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Case Series

Morphometric analysis of scaphoid: influence of screw design and surgical approach in scaphoid fracture fixation: a study in Indian population

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ABSTRACT

Scaphoid fractures are among the most frequent carpal bone injuries, and screw fixation has become the treatment of choice. The stability of fixation is maximized when the screw is centrally placed and of maximum possible length. In this case series, we examined scaphoid morphometry in the Indian population and assessed the influence of sex, surgical approach, and screw design on achievable screw length. The study was performed on ten computed tomography (CT) scans of normal wrists, including five men and five women. Three-dimensional reconstructions were created, and the central longitudinal axis of the scaphoid was defined. Virtual headless compression screws from five commercially available designs were positioned along this axis. The scaphoid length measured along its central axis was greater in men (mean 27.52 mm, standard error of the mean 0.70 mm) than in women (mean 23.32 mm, standard error of the mean 0.61 mm). Longer screws could be inserted through a volar approach (male mean 25.28 mm, standard error of the mean 0.84 mm; female mean 20.92 mm, standard error of the mean 0.91 mm) compared with a dorsal approach (male mean 24.84 mm, standard error of the mean 0.94 mm; female mean 20.48 mm, standard error of the mean 1.00 mm), irrespective of screw design. This case series highlights sex-related differences in scaphoid size and suggests that the volar approach permits the placement of longer screws. Screw design continues to play a crucial role in determining fixation options.

Keywords: Scaphoid morphometry, Surgical approach, Screw design, Indian population study, Fixation biomechanics

INTRODUCTION

Scaphoid fractures are the second most common carpal bone injury after distal radius fractures, accounting for nearly 60% of all carpal fractures and 11% of hand fractures.[1] Their annual incidence has been estimated at 38 per 100,000 men and 8 per 100,000 women.[2] These fractures most frequently occur following a fall on an outstretched hand and are particularly common in active young adults. The unique anatomical position of the scaphoid, combined with its retrograde blood supply, contributes to a high risk of complications. When diagnosis is delayed or when non-operative treatment is chosen inappropriately, patients are predisposed to non-union, malunion, carpal instability, and ultimately wrist osteoarthritis.[3-6]

Operative fixation is generally recommended for displaced scaphoid waist fractures, proximal pole fractures, and those associated with carpal malalignment.[3] Over the past decades, headless compression screws have become the gold standard for internal fixation because they achieve stable fixation with interfragmentary compression while preserving the integrity of the articular surface.[6,7]

Biomechanical research has shown that central screw placement along the long axis of the scaphoid provides superior stability compared to eccentric placement.[8] Achieving this optimal placement, however, is technically demanding. Surgeons must contend with precise axis identification, the risk of joint penetration or hardware prominence, and the challenge of accommodating the anatomical constraints of the proximal pole.[9-11]

Different screw systems vary in their leading and trailing thread diameters, thread pitch, available lengths, and guidewire dimensions. In most commercially available headless compression screws, the trailing diameter is larger than the leading diameter, a design feature that influences how deeply the screw can be buried beneath the cartilage at both ends of the scaphoid. This is particularly relevant in the proximal pole, the narrowest part of the bone, where the larger trailing end often restricts safe burial in shorter or smaller scaphoids.

The choice of surgical approach further complicates fixation. The volar approach often permits longer screw trajectories, especially when variable-pitch screws are used, but its application can be limited by the presence of the trapezium. By contrast, the dorsal approach provides a more linear access route but requires marked hyperflexion of the wrist and carries risks of injury to the extensor tendons and dorsal sensory nerves.[12,13] Several cadaveric and computational model studies have compared the entry points and trajectories for both approaches, highlighting their respective advantages and limitations.[14-17]

Another factor that warrants careful consideration is patient-specific anatomy. Morphological variation of the scaphoid across populations and between sexes has been well documented. Prior studies have consistently shown that female scaphoids are significantly smaller than those of males.[18] Despite this, most commercially available screw systems are designed on the basis of Western anatomical data, raising important questions regarding their suitability for populations with different anthropometric characteristics, such as Indian population.[5]

In light of these anatomical and technical complexities, there remains a strong need to explore how scaphoid morphology, screw design, and surgical approach together influence fixation outcomes in different patient groups. The present study uses three-dimensional imaging and modeling to examine scaphoid morphometry in the Indian population. It further evaluates how sex-based anatomical differences, screw design characteristics, and the choice of surgical approach impact the maximum allowable screw length and the potential for safe subchondral placement.

