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Anatomical anterior and posterior reconstruction for scapholunate dissociation: preliminary outcome in ten patients

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Abstract

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. This repair is a compilation of the components of a number of previously reported repair techniques, and based on published kinematic evidence. It aims to restore the anatomical mechanical constraints on both anterior and posterior aspects of the carpus. Patients were immobilized in a cast for 6 weeks, but no stabilizing wires were used. Ten patients have undergone the reconstruction and were assessed at a minimum 24-month follow-up. They achieved excellent realignment of the carpus, a postoperative median scapholunate gap of 3 mm and a recovery of more than 75% of grip strength and range of motion. No patient required secondary surgery or treatment related to the carpal stabilization.

Level of evidence: IV

Keywords

ANAFAB, scapho-lunate dissociation, carpal instability

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Introduction

The restoration of wrist function after 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 the development of a conceptual theory using forward kinematics to reconcile 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). They are generally based on the use of locally available tendons or synthetic materials to replace observed ligamentous deficits, which have been presumed to be important. This approach is guided by the interpretation of empirically derived biomechanical data, which is problematic given the variations in relationships and the 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 the coaptation of the scaphoid and lunate, without appreciating the more complex relationship of this particular motion segment with the other critical biomechanical factors that maintain carpal stability (Sandow et al., 2014). A more logical approach would be to define a general theory of carpal mechanics and use that concept to apply solutions to the variety of carpal dysfunctions that may occur that are based on theory and logic.

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The stable central column theory (SCCT) of carpal mechanics (Sandow et al., 2014) provides a basis on which observed wrist dysfunction can be explained and logic-based solutions defined and applied. Although disputed by some (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).

Although often part of 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 these deficits and seek the optimal means to do so, rather than adopting the usual approach of adapting locally convenient tissues (Papas and Sandow, 2001).

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 those of 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. The current study reviews the preliminary outcomes of this reconstruction with a hybrid synthetic tape/tendon weave in a consecutive group of patients with scapholunate dissociation. It was hypothesized it would achieve a more predictable outcome in terms of restoring carpal stability without excessive loss of motion.

Methods

Surgical technique

This repair technique used a hybrid of a synthetic tape (Labral Tape, Arthrex, FL, USA) and tendon strip, without temporary Kirschner (K)-wire stabilization. The reconstruction was done through anterior and posterior approaches. Through the anterior incision, a double strand of the synthetic tape was attached to the anterolateral facet of the trapezium using a 3.5 mm bone anchor (Swivel-Lock, Arthrex, FL, USA). This tape, supplemented with an approximately 3 mm diameter distally based strip of flexor carpi radialis (FCR) tendon, was passed from the trapezium to the scaphoid tuberosity, transosseously to the dorsum of the scaphoid, 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 it was then secured with an interference screw inserted from the posterior radius (Figure 1).

All transosseous drill holes were 3 mm in diameter. Posterior neurectomy was not specifically done, but may have occurred in some patients as part of the posterior capsular mobilization. The wrists were immobilized in a cast for 6 weeks and then mobilized in a supportive, but removable, soft brace for a further 6 weeks. Moderate loading was avoided for 3 months and heavy loading delayed until 6 months after the procedure.

Details of the technique details are available in the supplementary online documents (video and appendix).

Research methodology

After ethics approval (Royal Adelaide Hospital HREC approval R20171203), a retrospective review of prospectively gathered clinical outcome data was assessed in a consecutive series of ten patients (eight men and two women) with scapholunate dissociation who were treated with the ANAFAB procedure. The median age was 28 years (range 23–58).

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 of the current reconstructive

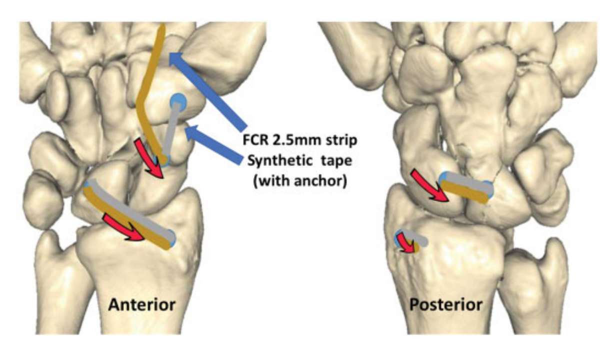

Figure 1. Anatomical anterior and posterior reconstruction (ANAFAB).

