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ORIGINAL STUDY

Three-Corner Arthrodesis (lunate – hamate – capitate) : clinical and kinematical evaluation

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In the absence of prosthetic arthroplasty offering good results for the treatment of wrist osteoarthritis, we studied the arthrodesis of three carpal bones (lunate – hamate – capitate) completed by triquetrum and scaphoid excision in the presence of Scapholunate Advanced Collapse (SLAC) or Scaphoid Nonunion Advanced Collapse (SNAC) stage II or III.

Clinical data on eight patients between the ages of 32 and 61 years at an average of 29 months after surgery was analyzed. Seven patients reached fusion with a carpal height ratio of 0.39.

These arc of dorsal-palmar flexion (DPF) attended 54° and the arc of radio-ulnar deviation (RUD) 29° using the optoelectronic stereophotogrammetry system.

The mean polar radius (R) was 14.5° and the envelope shape coefficient (K) was 1.66.

This operation could be considered as an alternative for the treatment of patients suffering of SNAC or SLAC stage II and III.

Type of study/level of evidence : Therapeutic IV

Keywords : Wrist ; instability ; arthritis ; intercarpal arthrodesis.

INTRODUCTION

There are several surgical options to treat Scapholunate Advanced Collapse (SLAC) and Scaphoid Nonunion Advanced Collapse (SNAC) (Watson et al.) *(1,2)*. One of the options, relieving pain and improving strength and motion is arthrodesis of the lunate – hamate – capitate completed by triquetrum and scaphoid excision. This operation has been first described by Delattre *(3)* under the name "Three Corner Arthrodesis" (TCA). It combines the advantages of Proximal Row Carpectomy (PRC) while maintaining the normal articular contact between the radius and the lunate and at least partially preserving the carpal height. As compared to the more classical Four Corner Arthrodesis (FCA), TCA achieves the same goals but is technically simpler, with the same rate of fusion.

The purpose of this study was to report the clinical results and wrist kinematics in a consecutive series of patients operated by a single senior surgeon.

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MATERIAL AND METHODS

Patients

Thirteen patients were operated of TCA by the same senior surgeon. All arthrodeses healed except one delayed union, and one nonunion, later treated by total arthrodesis. There were complications. One patient developed after the operation Complex Regional Pain Syndrome (CRPS) type I. This patient had been multi-operated before TCA. The patient who suffered a delayed union, because of a conflict between a screw head and the lunate fossa surface of the radius, needed a re-operation to extract the implants and treat the delayed union at the same time, four months after TCA. Among these thirteen patients, we excluded the case of CRPS, the case of delayed union and implant problem, and the case of late total fusion. One patient died and one refused to participate to the study. Eight patients (four women and four men) aged 32 to 61 years (mean, 51 years) provided a written informed consent to be evaluated 10 to 54 months (mean, 29 months) after the index operation. These eight patients, all manual workers, suffered all of post-traumatic degenerative osteoarthritis. The mean time elapsed between the initial trauma and the TCA was 98 months on average (10 to 300 months). The sample included seven right-handed and one left-handed patients, and all were affected on the dominant side. Three patients had had at least one previous operation. There were four SLAC III, three SNAC II and one SLAC II.