CASE SERIES

This case series reports the morphometric analysis of ten wrists, including five male and five female subjects, each evaluated using CT. All included cases were free from any known wrist pathology, and scans demonstrated no fractures, degenerative changes, avascular necrosis, intercarpal instability, or congenital anomalies. These ten individuals were selected to provide a representative distribution of scaphoid anatomy across sexes, thereby allowing a comparative assessment of scaphoid dimensions and screw fixation strategies. Although the number of cases is limited, the series provides a useful window into how scaphoid morphology and implant accommodation can vary between individuals, and how these differences can influence the safety and stability of surgical fixation.

All CT scans were performed using a dual-source Siemens scanner with a slice thickness and spacing of 0.5 mm to ensure high-resolution bone imaging. This level of detail was essential, as even submillimetre errors can significantly affect conclusions when dealing with small carpal bones and fine implant margins, 3D reconstructions were subsequently generated using mimics 13 and 3-matic (Materialise, Leuven, Belgium). These software platforms have been widely validated for morphometric and biomechanical modelling, and in our study, they provided measurement accuracy up to 0.01 mm (Figure 1). Creation of 3D digital bone models enabled precise and reproducible assessment of scaphoid dimensions and also facilitated safe simulation of screw placement.

In each wrist, the scaphoid length was determined by measuring the longest central axis extending from the proximal to distal pole. In addition, coronal and sagittal waist diameters were recorded at the narrowest mid-waist section. These measurements provided a fundamental dataset describing the available bone stock in each case. Since scaphoid fractures most frequently occur at the waist, accurate knowledge of this dimension is especially relevant for planning internal fixation.

To test implant suitability, five widely used commercially available headless compression screws were digitally reconstructed based on their manufacturer specifications. Each implant was modeled as two coaxial cylinders, representing the leading and trailing threads, allowing accurate representation of both shaft length and thread diameters (Figure 2). Simulations were performed by virtually inserting each screw into the scaphoid models, testing both volar and dorsal approaches. In the volar technique, the narrower leading thread was positioned proximally and the broader trailing thread distally. In contrast, the dorsal technique placed the broader portion proximally. In both methods, a trajectory was deemed acceptable only if the screw remained completely contained within the scaphoid cortex. For every simulated placement, maximum safe screw length was determined, and tip-to-articular distances at both proximal and distal ends were measured. In accordance with biomechanical studies, a margin of at least 2 millimetres was considered necessary to avoid articular penetration (Figure 3).

The results consistently revealed sex-based differences in scaphoid morphology. Male scaphoids were larger, with a mean length of 27.52 mm, coronal width of 15.28 mm, and sagittal width of 10.94 mm. Female scaphoids demonstrated smaller average dimensions, measuring 23.32 mm in length, 11.80 mm in coronal width, and 9.84 mm in sagittal width. These anatomical variations significantly influenced implant accommodation. In male scaphoids, volar approach allowed screw lengths averaging 25.28 mm, compared with 24.84 mm via the dorsal route. In female scaphoids, maximum achievable lengths were 20.92 mm and 20.48 mm for volar and dorsal approaches respectively. Although these differences appear modest in absolute values, they carry important clinical implications given the narrow safety margins available in scaphoid fixation.

Screw-specific performance also varied. While most implants respected 2 mm safety margin at both poles, cannulated short thread screw (Synthes) occasionally violated proximal articular surface when inserted dorsally in smaller female scaphoids, underscoring risk of iatrogenic complications when using screws with larger trailing diameters in narrow bone stock. In general, volar approach provided more reliable engagement of distal pole threads and allowed marginally longer screws to be placed without breaching cortical boundaries. Conversely, dorsal approach sometimes risked proximal thread prominence, particularly in cases with shorter scaphoids.