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. 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 3–6), assessed as the minimum separation between scaphoid and lunate in a neutral wrist position measured on plain posteroanterior radiographs. On quantitative analysis of three dimensional computed tomographic (3-D CT) images, the displacement of the attachments of the posterior scapholunate ligament were generally greater than that reflected on the plain radiograph owing to the associated posterior subluxation and pronation of the scaphoid (Figure 2 and supplementary material: video and appendix). All patients also had an abnormal scapholunate angle (>60°) when measured between the long axis of the scaphoid and lunate on the lateral image of the wrist. None had undergone previous surgery, apart from diagnostic arthroscopy in three patients. 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 3-D quantitative spatial analysis of the wrist using specialized software (True Life Anatomy, Adelaide, Australia), with many undergoing two-position analysis to quantify the presence or absence of isometry between various carpal bones to define the specific ligamentous disruption, as previously described by Sandow et al. (2014). Using the same imaging technology, most patients underwent computer-based virtual reduction and analysis to assist with localizing the attachment points of ligaments, which guided the location of drill holes and attachments for the subsequent repair (Figure 2 and supplementary material: video and appendix).

Patients were assessed pre- and postoperatively, with formal documentation of motion and strength, as well as subjective pain and loss of function at 3, 6, 12 and 24 months after operation. Subjective functional loss, range of motion, grip strength and the presence of a positive scaphoid shift sign were recorded preoperatively, but no objective pain score or patient-reported outcome measure was used. Strength was assessed using a Jamar dynamometer (JLW Instruments, Chicago, IL, USA) in the second

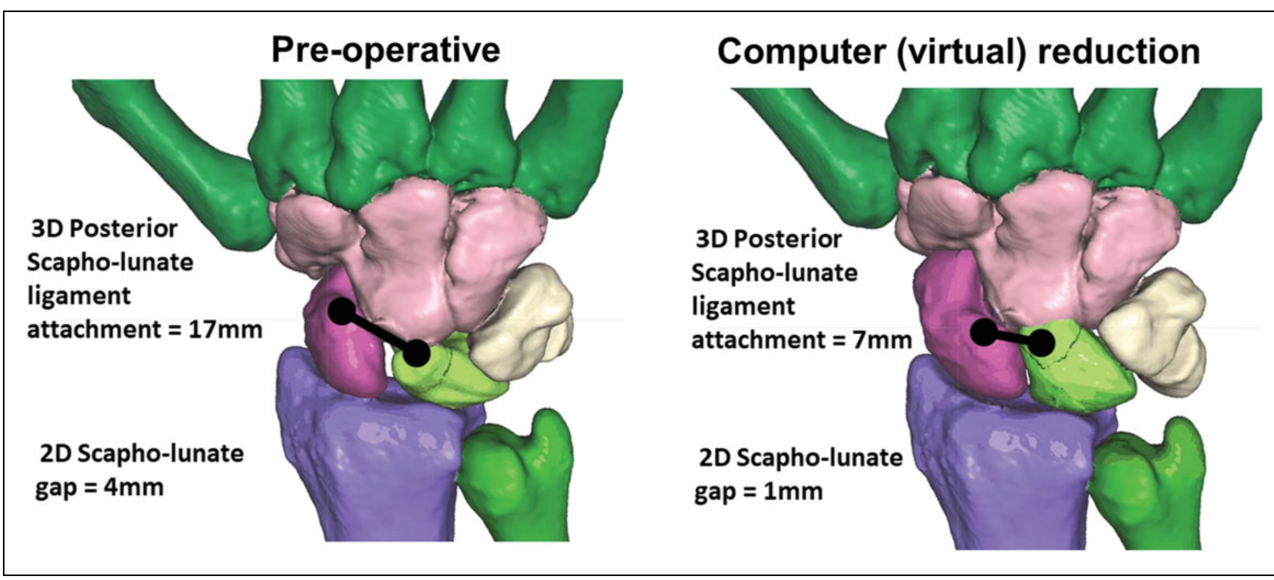

Figure 2. Quantitative three-dimensional computed tomographic (3-D CT) image analysis of the injured and computer (virtual) reduced scapholunate dissociation. This demonstrates that the separation of the attachments of the posterior scapholunate ligament are generally greater than reflected on the plain radiograph owing to the associated posterior subluxation and pronation of the scaphoid. In this example, the distance between the posterior scapholunate ligament attachments is 17 mm, with a 'radiological' scapholunate separation of 4 mm. After manual virtual reduction of the carpus, the distance between the posterior scapholunate ligament attachments is reduced to 7 mm, with a 'radiological' scapholunate separation of 1 mm. The pathological separation of the attachments of the posterior scapholunate ligament is therefore 10 mm, not 3 mm as would be suggested by the two-dimensional views. (Video reduction; supplementary material, available online).

grip setting with the elbow flexed at 90°, and compared with the opposite uninjured wrist. The values were not adjusted for dominance. Wrist motion was assessed with a manual goniometer to the nearest 5° and recorded for preoperative and postoperative comparison.

