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Anatomical Anterior and Posterior Reconstruction (ANAFAB) for Scapho-Lunate Dissociation – Preliminary Outcome in 10 patients.

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This study reviews the efficacy of a reconstruction to address scapholunate dissociation using an anterior and posterior approach with a hybrid synthetic tape/tendon weave between the trapezium, scaphoid, lunate and radius: an anatomical front and back (ANAFAB) repair. Patients were immobilised in a cast for six weeks, but no stabilising wires were used. Ten patients have undergone the reconstruction and were assessed to a minimum 24 month follow-up, and achieved excellent realignment of the carpus, correction of the S-L gap to (median) 3 mm, and a recovery of more than 75% grip strength and range of motion. No patient required secondary surgery or treatment related to the carpal stabilisation. This repair is a compilation of the components of a number of previously reported repair techniques, and based on published kinematic evidence aims to restore the anatomical mechanical constraints on both anterior and posterior aspects of the carpus. The ANAFAB procedure has achieved a consistent recovery of carpal stability and grip strength without significant loss of motion.

Level of Evidence: Level IV—Retrospective Case Series

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The restoration of wrist function following injury has been an enduring challenge and reliable reconstructive solutions have been elusive (Garcia-Elias, 2013; Sammer and Shin, 2012). A contributor to this challenge is that carpal research has been largely empirical (Garcia-Elias, 2013) and not based on forward kinematics to define a theory that embraces the variability of wrist biomechanics (Sandow et al., 2014).

The process of finding suitable surgical repairs to address carpal instability has involved extensive trials on potential solutions (Garcia-Elias, 2013), and is generally based on the opportunistic utilisation of locally available tendons or synthetic materials to replace observed, and thus presumed critical, ligament deficits. This is guided by the interpretation of empirically derived biomechanical data, which is problematic given the relationship variations and complex interactions between the various wrist structures in different individuals (Abe et al., 2018; Kamal et al., 2016; Moritomo et al., 2006).

In the case of scapholunate diastasis, this has generally created a narrow focus on maintaining coaptation of the scaphoid and lunate, without appreciating the more complex relationship of this particular motion segment with the wider biomechanics that maintain carpal stability (Sandow et al., 2014).

A more logical approach is to define an overarching theory of carpal mechanics and utilise that concept to apply theory and logic-based solutions to the variety of carpal dysfunctions that may present.

The Stable Central Column Theory (SCCT) of carpal mechanics (Sandow et al., 2014) provides a theoretical basis on which observed wrist dysfunction can be explained and logic-based solutions defined and applied. Although disputed by some authors (Rainbow et al., 2015; Tan et al., 2018; Xu and Tang, 2009), the existence of isometricity between multiple paired regions in the carpus is central to the rules-based motion concept of carpal mechanics (Papas and Sandow, 2001; Sandow et al., 2014).

While often a spectrum of injury, in the typical case of scapholunate dissociation there are variable degrees of diastasis between the scaphoid and lunate, flexion, pronation and proximal posterior subluxation of the scaphoid, and extension and possibly ulnar translation of the lunate (Omori et al., 2013). By applying the SCCT, the absence of certain specific ligamentous constraints could reasonably explain such biomechanical failure. These ligaments are the posterior scapholunate interosseous, scaphotrapezial and long radiolunate ligaments. On this premise, a reconstructive solution should focus on correcting such deficits and seek the optimal means to do so, rather than adopting the usual approach of adapting locally convenient tissues (Papas and Sandow, 2001).

Thus, the current reconstruction was developed to address the specific defined mechanical deficits and restore the precise geometric pattern of isometric restraint, as defined by the SCCT. Components of previously reported individual reconstructive procedures, including Almquist et al. (1991), Brunelli and Brunelli (1995), Garcia-Elias et al. (2006) and Henry (2013), have been adapted and combined to create an anatomically based restorative solution that addresses both the posterior and anterior structures: an anatomical front and back (ANAFAB) repair.

Based on the SCCT of carpal mechanics (Sandow et al., 2014), the current study reviews the preliminary outcomes of a reconstruction comprising an anterior and posterior approach with a hybrid synthetic tape/tendon weave, in a consecutive group of patients with scapholunate dissociation. It was hypothesised that the application of a theory and kinematic -based solution would achieve a more predictable outcome in terms of restoring carpal stability without excessive loss of motion.

