databases Medline, Ovid EMBASE, CINAHL, and Cochrane CENTRAL were searched from their inception up to 31 August 2020 with support from an experienced clinical librarian. The search terms included 'scaphoid', 'fracture' 'proximal' (and variants, including 'one-third', 'one-fifth', 'pole'), 'operative',

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'surgical', 'fixation', 'conservative', 'non-operative', 'union', and 'non-union'. No restrictions were placed on language, date of publication, or journal. Reasonable efforts were made to obtain English translations of potentially relevant non-English language studies; if unavailable, these studies were excluded. The search strategy is shown in Supplementary 1.

### Study selection

Five reviewers (HHC, KK, RS, MH and LA) independently screened paper titles and abstracts for inclusion. Where the title and abstract were not informative enough to make an inclusion decision, the full-text article was reviewed. Reference lists from the full-text articles were also screened to identify additional studies of relevance. The full texts of the studies that met the eligibility criteria were obtained and further categorised according to defined study sub-type criteria. In cases of selection disagreement, inclusion decisions were discussed among all authors, with the senior author (HS) arbitrating any selection conflict.

### Inclusion criteria

We included studies that reported clinical and radiological outcomes (i.e. fracture union) for adult patients (age $>16$ years) with acute proximal scaphoid fractures (i.e. presentation $\leq$ 8 weeks of injury). Studies that categorised outcomes by anatomic fracture site or by an alternate scaphoid classification were also included for screening to identify those that included a breakdown of data for any variant of 'proximal' fractures. We included randomised controlled trials (RCTs), non-randomised controlled trials, prospective cohort studies, and retrospective case series.

### Exclusion criteria

Non-clinical (laboratory or biomechanics), non-human (animal or predictive models) conference abstracts and expert opinion articles were excluded. Studies reporting the management of chronic scaphoid injuries, where the onset of injury was either not clearly defined or there was a delayed presentation (>8 weeks), delayed/non-union, scaphoid nonunion advanced collapse (SNAC) wrist, and technical reviews of specific surgical techniques or implants, were also excluded.

### Data extraction

The five reviewers independently extracted data from the selected full-text articles, with oversight from the senior author to address any discrepancies. This included study design, sample size, the definition of 'proximal' (including any sub-definitions as described by the study authors; for example, proximal pole or proximal third), the definition of 'union' (clinical/radiological), union rate, time to union, and follow-up duration.

### Risk of bias assessment

Three reviewers (HHC, RS, MH) independently assessed the risk of bias for each study. The $I^2$ statistic was used to assess study heterogeneity. An $I^2$ of zero implied that the data from the included studies were perfectly homogenous, whereas an $I^2$ closer to 100% implied significant heterogeneity between the studies. Publication bias was assessed using Funnel plot asymmetry. The quality of the studies was evaluated using the Robin-I and RoB 2 Tools outlined in the Cochrane Handbook (Supplementary 2 and 3) [12,13].

### Data synthesis and statistical analysis

The non-union rates of 'proximal component' scaphoid fractures were subdivided into 'proximal one-third', 'proximal one-fifth', and 'proximal pole' scaphoid fractures for analysis, as per study author definitions [1,14,15]. Descriptive statistics were used to calculate the prevalence of non-union for each category using pooled raw data. Meta-analysis was conducted using Review Manager 5.4 [Rev Man, The Nordic Cochrane Centre, Copenhagen, Denmark] to pool data with 95% confidence intervals (CI). A p-value of $<0.05$ was considered significant. Raw data for non-union events between all proximal and non-proximal scaphoid fractures were pooled to calculate relative risk (RR) using a fixed-effect (Mantel–Haenszel Test) model. Forest plots were formulated to illustrate the relative strengths and significance of the studies.

### Outcomes

The interesting outcomes were to establish 1) the different descriptive terms used to categorise or define 'proximal' scaphoid fractures, and 2) the RR between proximal and non-proximal scaphoid fractures in the development of non-union. Subgroup analysis included the RR of non-union in proximal scaphoid fractures based upon non-operative and operative management.

## Results

A total of 6697 studies were identified. After the removal of 3918 duplicates, 2779 studies were initially identified for potential eligibility based on the agreed protocol (Figure 1). Following the screening process, 12 articles were finally reviewed for a radiological description of 'proximal scaphoid' (Table 1) and 24 articles were included in the systematic review of union rate; of which 15 had adequate data for formal meta-analysis (Tables 2 and 3).

### Radiological definition

12 different descriptions of 'proximal' scaphoid fractures were identified (Table 1) [1,7,14–23]. In 1954, Bohler et al. reviewed 873 patients who first divided scaphoid fractures into anatomical one-thirds and tuberosity. London et al. and Duppe et al pictorially illustrated proximal third scaphoid fractures, while Cooney et al. described the proximal third of the scaphoid on a posterior-anterior (PA) plain radiograph of the scaphoid following the Mayo classification. In 1984, Herbert and Fisher proposed a classification based on fracture instability; also describing a 'proximal pole' to the scaphoid.

Schernberg et al. specifically defined the proximal pole as the 'proximal one-third of the distance from the tip of the proximal pole to the scaphoid tuberosity', measured at its radial border with the ulnar border of the fragment ending at the border of the capitate fossa [7]. Thereafter, Compson et al, Wong et al., and Drijkoningen et al. similarly described the proximal pole as the fragment proximal to the scapho-capitate facet or distal scapholunate interval. The AO foundation's general fracture classification system, later adopted by the Orthopaedic Trauma Association (OTA), describes three components for scaphoid fractures, namely the proximal pole, waist, and distal pole, albeit with no further anatomical detail [22]. Ramamurthy et al. described scaphoid fractures with the most precise mathematical ratio with a fragment ratio of 0–0.33 as the proximal third and a ratio of $0-0.14$ as the proximal one-sixth (equivalent to the proximal pole).