Results

At a minimum 24-month (range 28–36) follow-up, the patients who underwent the ANAFAB repair achieved excellent realignment of the carpus (Figures 3 and 4), with a median postoperative scapholunate gap of 3 mm (range 2–4) (Table 1). Although 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.

Owing to variation in the wrist position on lateral imaging, the scapholunate angle was determined to be the best measure of carpal realignment, and in all patients was close to or within the normal range (30°–60°). There was a recovery of more than 75% grip strength and range of motion (Table 1), with patients noting improvements in motion and strength between the 1- and 2-year review period. In most patients, the recovery of extension was nearly normal, but there was a modest (median 10°) loss of flexion.

Although not part of the original review protocol, patients were asked about their ability to perform their normal sporting activities and specifically their ability to do push-ups. At 6 months after operation, all patients were able to perform at least three push-ups, although one man and two women did modified wall or kneeling push-ups. All patients advised they had been able to perform push-ups before their wrist injury.

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

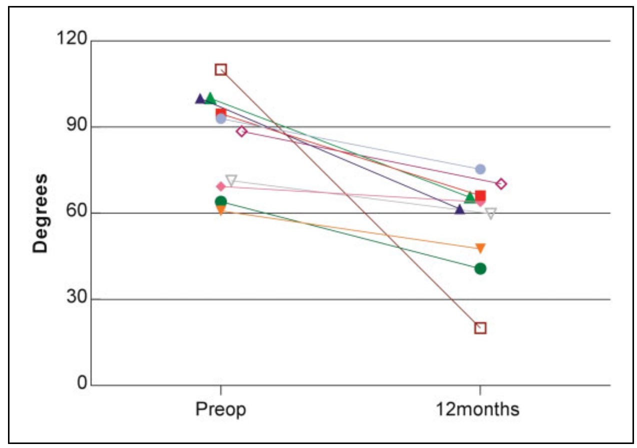

Figure 4. Scapholunate angles of the ten patients on lateral plain radiographs.

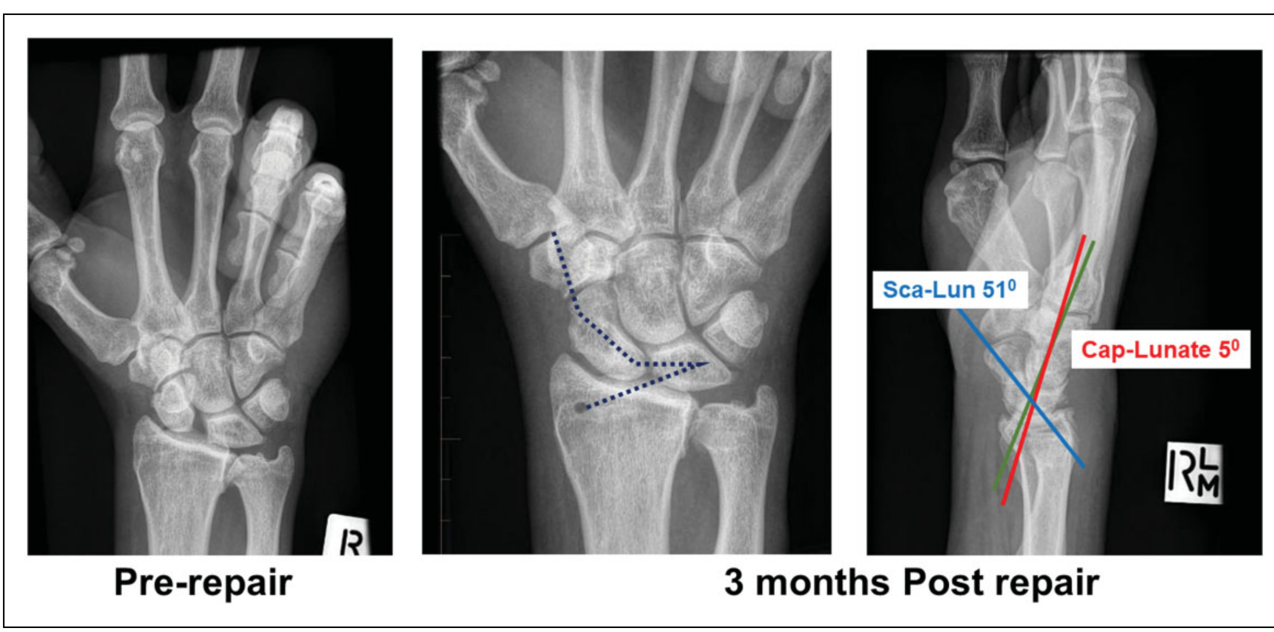

Figure 3. Pre- and postoperative radiographs showing carpal realignment.
Sca-Lun: scapholunate angle; Cap-Lunate: capitolunate angle.