MATERIALS AND METHODS

Surgical technique

This repair technique was a composite of various components of previously reported repairs and reconstructions and utilised a hybrid of a synthetic tape (Labral Tape, Arthrex, Naples USA) and tendon strip, without temporary k-wire stabilisation. The reconstruction was performed through an anterior and posterior approach. Through the anterior incision, a double strand of synthetic tape (Labral Tape, Arthrex, Naples, USA) was attached to the antero-lateral facet of the trapezium using a 3.5 mm bone anchor (Swivel-Lock, Arthrex, Naples Fl. USA). This tape, supplemented with an approximately 3 mm diameter distally based strip of flexor carpi radialis (FCR) tendon, was passed from the anterior trapezium to the scaphoid tuberosity, transosseously to the scaphoid dorsum, transosseously from posterior to anterior through the lunate and then anteriorly to the radial styloid. Tension was applied to the tape and tendon construct to reduce the intercarpal joints, and then secured with an interference screw inserted from the posterior radius (see Figure 1).

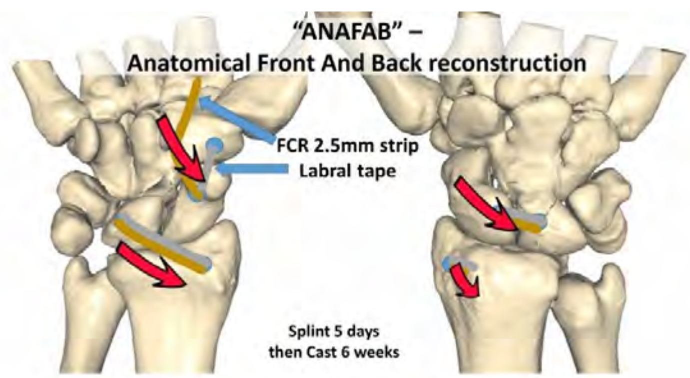

Figure 1: Anatomical anterior and posterior reconstruction (ANAFAB).

All transosseous drill holes were 3 mm in diameter. Posterior neurectomy was not specifically performed, but may have occurred in some patients as part of the posterior capsular mobilisation. Patients were immobilised in a cast for six weeks, but no stabilising wires were used. Technique details are available in the supplementary documents and at

www.woc.com.au/ANAFAB .

Patients were then mobilised in a supportive, but removable, soft brace for a further six weeks. Moderate loading was avoided for three months and heavy loading delayed until six months after the procedure.

Research methodology

Following ethics approval (Royal Adelaide Hospital HREC approval R20171203), a retrospective review of prospectively gathered clinical outcome data was assessed in a consecutive series of patients with scapholunate dissociation who were treated with the ANAFAB procedure.

All patients attended a review clinic at a minimum follow-up of 24 months to obtain outcome information, which was then combined with their prospectively gathered data.

Inclusion criteria were patients over the age of 18 who were well informed and prepared to undergo the new composite repair. They all had a positive scaphoid shift sign (Lane 1993, Tomas 2018) and subjective loss of function due to pain and/or weakness. All patients had a scapholunate diastasis of 3 mm or greater (median 3 mm, range 3 mm–6 mm), assessed as the minimum separation between scaphoid and lunate in a neutral wrist position measured on plain anterior-posterior radiographs. On quantitative CT 3D analysis, the separation of the attachments of the posterior scapho-lunate were generally greater than that reflected on the plain radiograph due to the associated posterior subluxation and pronation of the scaphoid (Figure 2 and supplementary material). All patient also had an abnormal scapholunate angle (>60^0) when measured between the long axis of the scaphoid and lunate on the sagittal image of the wrist. All patients were well informed of the current reconstructive options and prepared to undergo a non-standard procedure. Patients were advised that the actual procedure was a compilation of components of previous reconstructive techniques, but adapted to address the mechanical deficit identified in their wrist.

Two patients with early degenerative changes in the radioscaphoid joint were included, but any patient with significant mid-carpal degeneration was not considered for the procedure.

All patients also underwent 3D quantitative spatial analysis (True Life Anatomy, Adelaide, Australia) of their wrist, with many undergoing two position analysis to quantify the presence or absence of isometry between various carpal bones, as previously described by Sandow et al. (2014) to define the specific ligamentous disruption.

Using the same imaging technology, most patients underwent computer based virtual reduction and analysis to assist with localising the ligamentous attachment points, which guided the location of drill holes and attachments for the subsequent repair (Figure 2 and supplementary material).