Most recently, the SWIFFT study defined waist fractures as the 'middle 60%' and the proximal pole as the 'proximal fifth' [1]. This was based on two earlier studies by the same lead author, one of

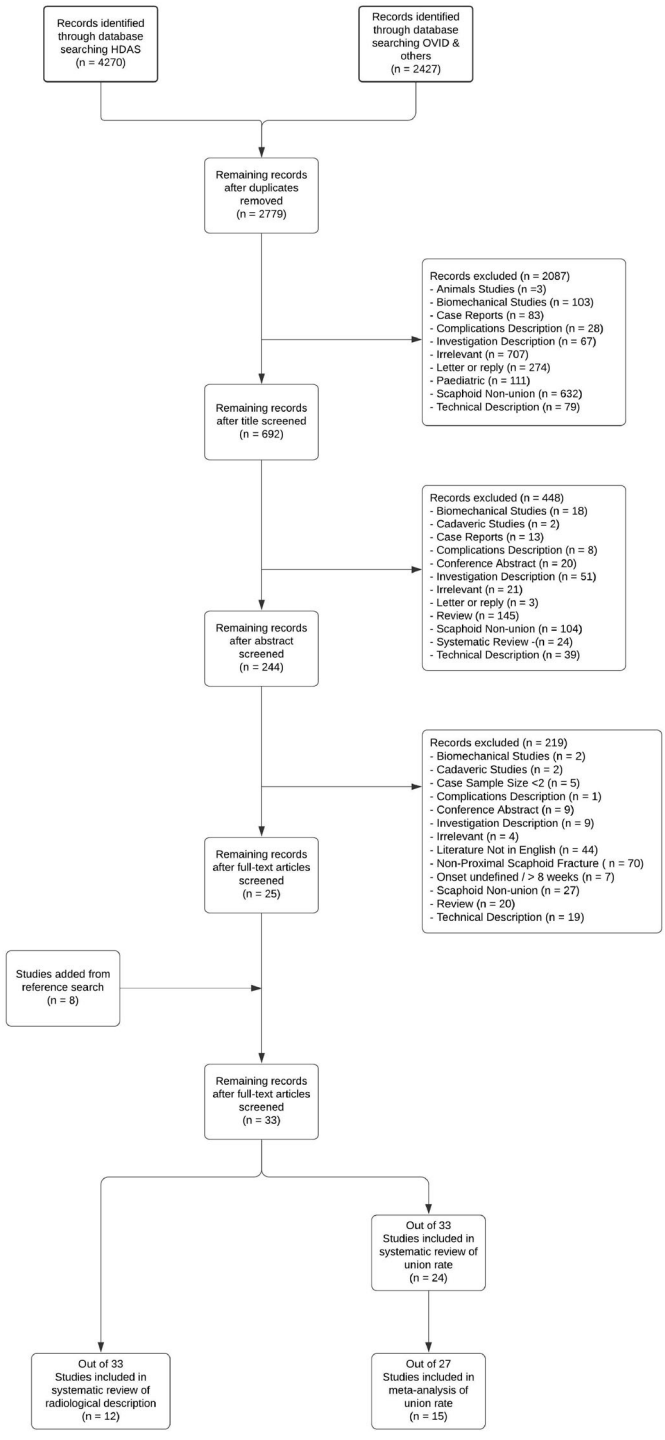


Figure 1. PRISMA flowchart of selection of studies.

which presented a pictorial representation including proximal scaphoid fracture planes (without specific measurements), with both proposing the definition of the proximal scaphoid to be the 'proximal 20% of the bone' (i.e. proximal fifth) [2,24].

### Proximal third and proximal (undefined) fractures

Table 2 outlines the studies that defined the proximal scaphoid as either 'proximal third' or 'proximal (undefined)'. 41 fractures from 9 eligible studies were identified [8,9,19,25–30]. Sample sizes ranged from 2 to 8 scaphoids. 39 were treated non-operatively (with plaster cast) and 2 were treated operatively (screw fixation). Five studies reported their follow-up, with a mean of 2 years (6 months – 5 years). The remaining 4 studies did not report their mean follow-up. The accumulated non-union rate was 22% (9 of 41).

### Proximal pole fractures

Table 3 outlines the studies that defined the proximal scaphoid as 'proximal pole'. 276 acute proximal pole scaphoid fractures were extracted from 15 eligible studies [10,31–44]. Sample sizes ranged from 2 to 65 scaphoids, with a mean follow-up range of 2 to 80 months. 93 were treated non-operatively and 179 were treated operatively. The accumulated non-union rate was 9% (24 of 272).

### Proximal fifth fracture

No studies reported outcomes after defining the proximal scaphoid as 'proximal fifth'.

### Meta-analysis

#### Overall

On pooled analysis, 11% of all proximal scaphoid fractures (all definitions) progressed to non-union by final follow-up. 18% [22/131] of non-operatively managed fractures developed non-union compared to 6% [11/182] of operatively managed fractures. Pooled meta-analysis comparing union rate of acute proximal scaphoid versus non-proximal (i.e. waist and distal) fractures is presented in Figures 2, 3 and 4. After pooling all included studies ($n = 15$), a meta-analysis demonstrated a RR of 3.1 (95% CI, 2.07–4.74, $p \leq 0.01$) of acute proximal scaphoid fractures developing non-union, compared to non-proximal scaphoid fractures. The RR for non-union was 3.3 (95% CI, 2.02–5.24, $p \leq 0.01$) and 2.9 (95% CI, 1.32–7.18, $p \leq 0.01$) when acute proximal scaphoid fractures were managed non-operatively and operatively, respectively.

#### Proximal (undefined)

2 studies presented adequate data for pooled union rate meta-analysis [27,45]. Both studies involved non-operative management. The non-union rate was 23% (3/13). The RR for non-union was 4.6 (95% CI, 1.63–12.66, $p \leq 0.01$) for acute proximal (undefined) scaphoid fractures, as compared with non-proximal fractures.

#### Proximal third

6 studies presented adequate data for meta-analysis [9,19,25,26,28,29]. The non-union rate was 23% (6/26) with non-operative management. No non-unions were reported following the only two cases managed operatively. Acute proximal third scaphoid fractures yielded a RR of 2.3 (95%CI, 1.07–5.00; $p = 0.03$), suggesting a 2.3× higher likelihood of progression to non-union compared with non-proximal fractures. 5 of these studies involved non-operative management, with a RR for non-union of 2.5 (95%CI, 1.11–5.50; $p = 0.03$). There were inadequate studies of operative management to be pooled.