This case series highlights several key considerations. First, scaphoid morphology varies not only between individuals but also between sexes, and this variability can determine whether a particular screw is appropriate for safe fixation. Second, implants with trailing thread diameters greater than 3.9 mm may not be suitable for female scaphoids, where smaller bone dimensions create narrower margins of safety. Third, screws available in one-millimetre length increments are particularly advantageous, as they enable surgeons to select implants that maximize bone purchase while minimizing the risk of articular violation. Finally, although both volar and dorsal techniques are commonly employed in practice, the volar approach appears to provide a slight advantage in the terms of the achievable screw length and the distal pole engagement.

Although limited by small sample size, the findings of this case series underscore the value of preoperative CT-based morphometric analysis and virtual implant simulation. In clinical practice, such tools can help surgeons anticipate fixation challenges, tailor implant choice to individual anatomy, and potentially avoid intraoperative complications. Importantly, this series demonstrates that even with a modest number of cases, clinically relevant patterns can be identified that have direct implications for the management of scaphoid fractures.

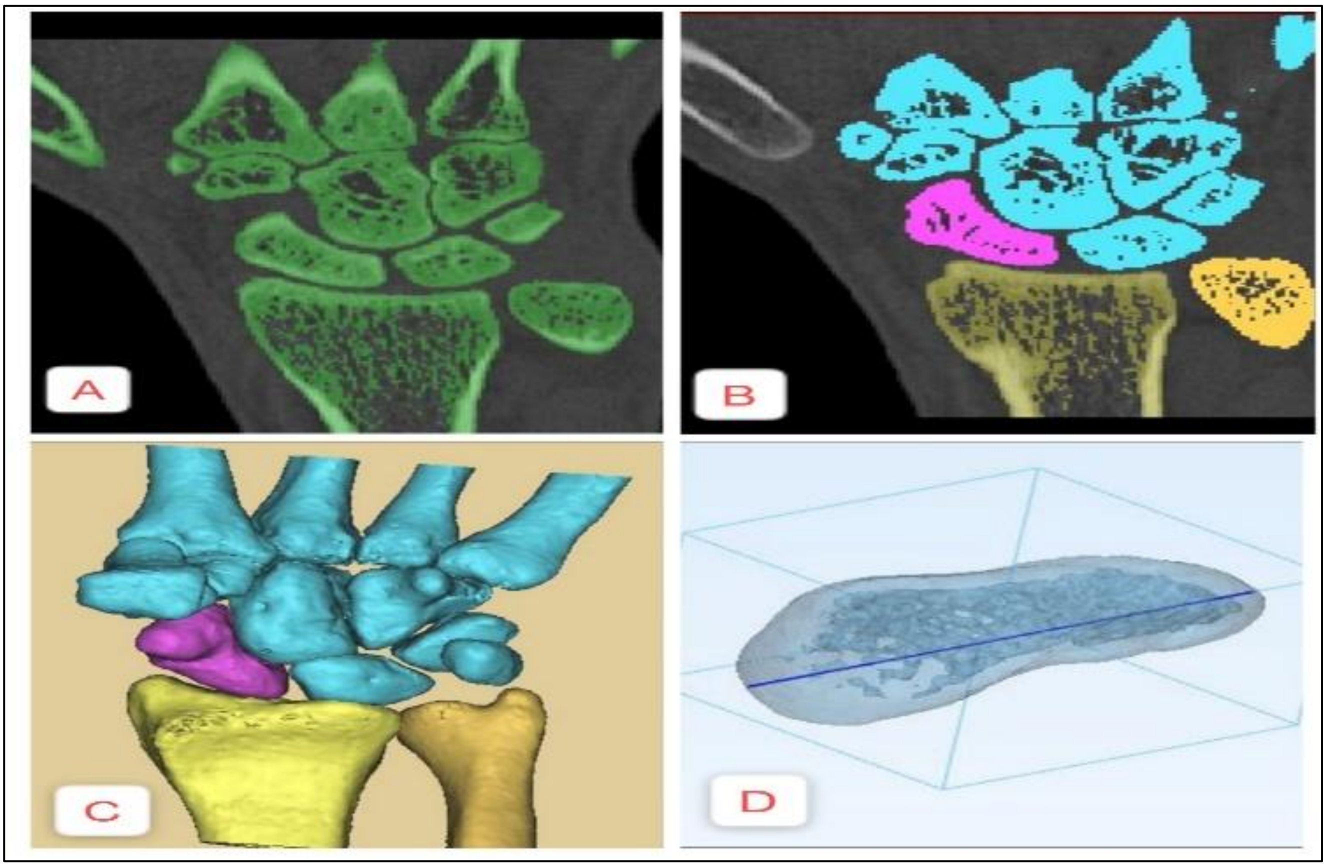

Figure 1 (A-D): A-Thresholding was done to separate the bone from soft tissue. B-Segmentation and region growing. C-Calculate 3D command was used to design a virtual 3D model for analysis. D-Longitudinal axis of the scaphoid was determined.