Outcomes were assessed preoperatively and at regular postoperative times in line with appropriate clinical management, with formal documentation of motion and strength, as well as subjective pain and loss of function at 3, 6, 12 and 24 months postoperatively. Subjective functional loss, range of motion, grip strength and the presence of a positive scaphoid shift sign (Lane 1993, Tomas 2018) was recorded preoperatively, but an objective pain score, or wrist PRO (Patient Reported Outcome) score was not preoperatively documented

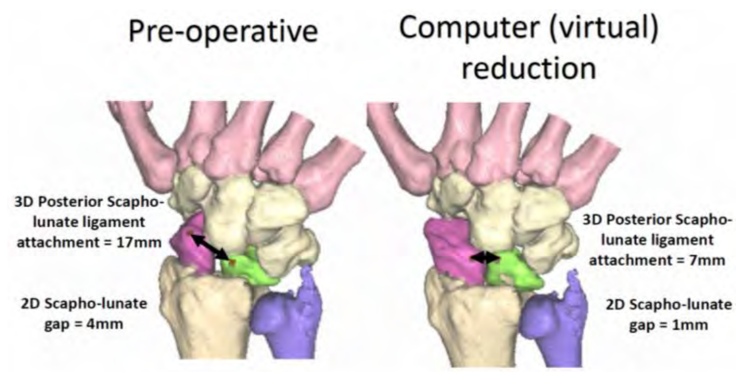

Figure 2: Quantitative CT 3D analysis of the injured and computer (virtual) reduced scapho-lunate dissociation. This demonstrates that the separation of the attachments of the posterior scapho-lunate were generally greater than that reflected on the plain radiograph due to the associated posterior subluxation and pronation of the scaphoid. In this example the distance between the posterior scapho-lunate ligament attachments is 17mm, with a "radiological" scapho-lunate separation of 4mm. Following manual virtual reduction of the carpus, the posterior scapho-lunate ligament attachments reduce to 7mm, with a "radiological" scapho-lunate separation of 1mm. The pathological separation of the attachments of the posterior scapho-lunate ligament are therefore 10mm, not 3mm as would be suggested by the 2D views. (Video reduction – supplementary material).

Strength was assessed using a Jamar dynamometer (JLW Instruments, Chicago, Il, USA) in the second grip setting with the elbow flexed at 90 degrees, and compared to the opposite uninjured wrist. The values were not adjusted for dominance. Wrist motion was assessed with a manual goniometer to the nearest 5 degrees and recorded for preoperative and postoperative comparison.

None had undergone previous surgery, apart from diagnostic arthroscopy in three patients.

Statistical analysis was considered, but not considered valuable due to the limited number of patients and modest changes from preoperative to postoperative subjective and objective outcome measures.

RESULTS

Ten patients (eight males, two females) have undergone the reconstruction and were assessed prospectively, including scapholunate (S-L) gap, pain, grip strength and carpal alignment. The median age was 28 years (range 23 years–58 years).

At a minimum 24-month (range 28 month—36 months) follow-up, the patients who underwent ANAFAB repair achieved excellent realignment of the carpus (Figure 3 and 4), with correction of the S-L gap to (median) 3 mm (Table1).

While preoperative pain was not formally quantified in all patients, it was noted to be quite variable and often only present under heavy load. At final review, the median pain score was 1 out of 10 (range 0–5) on the visual analogue scale, and all patients had a negative scaphoid shift test.

Figure 3: Pre and postoperative radiographs showing carpal realignment.

Due to variation in the wrist position on sagittal imaging, scapholunate angle was determined the best measure of carpal realignment, and in all patients was close to or within the normal range (30^0–60^0). There was a recovery of more than 75% grip strength and range of motion (see Table 1), with patients noting improvements in motion and strength between the one and two year review period.

In most patients, the recovery of extension was nearly normal, but there was a modest (median 10^0) loss of flexion.

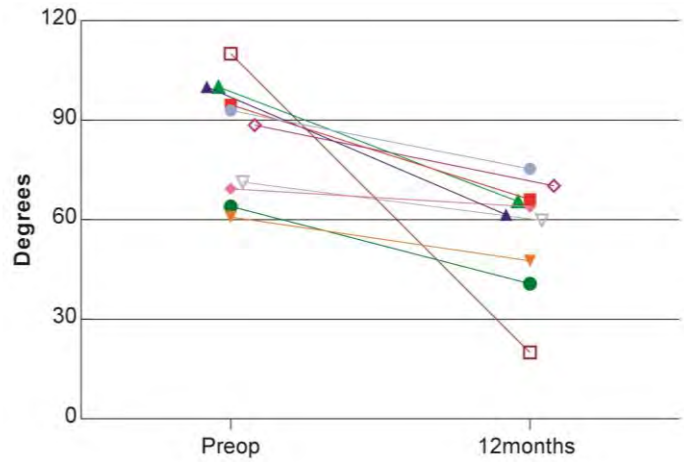

Figure 4: Scapholunate angle on lateral plain radiograph.