#### Proximal pole

7 studies presented adequate data for pooled meta-analysis [10,31,36,39–41,44]. The non-union rate was 14% (13/92) with non-operative management compared to 6% [11/180] with operative management. The RR for non-union was 3.4 (95% CI, 1.97–5.94, $p \leq 0.01$) for acute proximal pole scaphoid fractures,

**Table 1.** Radiological description of 'proximal' scaphoid.

| Author | Year | | Classification | Description of proximal |
|---|---|---|---|---|
| Bohler et al. [18] | 1954 | 1 | Tuberosity | No anatomical description mentioned. |
| (German article) | | **2(a)** | **Proximal Third** | |
| | | 2(b) | Border, Middle/Proximal Third | |
| | | 2(c) | Middle Third | |
| | | 2(d) | Middle Third; Wedge Chipped Out | |
| | | 2(e) | Distal Third | |
| London et al. [19] | 1961 | **1** | **Proximal Third** | Pictorial illustration, no anatomical description mentioned. |
| | | 2 | Middle Third | |
| | | 3 | Distal Third | |
| Mayo classification; Cooney et al. [14] | 1980 | 1 | Distal Tuberosity | Proximal third on PA radiograph |
| | | 2 | Distal Articular Surface | |
| | | 3 | Distal Third | |
| | | 4 | Middle Third | |
| | | **5** | **Proximal Third** | |
| Herbert et al. [15] | 1984 | A1 | Tubercle | Type A/B classification is acute fractures < 6 weeks old, with type B as unstable configuration. No anatomical description mentioned. |
| | | A2 | Incomplete Waist | |
| | | B1 | Distal Oblique | |
| | | B2 | Complete Waist | |
| | | **B3** | **Proximal Pole** | |
| | | B4 | Fracture Dislocation | |
| | | B5 | Comminuted | |
| Schernberg et al. [7] | 1984 | **I** | **Proximal Pole** | Proximal 3rd of the distance from tip of proximal pole to scaphoid tuberosity, measuring at its radial border. Ulnar border ended at border of capitate fossa. |
| (French article) | | II | Waist | |
| | | III | Waist | |
| | | IV | Waist | |
| | | V | Distal | |
| | | VI | Tubercle | |
| Duppe et al. [20] | 1994 | **1** | **Proximal** | Pictorial illustration, no anatomical description mentioned. |
| | | 2 | Waist, Vertical Oblique | |
| | | 3 | Waist, Transverse | |
| | | 4 | Waist, Horizontal Oblique | |
| | | 5 | Waist, Distal | |
| | | 6 | Tuberosity | |
| Compson et al. [21] | 1998 | 1 | 'Surgical Waist' | Originates at the scaphoid dorsal apex, proximal to the scaphoid dorsal ridge. Fracture crosses the radio-scaphoid joint and then the scapho-capitate joint near proximal end. |
| | | 2 | Dorsal Sulcus | |
| | | **3** | **Proximal Pole** | |
| AO/OTA [22] | 2007 Updated 2018 | **72-A1** | **Proximal pole** | No anatomical description mentioned. |
| | | 72-A2 | Waist | |
| | | 72-A3 | Distal pole | |
| | | 72-A4 | Waist, comminuted | |
| Ramamurthy et al. [23] | 2007 | **0-0.33** | **Proximal Third** | Fracture site defined by fragment ratio in relation to long axis of scaphoid. Proximal 1/6th and 2/6th correlate with the ratio of proximal third. |
| | | 0.33-0.66 | Middle Third | |
| | | 0.66-1 | Distal Third | |
| | | **0-0.14** | **Proximal 1/6th** | |
| | | 0.15-0.30 | Proximal 2/6th | |
| | | 0.31-0.45 | Middle 3/6th | |
| | | 0.46-0.60 | Middle 4/6th | |
| | | 0.61-0.75 | Distal 5/6th | |
| | | 0.76-1 | Distal 6/6th | |
| Wong et al. [16] | 2011 | A1 | Tubercle | Proximal body 3rd is defined by scaphoid body articulating with capitate, dividing the scapho-capitate facet into 3 equal portions in the scaphoid view. Proximal pole is defined as fracture line proximal to scapho-capitate facet. |
| | | A2 | Distal Articular | |
| | | B1 | Body - Distal 1/3 | |
| | | B2 | Body - Middle 1/3 | |
| | | **B3** | **Body - Proximal 1/3** | |
| | | B4 | Body - Sulcal | |
| | | **C** | **Proximal Pole** | |
| | | D | Trans-Scaphoid Perilunate Fracture Dislocation | |
| Drijkoningen et al. [17] | 2019 | 1 | Distal | Proximal to the distal scapho-lunate interval |
| | | 2 | Waist | |
| | | **3** | **Proximal Pole** | |
| Dias et al. (SWIFFT)* [1] | 2020 | 1 | Distal 20% (1/5) | Pictorial illustration from original article, no anatomical description mentioned. |
| | | 2 | Middle (waist) 60% (3/5) | |
| | | 3 | **Proximal 20% (1/5)** | |

*Definition quoted from original article Garala et al. [19]; **Bold:** Definition of proximal scaphoid fracture described in each study.

compared with non-proximal fractures. Sub-group analysis demonstrated a non-union RR of 3.8 (95% CI, 1.82–7.71, $p \leq 0.01$) when acute proximal pole scaphoid fractures were managed non-operatively. In comparison, a pooled meta-analysis of 5 studies presenting outcomes of acute proximal pole scaphoid fractures managed operatively demonstrated a RR for non-union of 3.2 (95% CI, 1.38–7.18, $p \leq 0.01$), compared with non-proximal fractures.