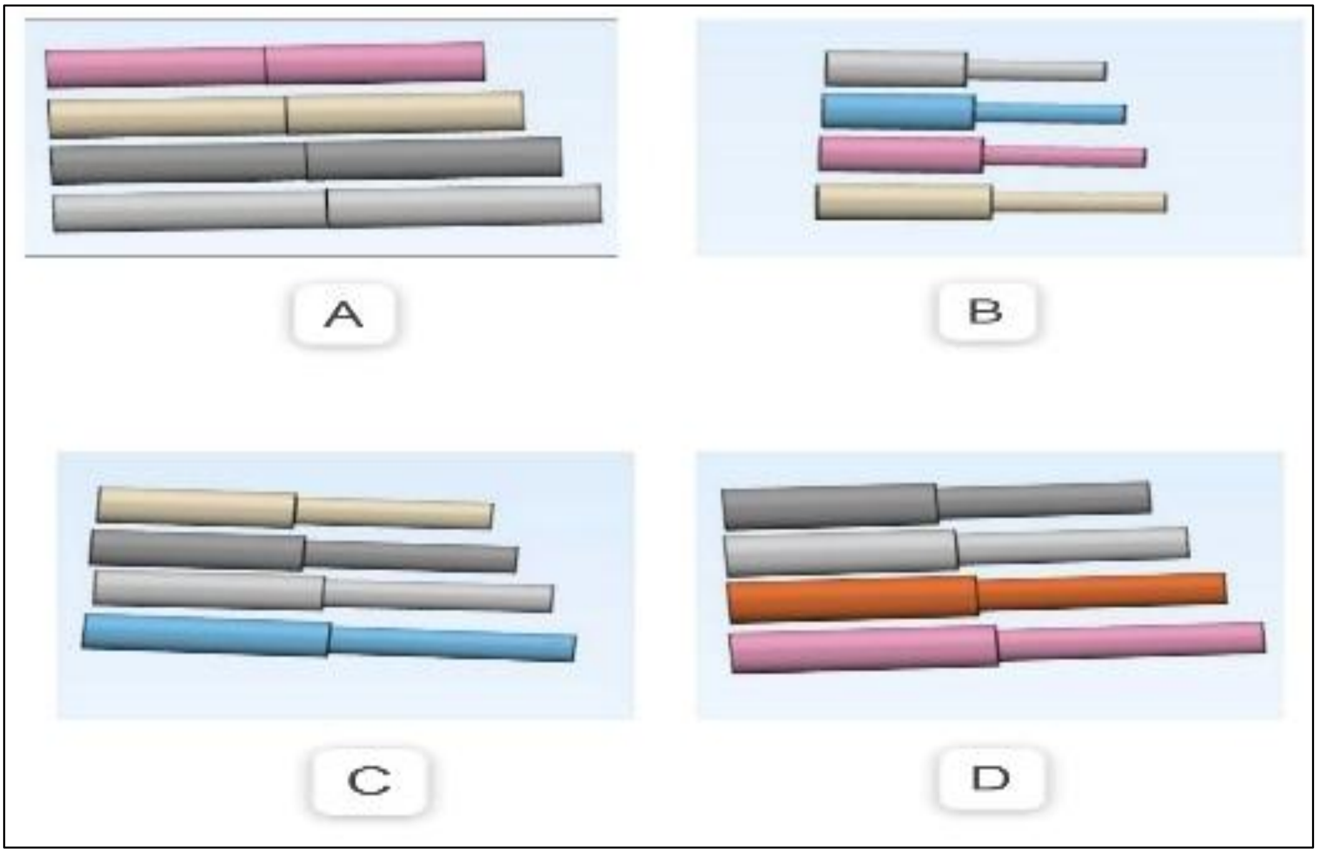

Figure 2 (A-D): A-Acutrak 2 mini (Acumed). B-Cannulated short thread (Synthes). C-Herbert™ scaphoid (Zimmer). D-TwinFix1 (Stryker).