Functional outcome

Although not part of the original review protocol, patients were asked about their ability to perform their normal sporting activities; specifically, their ability to perform push-ups. This was generally assessed at six months. Early in the series, patients who had already performed push-ups were asked to do so. Subsequently, as this activity appeared to create no difficulty, all patients were able to perform at least three push-ups, although one males and two female patients performed modified wall or kneeling push-ups. All patients advised they had been able to perform push-ups prior to their wrist injury.

Complications

There were no wound issues or changes in the lunate suggestive of avascular necrosis. As k-wires were not used, the often noted pin irritation and need for secondary surgery for wire removal was avoided. There was no loss of correction of the scapholunate coaptation or alignment in any of the patients; however, one patient developed an excessively flexed lunate while in the postoperative cast, with a secondary posterior distal radioulnar joint subluxation. When this was investigated by 3D CT quantitative analysis, the anterior portion of the lunate, which has a more prominent profile than the central or posterior regions, appeared to have caused a secondary ulnar carpal impaction pushing the distal ulna head in a posteriorly displaced position relative to the radius, resulting in a secondary distal radioulnar subluxation.

This was addressed by ulna shortening at the ulna mid-shaft, which resulted in an immediate reduction of the distal radioulnar joint. The patient achieved a stable carpus with a correction of the scapholunate dissociation, but only a fair outcome overall.

Parameter	Preop	3months	6months	12months	24 months
Scapholunate gap in mm, median [range]	3 [3-6]	3 [2-4]	2.5 [1.4-3.5]	2.75 [2-4]	3 [2-4]
Grip strength - % of other wrist , median [range]	66.5 [25-100]	77.5 [40-100]	84 [40-100]	89 [68-100]	94 [20-100]
Flexion in degrees, median [range]	60 [20-80]	30 [30-40]	40 [30-60]	50 [30-70]	50 [40-80]
Extension in degrees, median [range]	60 [30-90]	40 [30-60]	50 [30-60]	60 [30-70]	60 [40-75]

Table 1: Scapholunate gap (2D measurement in mm), Grip strength (percentage of opposite uninjured wrist), Flexion range (degrees) and Extension range (degrees). Scapholunate gaps were generally larger on 3D assessment, but only the 2D measurements are included in the graph to allow follow-up comparison, as 3D analysis (from CT scan) was not generally performed postoperatively. Variations with apparent decrease in gapping after 3 months may relate to variable plain radiological positioning.

DISCUSSION

This paper presents the preliminary results of the ANAFAB procedure, based on the SCCT, which appears to restore carpal stability and grip strength without significant loss of motion. Based on published kinematic theory, the reconstruction aimed to restore the anatomical mechanical constraints on both anterior and posterior aspects of the carpus. An important part of this study was the ability to quantify in 3D the specific multi-planar displacement of the scaphoid, and apply a quantitative analysis to identify the missing ligaments with reference to their expected isometry (Sandow et al. 2014).

There are many alternate reconstructive procedures suggested to address scapholunate dissociation. While the SCCT has not been widely adopted as an accepted explanation of carpal mechanics, this concept was the basis of the ANAFAB reconstruction and the impetus to create a repair construct by combining selected components of existing repairs. An important reason for the SCCT not being widely accepted as true and valid is that it fails to reconcile with the established works of others (Kamal et al., 2016; Rainbow et al., 2015). Given the accepted position that a reliable repair option for scapholunate instability has been elusive (Garcia-Elias, 2013; Sammer and Shin, 2012), an alternative approach such as the one embodied in the SCCT, may have credibility as a potential new solution (Rainbow et al., 2016).

The theoretical basis of the ANAFAB repair challenges a number of currently used reconstructive procedures; however, at the very least, this study demonstrated the non-inferiority of the ANAFAB technique compared to alternative approaches.

The FCR tendon is an important motor to animate the distal carpal row, which normally pivots around an isometric constraint on the anterolateral margin of the trapezium and scaphoid (Moritomo et al., 2006; Sandow et al., 2014). To utilise this motor unit as a restraint replacement is non-anatomical and, based on the SCCT of carpal mechanics, a flawed concept and not likely to restore normal biomechanics. Further, the angle subtended by the FCR as it enters the drill hole in the scaphoid tuberosity adds a pronation moment, which may theoretically increase the abnormal motion and loading on the scaphoid.