**Table 2.** Characteristics of studies investigating acute proximal (third/undefined) scaphoid fractures.

| Study/method | Definition/onset | Method of treatment | Definition of union | Proximal (*n*=) | Outcome (*n*=) | | | | Time required to achieve union | Follow-up |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Union | Non-union | Delayed union | Possible union | | |
| London [19] Prospective | 'Proximal third'; Pictorial description with no anatomical information. <4 weeks. | Thumb & wrist plaster | Plain radiograph; normal scaphoid texture in all radiograph views clinical; steady improvement with strong, supple and painless wrist. | 8 | 5 | – | – | 3 | Duration unclear, >12 months in some cases | Duration unclear |
| Margo and Seely [25] Retrospective | 'Proximal third'; no other anatomical description. <5 days | Scaphoid Cast | Plain radiograph; no radiolucent fracture line or sclerosis of the fracture margins | 4 | 3 | 1 | – | – | Duration unclear | Duration unclear |
| Riester et al. [26] Retrospective | 'Proximal third'; no other anatomical description. <2 days | Short thumb spica | Plain radiograph; not specified | 3 | – | 2 | 1 | – | Duration unclear. >9 months in delayed union. | Mean 3.9 years (range 2–9 years) |
| Terkelsen and Jepsen [27] Prospective | 'Proximal'; no other anatomical description. <6 weeks | Long-arm plaster cast, short-arm orthoplast cast | Plain radiograph and clinical; not specified | 5 | 3 | 2 | – | – | Duration unclear | Up to 5 years |
| Gellman et al. [28] RCT | 'Proximal third'; no other anatomical information. <2 weeks | Thumb spica cast | Plain radiograph and clinical; absence of tenderness over snuffbox, presence of osseous trabeculae over fracture line | 5 | 3 | 1 | 1 | – | Range 8 – 24 weeks | Mean 12 months (range 6–24 months) |
| Khan and Al Harby [29] Retrospective | 'Proximal third; No other anatomical information. <2 weeks. | Long thumb spica | Plain radiograph; normal looking scaphoid with fracture line not visible. | 6 | 4 | 2 | – | – | 6 weeks | Duration not clearly defined |
| Rettig and Kollias [9] Retrospective | 'Proximal third'; no other anatomical description. <4 weeks | Herbert screw fixation | Plain radiograph; no lucency present at the fracture site Clinical; Non-tender over the scaphoid, range of motion and grip strength is within 10% of uninjured side. | 2 | 2 | – | – | – | 8 weeks | Range 6 – 90 months |
| Dawson et al. [30] Prospective | 'Proximal'; no other anatomical description. <2 weeks | Colles-type cast | CT scan; Non specified | 2 | 1 | 1 | – | – | Duration unclear; CT scan at 12 weeks | Duration unclear |
| Rhemrev et al. [8] Retrospective | 'Proximal'. Defined using MAYO classification. <2 weeks | Thumb spica cast | Plain radiograph and clinical; Patient have no complains, experience no axial / longitudinal compression pain, regained full function | 6 | 5 | – | 1 | – | Union – 6 weeks, delayed union – 12 weeks (not specified) | Mean >1 year |
| Total | | | | 41 | 26 | 9 | 3 | 3 | | |

RCT: randomised controlled trial; CT: computerised tomography.

**Table 3.** Characteristics of studies investigating acute proximal pole scaphoid fractures.

| Study/method | Definition/onset | Method of treatment | Definition of union | Proximal Pole (*n*=) | Outcome (*n*=) | | | | Time required to achieve union | Follow-up |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Union | Non-union | Delayed union | Possible union | | |
| Clay et al. [10] RCT | Bohler fracture type and Herbert B3. <2 weeks | Scaphoid vs. colles cast | Plain radiograph; complete disappearance of the fracture line | 12 | 7 | 4 | – | 1 | ~6 months | 12 months |
| Filan and Herbert [31] Retrospective | Defined as B3 by Herbert classification system. <6 weeks. | Herbert screw fixation | Plain radiograph; presence of cross-trabeculation with fracture line not visible, no lucency around screws. | 13 | 11 | 2 | – | – | ~6 months | 34.2 months |
| Rettig et al. [37] Retrospective | No anatomical description. <4 weeks | Retrograde Herbert screw ± bone graft | Plain radiograph, CT scan and clinical; non tender at th fracture site, union on imaging modality | 17 | 17 | – | – | – | Displaced – 11 weeks<br>Non-displaced – 9.5 weeks<br>Mean – 10.25 weeks | Mean 37 months (range 12 – 63 months) |
| Chung [38] Prospective | No anatomical description. <1 week. | Acutrak screw fixation | Plain radiograph; no visible fracture line, no screw loosening. | 2 | 2 | – | – | – | 8 weeks | 8–20 weeks |
| Vos and Vandenberghe [39] Retrospective | Defined as B3 by Herbert classification system. <50 d | Herbert screw fixation | Plain radiograph and clinical; no fracture gap visible at 12 weeks | 8 | 2 | 2 | 4 | – | Union at 6 weeks; Delayed union if > 12 weeks | 27 months (range 2–60) |
| Slade and Gillon [40] Retrospective | No anatomical description. <6 weeks | Arthroscopic screw fixation | CT Scan; Healing demonstrated by > 50% crossing bone trabeculations at the fracture site | 65 | 65* | – | – | – | Up to 12 weeks | Duration unclear |
| Tu et al. [41] Retrospective | No anatomical description. <2 d | Screw fixation. | Plain radiograph; no gap observed at the site of fracture, bridging trabeculae on AP and lateral view | 20 | 17 | 3 | – | – | Mean 10.5 weeks (8–14 weeks) | Mean 3.5 years (range 2–6 years) |
| Ikeda et al. [42] Retrospective | No anatomical description. <2 months | Herbert mini or Acutrak screw fixation | Plain radiograph; Not specified | 12 | 12 | – | – | – | 3.5 ± 1.1 months | Duration unclear |
| Gurbuz et al. [43] Retrospective | Defined as Herbert B3. <6 weeks | Screw fixation | Plain radiograph; trabeculation crossing fracture site. | 3 | 3 | – | – | – | Duration unclear | mean 51.7 ± 28.3 months |
| Grewal et al. [44] Retrospective | No anatomical description. <6 weeks | Below elbow thumb spica cast | CT Scan; >50% continuity of trabecular pattern across fracture site | 28 | 24 | 4 | – | – | 113 ± 109 d | Duration unclear; Union up to 1 year |
| Brogan et al. [32] Retrospective | No anatomical description. <4 weeks | Screw fixation | Plain radiograph and CT Scan; >50% union in two views | 23 | 10 | 3 | 9 | 1** | Union – 14 weeks<br>Delayed /Partial Union – mean 20 weeks | Median 27.7 weeks (7.3 weeks–13.9 years) |
| Grewal et al. [33] Retrospective | No anatomical description. <6 weeks | Short-arm thumb spica cast, open reduction internal fixation | CT Scan; >50% continuity of trabecular pattern across fracture site | 53 | 48 | 5 | – | – | 14 ± 11 weeks | Duration unclear; Union up to 1 year |
| Sahu [34] Prospective | Defined as B3 by Herbert classification system. <6 weeks. | Herbert screws | Clinical; no tenderness at anatomical snuff box or scaphoid tubercle<br>Plain radiograph; evidence of trabeculae crossing fracture on at least three views | 6 | 3 | – | | 3 | 16 weeks | 12 months |
| Schreiber et al. [35] Retrospective | <20% of total scaphoid length on CT scan. <7 weeks. | Screw fixation with bone grafting | Plain radiograph and CT scan; bridging trabeculation across minimum two consecutive slices in coronal/sagittal planes | 6 | 6 | – | – | – | Median 6 weeks (6–7 weeks) | Mean 45 weeks (11–92 weeks) |
| Severo et al. [36] Retrospective | Defined as B3 by Herbert classification system. <8 weeks | Screw fixation | Imaging and clinical; not specified | 4 | 3 | 1 | – | – | 10.33 ± 0.65 weeks | Duration unclear; >24 weeks |
| Pooled | | | | 272 | 230 | 24 | 13 | 5 | | |

*Assumed union; **Lost to follow-up; RCT: randomised controlled trial; CT: computerised tomography.