Table 1. Scapholunate gap, grip strength and range of motion.

Parameter	Pre-op	3 months	6 months	12 months	24 months
Scapholunate gap in mm. Median [range]	3 [3–6]	3 [2–4]	2.5 [1.4–3.5]	2.8 [2–4]	3 [2–4]
Grip strength as % of other wrist. Median [range]	67 [25–100]	75 [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]

Scapholunate gaps were generally larger on three-dimensional (3-D) assessment, but only the two-dimensional radiographic measurements are shown to allow follow-up comparison, as 3-D analysis (from computed tomography) was not generally used postoperatively. Variations with apparent decrease in gapping after 3 months may relate to variable positioning on plain radiographs.

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 3-D 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 and resulting in a secondary distal radioulnar subluxation. This was addressed by shortening at the mid-shaft of the ulna, 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.

Discussion

The ANAFAB reconstruction, based on the SCCT, aims to restore the anatomical mechanical constraints on both anterior and posterior aspects of the carpus. The preliminary results indicate that it restores carpal stability and grip strength without significant loss of motion. An important part of this study was the ability to quantify in 3-D the pathological multi-planar displacement of the scaphoid, and define the extent of ligament disruption by identifying a loss of isometry between specific carpal bones (Sandow et al., 2014).

Many alternative reconstructive procedures have been suggested to address scapholunate dissociation. Although 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 is that it fails to accord with the works of others (Kamal et al., 2016; Rainbow et al., 2016). Given 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 based on the SCCT, may be a potential new solution. This study has shown that the ANAFAB appears to be at least as good as other procedures.

The FCR tendon is important in moving 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 use the tendon as a replacement restraint is non-anatomical and, based on the SCCT of carpal mechanics, a flawed concept that is 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.

Repairs that rely on free or transferred tendon weaves may be unable to functionally or anatomically match the original ligaments owing to their differing viscoelastic properties and the time-scale of their revascularization and maturation (Hefti and Stoll, 1995). In the ANAFAB repair, the synthetic tape proved a durable stabilizing 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 cause longer term problems, but none were evident at the minimum 2-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 and Greene, 2018; Kakar et al., 2017) or by fusion (Hurkmans et al., 1996), may not be able to restore optimum, reliable or predictable wrist biomechanics.

The development of the ANAFAB procedure was the culmination of work to define the intercarpal isometric connection using computationally derived linkages (Papas and Sandow, 2001; Sandow et al., 2014). This showed that the 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. By then using quantitative 3-D motion analysis in the injured patients with specialized software (True Life Anatomy, Adelaide, Australia), the pattern of biomechanical defects could be characterized and reverse-engineered to propose a reconstructive solution to address the identified deficits.

The stable central column of the carpus requires the motion of the lunate to be controlled and to 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 (2017) and Wahegaonkar and Mathoulin (2013) has been pivotal in defining the connection of the lunate to the dorsal intercarpal ligament (DIC) (Viegas, 2001), which functions as the posterior distal tether for that bone. This role of the DIC is quite compatible with the concept of the SCCT. Surgical reattachment of the DIC to the lunate has been shown to be very effective in addressing wrist instability at the predynamic stage (Mathoulin, 2017; Wahegaonkar and Mathoulin, 2013). However, the 'Mathoulin' approach did not fully address static scapholunate diastasis and additional stabilization procedures were required (Mathoulin, 2017). All patients in the current study had static scapholunate diastasis and instability; they were therefore in a different group from that managed by the reconstruction described by Mathoulin (2017).

A limitation of this study is that it was an observational retrospective review without a comparator. Although patients will generally present with activity-related pain when seeking treatment, this was not formally quantified in all cases at the preoperative stage. Further, as the ANAFAB construct was a composite of various components of a number of other reconstructions, formal ex-vivo biomechanical analysis of the specific reconstruction technique was not undertaken before using the repair.

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 ability of the ANAFAB reconstruction to allow patients to perform push-ups provides compelling evidence of its ability to restore longitudinal stability of the carpus without a significant loss of motion, indicating the successful restoration of functional carpal biomechanics.

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Declaration of conflicting interests The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Michael Sandow has a commercial interest in the 3-D imaging software used to quantify the ligamentous disruption and plan the repair technique. This author, their immediate family, and any research foundation with which they are affiliated did not, but may in the future receive a financial payments or other benefits from any commercial entity related to the subject of this article. Thomas Fisher, in the conduct of this study will receive, no direct or indirect personal benefits in the form of financial payments or other benefits where received from any commercial entity related to the subject of this article. There is no agreement of any kind that prevents the authors publishing both positive and negative results, nor any other restriction of any kind in relation to this research.

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Supplemental material Supplemental material for this article is available online.

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