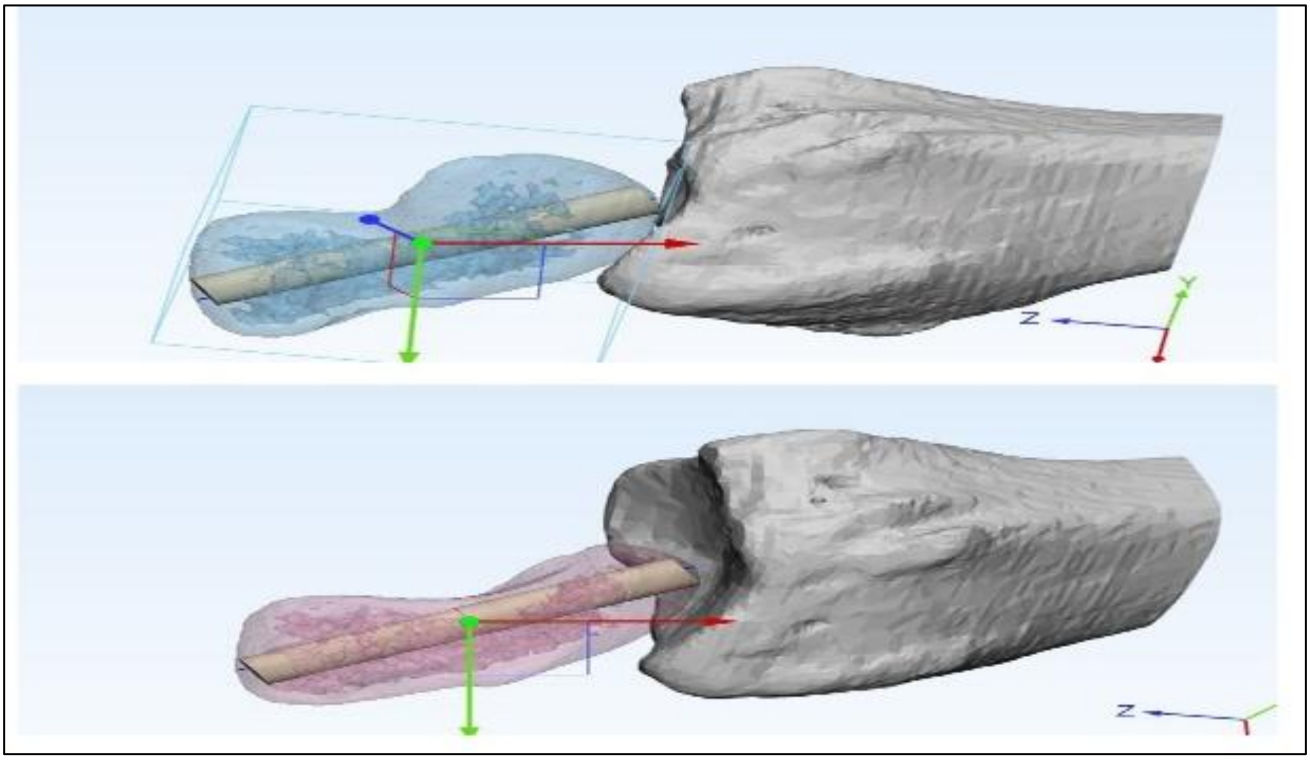

Figure 3 (A and B): 3-dimensional illustration of the scaphoid demonstrating measurement of pTAD, dTAD, and screw length. The image shows placement of an Acutrak 2 mini screw inserted via the volar approach (blue, above) and dorsal approach (red, below) along the central axis of the scaphoid.

Table 1: Overview of screw types and dimensions.