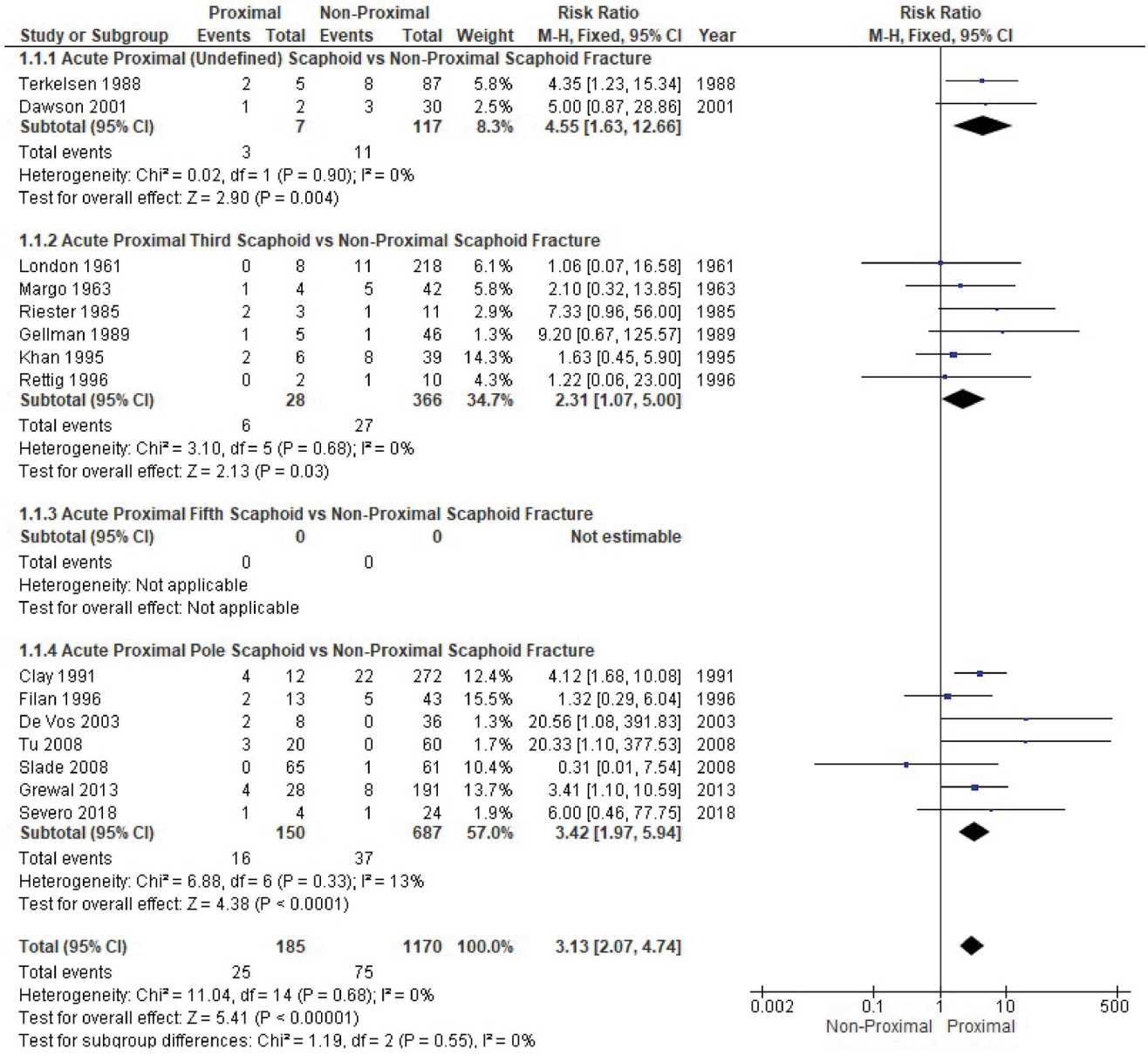


Figure 2. Forest plot showing the risk ratio of non-union for acute proximal scaphoid fractures. Events = non-union cases reported; total = total sample; M–H = Mantel–Haenszel analysis; CI = confidence interval; $I^2$ = level of heterogeneity.

### *Proximal fifth*

No studies presented outcomes of the management of acute proximal fifth scaphoid fractures.

### *Heterogeneity and risk of bias analysis*

In the meta-analysis of the non-union rate of proximal scaphoid fractures, low heterogeneity was reported, with an $I^2$ value of 0–13% for all the included studies pooled as one group, with degrees of freedom (df)=14. The heterogeneity of pooled subgroup analysis of non-operative and operative management was also between none to low, with an $I^2$ value of 0% and 28%, respectively. The between studies variance ($\tau^2$) of the included articles ranged between 0 and 1.06, with pooled analysis $\tau^2$ ranging between 0 and 0.65, as shown in the sub-analysis adopting the DerSimonian and Laird (DL) estimator. Figure 5 demonstrates the potential publication bias across the studies. By assuming the smaller studies scatter widely at the bottom, and larger studies show narrow spread at the top, an inverted funnel shape (with all lying within the demarcated SE-log RR funnel plot, symmetrically scattered at both ends) suggests a low risk of publication bias. The quality assessment of each study is summarised in Supplementary 2 and 3. Most studies were subject to a moderate to serious risk of bias due to their methodology. Two studies had a low risk of bias; one RCT and one well-designed retrospective case series.

## Discussion

Our findings highlight the heterogeneity in both, reporting of definitions of 'proximal' scaphoid fractures, and variation in union rates of proximal scaphoid fractures depending upon anatomical descriptors. This confirms our hypothesis that the term 'proximal' is poorly defined by the majority of studies reporting the clinical and radiological outcomes of these fractures.