Further, repairs that rely on various tendon weaves may not be ideal due the viscoelastic and healing capabilities, plus the frequent inability to functionally or to anatomically match the injured ligaments by the free or transferred tendon, given the revascularisation and maturation time course of the tendon (Hefti and Stoll, 1995). In the ANAFAB repair, the synthetic tape proved a durable stabilising structure while soft tissue healing and maturation occurred. The FCR tendon weave in the ANAFAB procedure takes relatively little initial load; however, it provides a source of collagen to facilitate the progressive transition from synthetic tape to reformed ligament as healing progresses. As the synthetic tape is non-biodegradable it may create longer term effects, but none were evident at the minimum two year follow-up.

Given the normal differential rotation between the scaphoid and lunate (Kamal et al., 2016; Rajan and Day, 2015; Sandow et al., 2014), reconstructions that attempt to restrain both the posterior and anterior region by applying a rigid central axis restraint (Lee et al., 2014; Rosenwasser et al., 1997; Ross et al., 2013), anterior and posterior scapholunate soft tissue connection (Corella et al., 2017; Ho et al., 2015; Kakar et al., 2017; Kakar and Greene, 2018), or by fusion (Hurkmans et al., 1996), may not be able to restore optimum, reliable or even predictable wrist biomechanics.

The development of this approach was the culmination of work to define the intercarpal isometric connection using computationally derived linkages (Papas and Sandow, 2001; Sandow et al., 2014). This study showed that wrist is composed of a complex array of variable biomechanical linkages. In an effort to reconcile this complexity, the connection between the proximal and distal rows has been described as a two-gear, four-bar linkage (Sandow et al., 2014).

These findings were expanded into a theory to explain carpal stability and define critical linkages (Sandow et al., 2014). By then using quantitative 3D motion analysis (True Life Anatomy, Adelaide, Australia) in the injured patients, the pattern of biomechanical defects could be characterised and reverse engineered to propose a reconstructive solution to address the identified deficits.

The stable central column of the carpus presented in that work requires the motion of the lunate to be controlled and resist its natural tendency to rotate into extension (Rainbow et al., 2015). As the lunate does not have any direct tendon connections, this stability can be achieved by an anterior tether pulling proximally and, in particular, the long radiolunate ligament (Sandow et al., 2014), acting with a presumed posterior tether pulling distally. Work by Mathoulin (Mathoulin, 2017; Wahegaonkar and Mathoulin, 2013) has been pivotal in defining the connection of the lunate to the posterior intercarpal ligament (DIC) (Viegas, 2001), which functions as the logical posterior distal tether for that bone. The presence of a posterior tether to the DIC is quite compatible with the concept of the SCCT. Surgical reattachment of the lunate to the DIC has been shown to be very effective in addressing wrist instability at the predynamic stage (Mathoulin 2017; Wahegaonkar and Mathoulin, 2013). However, patients with static scapholunate diastasis were not addressed solely by the 'Mathoulin' approach and required additional stabilisation procedures (Mathoulin, 2017). All patients in the current study had static scapholunate diastasis and instability; thus, they were part of a different group to that managed solely by the reconstruction described by Mathoulin (2017).

The ANAFAB procedure appears to have the ability to reverse the scapholunate diastasis and proximal scaphoid subluxation, but still retain functional motion. Significant load on the carpus and radius is generated during a push-up (Scordino et al., 2016; Smith et al., 2018). The ANAFAB reconstruction being able restore patients' ability to perform push-ups provides compelling evidence of its ability to restore longitudinal stability of carpus without a significant loss of motion, indicating the successful restoration of functional carpal biomechanics.

A limitation of this study is that it is an observational retrospective review without a comparator. Although patients will generally present with pain when seeking treatment, this was not formally quantified in all cases at the preoperative stage.

Further, as it was deemed that as the ANAFAB construct was a composite of various components of a number of other reconstructions, formal biomechanical analysis was not undertaken prior to performing the repair.

The ANAFAB technique is a compilation of components of various previously described reconstructive procedures, and is based on the SCCT of carpal mechanics. In this feasibility study, it appears to have achieved a clinical outcome that is no worse than, and may be an improvement on, outcomes achieved by previous reconstructions. The ability to perform push-ups is not typically reported in other series. Further clinical experience—specifically, comparisons with alternate repair options—is required to assess if this approach will provide a better long-term solution than what is currently on offer to patients; however, the short-term results to two years have been very satisfactory.

Conflict of interest **-** Associate Professor Sandow has a commercial interest in the 3d imaging software used to quantify the ligamentous disruption and plan the repair technique.

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