Screw manufacturer	Leading diameter (mm)	Trailing diameter (mm)	Length range (increment)	Guide pin size (mm)
Acutrak 2 mini (Acumed)[a]	3.5	3.6	16-30 (2 mm)	1.1
Headless bone screw (HBS) (KLS Martin)[b]	3.0	3.9	10-30 (1 mm)	1.0
Cannulated short thread (Synthes)[c]	3.0	5.5	8-30 (1 mm), 32-40 (2 mm)	1.1
Herbert™ scaphoid (Zimmer)[d]	3.0	3.9	12-30 (2 mm)	NA
TwinFix1 (Stryker)[e]	3.2	4.2	14-20 (2 mm), 21-30 (1 mm), 32-34 (2 mm)	1.0

*a. Acutrak 2 Mini uses a fully threaded variable pitch design intended for precise bone purchase. b. HBS from KLS Martin offers 1-mm length increments for high placement accuracy. c. Synthes short thread screws have a wide trailing diameter (5.5 mm), allowing strong cortical engagement. d. Herbert™ screws are widely used for scaphoid waist fractures due to their classic compression characteristics. e. TwinFix1 combines triple-threaded pitch with a tapered core for optimal compression and control.

Table 2: Comparison of mean screw lengths between volar and dorsal approaches by screw design.

Screw design	Volar length (mm)	Dorsal length (mm)	P value
Acutrak 2 mini (Acumed)[a]	24.78	23.56	0.31
Headless bone screw (HBS) (KLS Martin)[b]	24.84	23.12	0.002
Cannulated short thread (Synthes)[c]	23.35	22.32	<0.0001
Herbert™ Scaphoid (Zimmer)[d]	23.90	23.10	0.0006
TwinFix1 (Stryker)[e]	23.60	23.08	0.01

*a. Acutrak 2 Mini-Manufactured by Acumed (USA); titanium alloy, fully threaded with variable pitch; widely used in hand and wrist surgery. b. HBS-Produced by KLS Martin (Germany); headless, double-threaded screw available in 1-mm length increments for high-precision placement. c. Synthes Cannulated Screw-Made by DePuy Synthes (Switzerland); short-thread design with large trailing diameter for aggressive bone purchase. d. Herbert™ Scaphoid-Developed by Zimmer Biomet (USA); classical dual-threaded compression screw for scaphoid nonunion and waist fractures. e. TwinFix1-Designed by Stryker (USA); variable pitch screw with a tapered profile; offers strong compression in minimally invasive fixation.

Table 3: Comparison of proximal and distal tip-to-articular distances (pTAD and dTAD) by screw design and approach.

Screw design	pTAD volar (mm)	pTAD dorsal (mm)	dTAD volar (mm)	dTAD dorsal (mm)
Acutrak 2 mini (Acumed)[a]	1.40	1.49	0.71	0.69
Headless bone screw (HBS) (KLS Martin)[b]	1.17	1.62	0.67	0.68
Cannulated short thread (Synthes)[c]	1.16	2.59	1.27	0.50
Herbert™ scaphoid (Zimmer)[d]	1.16	1.62	0.67	0.68
TwinFix1 (Stryker)[e]	1.25	1.75	0.89	0.69

*a. pTAD and dTAD within safe limits in both approaches. b. pTAD (Proximal Tip-to-Articular Distance) larger dorsally, may affect subchondral purchase. c. Elevated dorsal pTAD suggests risk of proximal cortex breach. d. Consistent pTAD/dTAD balance across volar and dorsal entries. e. Acceptable pTAD (≤2 mm) with slightly higher dorsal values.

DISCUSSION

This study was designed to evaluate how anatomical variation, screw design, and surgical approach influence the maximum allowable screw length and the safety of subchondral screw placement in scaphoid fracture fixation. Findings demonstrate that sex-based differences in scaphoid morphology, combined with implant geometry and surgical access route, play a central role in optimizing fixation strategies and achieving reliable outcomes.