Proximal scaphoid fractures are at risk of non-union and osteonecrosis, particularly when managed non-operatively [10,27,28]. The recent SWIFFT trial has provided robust evidence that this is

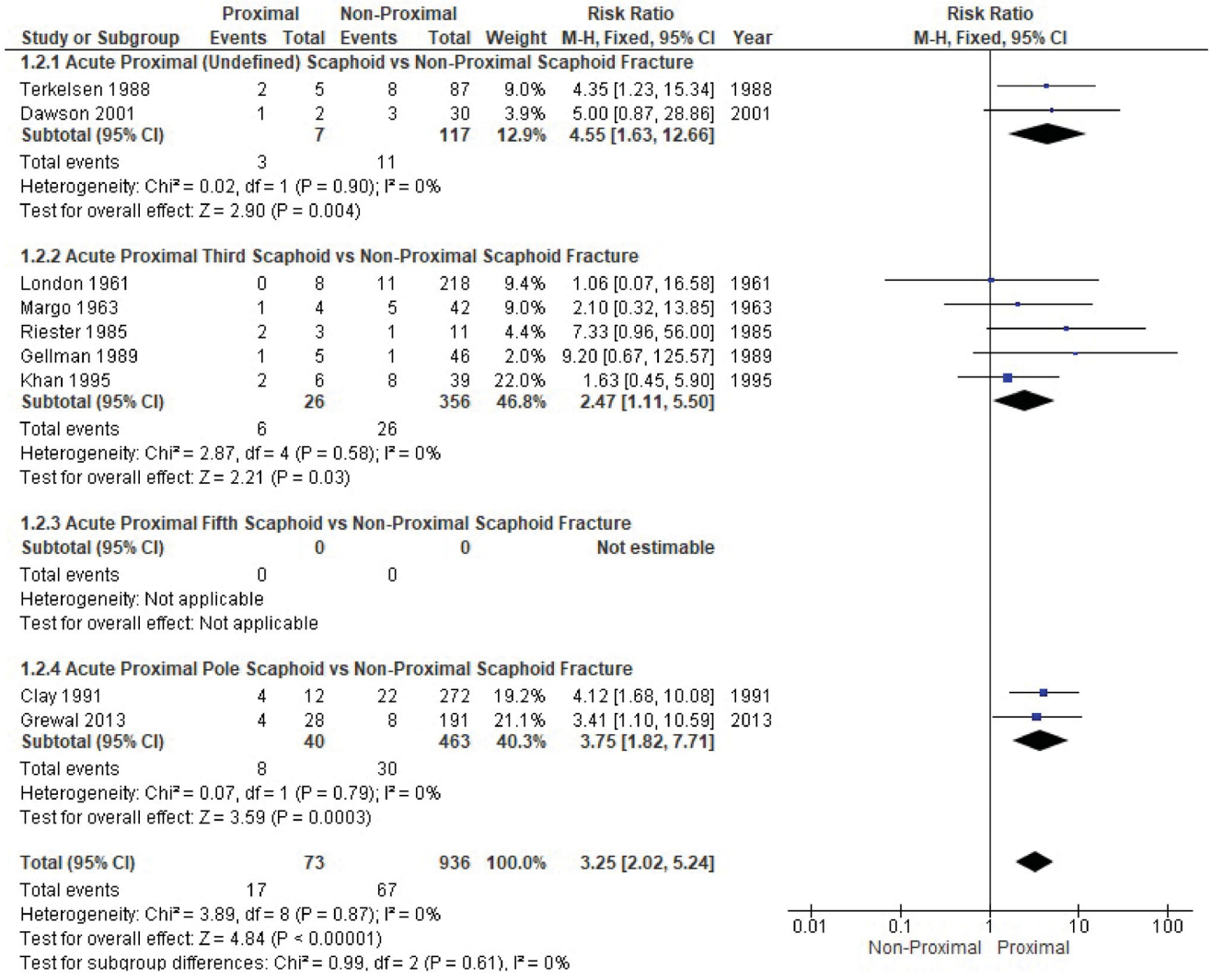


Figure 3. Forest plot showing the risk ratio for non-union of acute proximal scaphoid fractures managed non-operatively. Events = non-union cases reported; total- = total sample; M–H = Mantel–Haenszel analysis; CI = confidence interval; $I^2$ = level of heterogeneity.

not necessarily the case for non-proximal (waist) fractures, which may be successfully managed non-operatively if minimally displaced [1]. It is therefore essential to correctly define the anatomy of the fracture to guide management and accurately report outcomes. We found that 'proximal' was poorly defined by the majority of studies reporting outcomes, with few authors using clear anatomical landmarks, and inconsistent reporting of site and displacement between studies.

Numerous classification systems have been described for scaphoid fractures, based on a combination of anatomy, displacement, stability, and fracture plane [7,14,15,18,21,22,46]. Each has its merits with regards to guiding management and prognosis. The Herbert, Russe, and Mayo classifications are perhaps the most widely utilised in the scaphoid literature [14,15,46]. Evidence suggests highly variable interobserver reliability (ranging from fair to good) in the description, particularly of displacement, with no classification demonstrating significant superiority over another with regard to predicting union and therefore guiding management [47–49]. Furthermore, with the majority based on 2-dimensional (2D) imaging (plain radiographs), these do not account for the complexities of the scaphoid's complex 3-dimensional (3D) structure. This resultant heterogeneity in the literature results in difficulty in making comparisons to guide management.

While computed tomography (CT) is agreed to be a more reliable way to define fracture anatomy, displacement, and union, the majority of studies utilised plain radiographs [44]. The national institute for health and care excellence (NICE) in the United Kingdom (UK) advocates magnetic resonance imaging (MRI) for the diagnosis of suspected scaphoid fractures [50], although plain 'scaphoid view' radiographs remain the first-line investigation in the UK practice due to their cost-effectiveness and ease of access. Therefore, any standardised definition of 'proximal' must therefore be applicable to plain radiographs.

With an important recent RCT (SWIFFT) including some fractures previously defined as 'proximal third' (i.e. the 'larger' proximal fragments identified as at higher risk of non-union in our meta-analysis) within the category of 'waist' (i.e. central 60%), and recommending prompt fixation of those going onto non-union, a more focused definition of 'proximal' would be consistent with this study and serve to ensure that both, 'waist' and 'proximal' fractures are managed with the appropriate thresholds for intervention to minimise the risk of non-union [1].

We, therefore, recommend the use of fixed anatomical landmarks that are consistent and can be reliably identified on plain radiographs between observers. Figure 6 highlights these parameters on a standard PA view and scaphoid PA view, with the radioscaphoid joint/one-fifth radial border length, and scapho-capitate

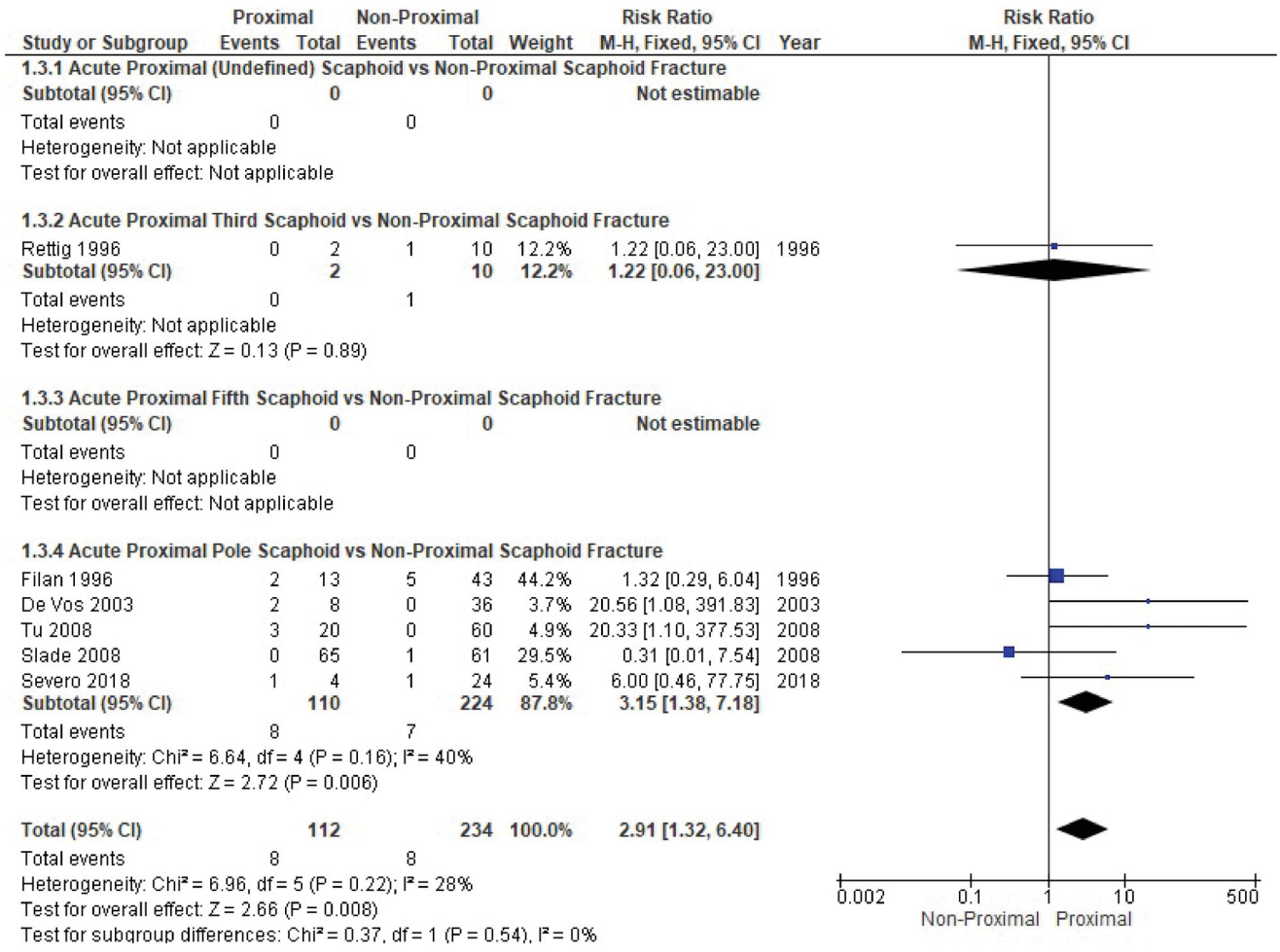


Figure 4. Forest plot showing the risk ratio for non-union of acute proximal scaphoid fractures managed operatively. Events = non-union cases reported; total = total sample; M–H = Mantel–Haenszel analysis; CI = confidence interval; $I^2$ = level of heterogeneity.

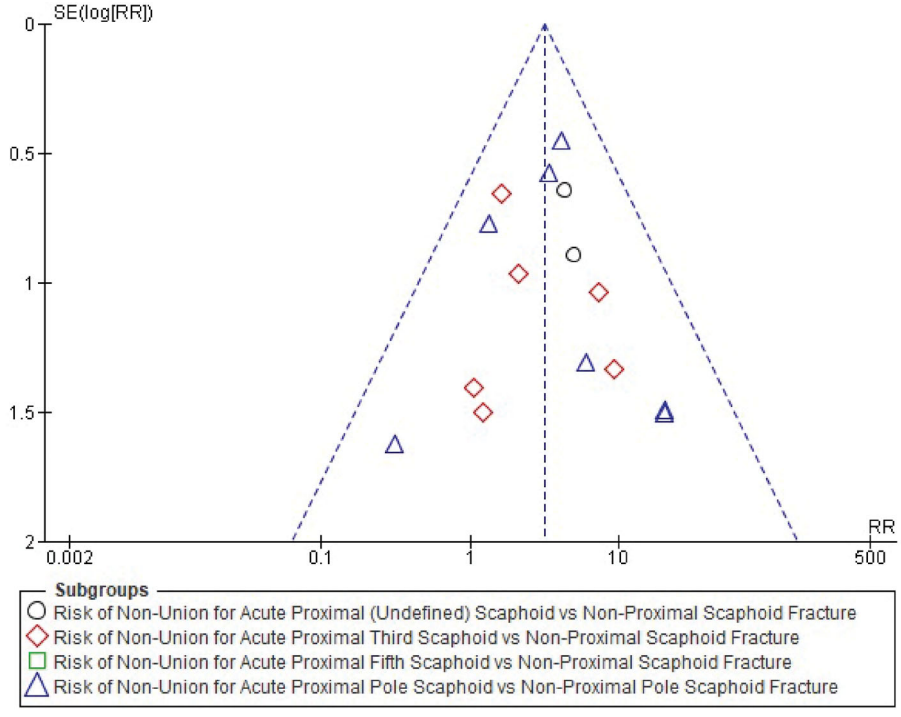


Figure 5. Funnel plot created with treatment effect plotted on the horizontal axis and study size on the vertical axis. By assuming that the smaller studies scatter widely at the bottom, and larger studies showing narrow spread at the top, an inverted funnel shape rules out publication bias.