The results confirmed that the scaphoid is significantly smaller in women compared to men, both in terms of the length and width, which is consistent with the anatomical work of Vasilas et al and Clay and Dias.[19,20] Heinzelmann et al reported mean scaphoid lengths of 31.3 mm in men and 27.3 mm in women, whereas the values in our study were slightly lower.[18] This is likely attributable to the use of high-resolution three-dimensional CT reconstructions, which allow more precise definition of the central anatomical axis while minimizing manual measurement error. The clinical implication of these differences is important, as a smaller scaphoid in women naturally restricts the screw length that can be safely accommodated. However, with appropriate implant selection-particularly screws with smaller diameters and finer incremental lengths-safe subchondral placement within 2 mm of the articular surface remains feasible in both sexes, preserving biomechanical sufficiency.[21]

The role of screw design emerged as another important factor in fixation safety. Screws with leading thread diameters above 3.0 mm and trailing thread diameters greater than 3.9 mm substantially reduced the maximum safe screw length, particularly in smaller scaphoids. These dimensions also carried a greater risk of violating the articular cortex or leaving inadequate subchondral purchase, a finding consistent with earlier biomechanical and anatomical studies.[22] In contrast, screws available in 1-mm length increments provided greater intraoperative adaptability, allowing the surgeon to optimize screw seating while preserving cartilage integrity. This is of particular value in the Indian population, where scaphoid dimensions are often smaller compared to Western populations.[5] At the same time, a clear trade-off exists between size and stability: while smaller screws offer placement flexibility, larger diameter implants confer greater resistance to bending and shear forces, a point highlighted by Grawe et al and other biomechanical evaluations.[23,24] Hence, screw selection requires careful balance between anatomical feasibility and the mechanical demands of fracture stability.

The surgical approach itself influenced both achievable screw length and placement accuracy. The volar approach, particularly with variable-pitch screws, allowed longer trajectories along the central scaphoid axis, consistent with the findings of Verstreken and Meermans and Park et al.[25,26] Yet this approach can be technically constrained by the trapezium, at times necessitating partial resection or a transtrapezial route as described by previous authors.[13,27] Conversely, the dorsal approach provides easier access for proximal pole fractures but requires wrist hyperflexion and carries a risk of dorsal sensory nerve and extensor tendon injury.[28,29]

The quality of subchondral placement was assessed using proximal and distal tip-articular distances (pTAD and dTAD). Optimal fixation is considered to be within 2 mm of the articular surface, a threshold that minimizes the risk of joint penetration while ensuring firm engagement in dense subchondral bone. In our series, screws with larger trailing diameters frequently exceeded this threshold, especially when inserted dorsally, underscoring their higher risk of cortical breach. These observations corroborate the work of Grawe et al who demonstrated that reduced pTAD correlates with greater stability and lower risk of screw migration.[30] In contrast, headless compression screws such as Herbert™ and KLS systems consistently achieved subchondral placement within the safe range, making them particularly suitable for smaller scaphoids.

Despite these findings, the study has limitations. Anthropometric variables such as patient height or body size, known to correlate with carpal bone morphology, were not factored into analysis.[31] Furthermore, the reliance on digitally reconstructed axis alignment may not fully replicate intraoperative conditions in the absence of navigation tools.[32] Another limitation is the homogeneity of the study population, which consisted exclusively of Indian patients. While this provides valuable region-specific insights, it restricts the wider generalizability of the data, since racial variation in carpal bone morphology has been documented in several studies.[33,34]

The results of this study highlight the complex interplay between patient anatomy, implant geometry, and surgical technique. Careful preoperative planning, aided by CT-based measurements, and judicious intraoperative decision-making are critical to optimizing scaphoid fixation and minimizing complications.

Limitations

The height of the subjects was not considered, which could have a influence on the scaphoid morphology. The central axis was determined by the computer software. Placement along this axis can be technically demanding.

CONCLUSION

This study underscores the multifactorial nature of screw placement in scaphoid fracture fixation. Sex-related differences in bone morphology, the dimensions and design of implants, and the choice of surgical approach all directly influence the maximum safe screw length and the precision of subchondral seating. While smaller-diameter screws with fine length increments facilitate safe placement in smaller scaphoids, they may be biomechanically inferior to larger implants, necessitating careful tailoring of screw choice to fracture configuration. Volar access generally provides longer and more centrally aligned trajectories, though dorsal access remains indispensable for proximal pole fractures. Preoperative CT planning and meticulous intraoperative imaging remain indispensable in achieving optimal trajectories, respecting the 2-mm tip-articular margin, and reducing the risk of hardware complications. Ultimately, individualized planning based on patient anatomy and fracture type is essential for improving fixation outcomes in scaphoid surgery.

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