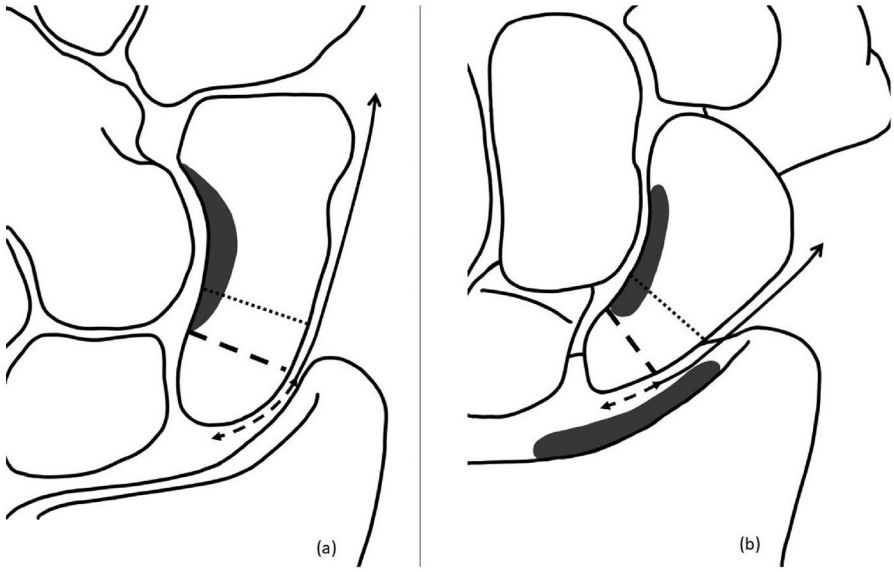


Figure 6. Suggested definition of proximal pole scaphoid fracture; Solid arrow line = total radial border length of the scaphoid, bounded distally at tuberosity and proximally at the tip of the proximal pole; Dashed dotted arrow line = proximal 1/5 of the total radial border length; Dashed line = proximal pole scaphoid fracture; Dotted line = proximal third scaphoid fracture. (a) PA scaphoid view (wrist in ulnar deviation) plain radiograph. Proximal pole fracture, with radial border proximal to distal radio-scaphoid joint (proximal 1/5 of total radial border length) and ulnar border proximal to scapho-capitate joint. (b) Standard PA wrist plain radiograph. Proximal pole fracture, with radial border proximal 1/5 of total length and ulnar border proximal to scapho-capitate joint.

joints as the primary landmarks. This definition follows logically from the work of Wong et al., Drijkoningen et al., and Dias et al., and proposes to utilise a more conservative definition of 'proximal' [1,16,17]. With our meta-analysis demonstrating a lower risk of non-union with smaller, more discrete proximal fractures (likely secondary to a lower threshold for early operative fixation), a universal definition that seeks to encompass the prevailing philosophy of early fixation of fractures at high risk of non-union if left untreated, is likely to be more readily accepted and relevant. By utilising this simple anatomical descriptor, we hope to reduce interobserver variability and provide a platform for standardised reporting of future clinical studies.

For waist fractures, there is evidence to suggest that displacement is associated with instability and non-union, with operative management (fixation) advocated to minimise non-union [1,51,52]. However, a combination of diagnostic difficulty due to poor visualisation of the fracture on plain radiographs, interobserver variation in classification (varying definition of the boundaries between waist and proximal) and finally, the differences in fracture configuration (transverse vs oblique) leads to differences in treatment, contributing to the heterogeneity in reported outcomes. The task becomes more complex when proximal fractures are considered, with less evidence to guide management. The goals of treatment are to prevent the sequelae of non-union and osteonecrosis. As non-union of proximal scaphoid fractures is more likely to progress to degenerative changes (SNAC) than their distal counterparts, operative management is usually recommended [53,54].

Eastley et al.'s meta-analysis calculated a non-union rate of 34% for all non-operatively managed acute proximal scaphoid fractures [24]. This study found a lower non-union rate of 18% for all non-operatively managed proximal scaphoid fractures (compared to 6% for operatively managed fractures). The difference is likely due to a combination of inclusion of more updated studies performed over the past decade, and an expanded definition of 'proximal' to minimise ambiguity and variation in anatomic descriptions.

The term 'proximal pole' was popularised by Herbert et al. [10] in 1984, with a shift in trend to 'proximal third' from the 1990s onwards. Studies reporting the outcomes of the smallest, most discrete anatomical region (the proximal pole) report lower non-union rates than those reporting outcomes of broader anatomical definitions of proximal (such as 'proximal third'). A likely reason for this is the differing management of these two cohorts. Fractures defined as 'proximal pole' were more likely to be surgically treated (over 50% of our included cohort), compared with those defined using other definitions of proximal (only 5%). With waist fractures more likely to be managed non-operatively, the more distally located 'proximal scaphoid' fractures are likely to overlap with the boundaries of fractures defined as 'waist'. These findings reinforce the need for a unified anatomical definition, with clear fracture boundaries to guide management.

Our study has several limitations. There is limited published evidence with significant descriptive variation in the radiographic classification systems adopted throughout the literature. This heterogeneity in the basic definition of proximal scaphoid fractures limits the comparison of outcomes between studies. Only a few studies had large sample sizes or were of adequately high methodological quality, potentially introducing small-study effects to our analysis. There were variations in the management strategies adopted by each study, including operative versus non-operative, cast type, duration of immobilisation, type of fixation, and duration of follow-up. Most significantly, there was a lack of standardised definitions for 'proximal', 'union', and timing of established non-union, resulting in significant heterogeneity and limiting outcomes comparison.

In conclusion, there is a clear lack of homogeneity in definitions of 'proximal' scaphoid fractures across the published literature. We, therefore, encourage future studies to adopt our recommended definitions, which are easily reproducible using fixed anatomical landmarks on plain radiographs and aim to minimise inter- and intraobserver variability. This will allow for a more specific calculation of non-union rates and clinical outcomes, allowing clinicians to more accurately counsel patients regarding treatment and prognosis.

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No potential conflict of interest was reported by the author(s).

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