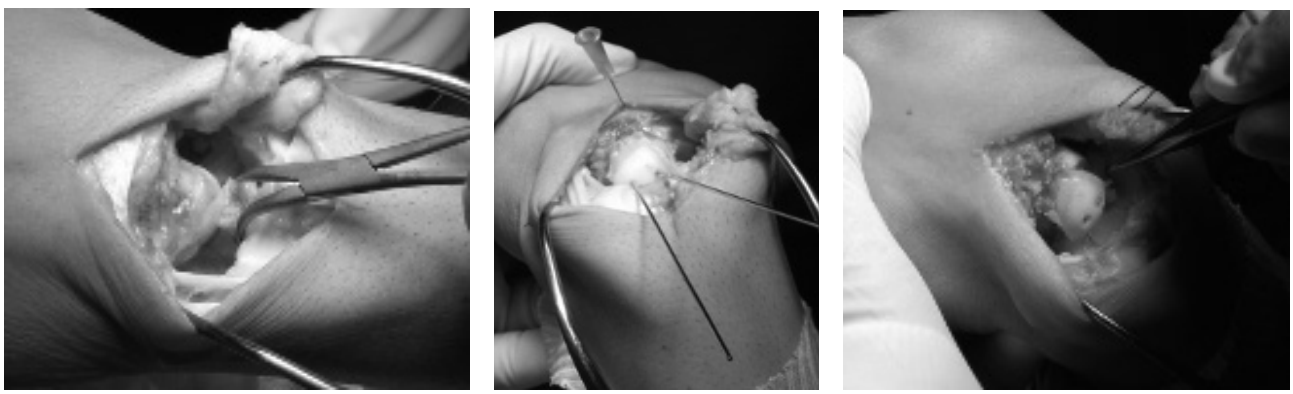
Surgical technique

The carpus was approached through a dorsal longitudinal incision. The posterior interosseous nerve was systematically resected. The capsular-ligamentous layer was opened according to Berger and Bishop *(4)*, permitting scaphoid and triquetrum resection. Using an oscillating saw, the proximal parts of the capitate and of the hamate were excised. The Dorsal Intercalated Segment Instability (DISI) (Chantelot *(5)*, Fontes *(6)*) was then corrected and temporarily fixed by two axial luno-radial K-wires. With the lunate checked in good position facing the lunate fossa, using a C-arm, another cut was done in the distal part of the bone, parallel to the cuts through the proximal capitate and hamate, allowing good apposition of the three bone surfaces.

Cancellous bone, harvested from the resected scaphoid and/or triquetrum, closed any persistent gap at the arthrodesis site, promoting subsequent bone healing. Bone fixation was achieved by two anterograde headless screws, lunate-hamate and lunate-capitate, taking great care to bury their proximal extremity deep under the surface of lunate cartilage. (Fig. 1a, 1b and 1c).

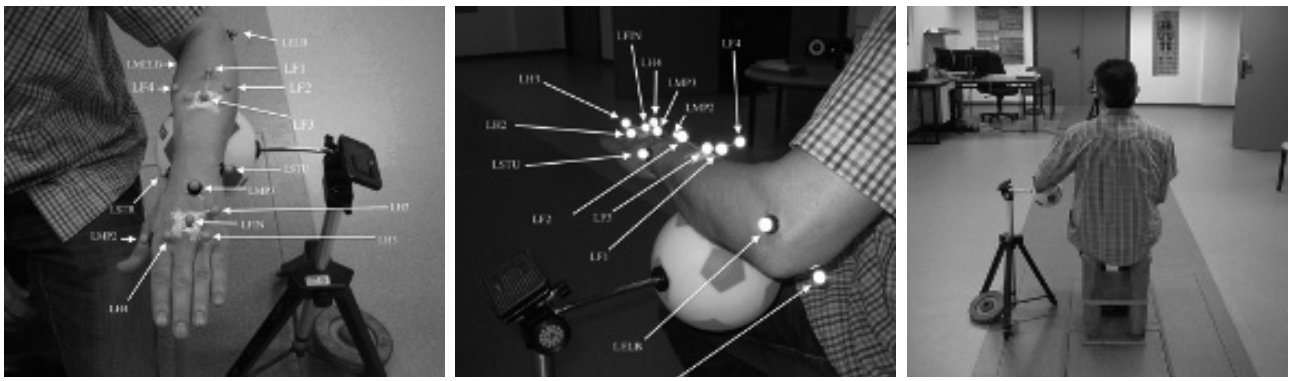
Clinical examination

The patients were evaluated using the questionnaires “Disabilities of the Arm, Shoulder and Hand (DASH)” (Jester et al.) *(7)* and “Patient Rated Wrist Evaluation” (PRWE) (MacDermid et al.)



a b c

Fig. 1. — a, b and c. The DISI is corrected and temporarily fixed by two axial luno-radial K-wires. Bone fixation was achieved by two anterograde headless screws, lunate-hamate and lunate-capitate.



a b c

Fig. 2. — a, b and c. Reflective markers are place on the skin surface (using double-sided tape) on the different anatomical landmarks of the forearm and the hand in order to build anatomical references needed for kinematic calculations. We systematically draw lots to set the order of limb to experiment. After the markers are placed, we perform a « warm-up » during which we explain beforehand the sequence of movements the patient will have to execute. The subject then is sitting with the forearm laid on a reposoir formed by a camera tripod and a soft ball adopting the reference position.

(8). Pain was evaluated on a visual analogic scale (VAS). The Mayo Wrist Score (Amadio et al.) *(9)* was also used to assess function and pain.

The evaluation of the joint amplitudes was performed using an angle rule goniometer. The quality of the thumb opposition was estimated using the Kapandji score *(10)*. Grip and pinch strengths were assessed using electronic dynamometers (E-Link Biometrics). The grip strength was assessed in two ways by a Jamar dynamometer (Precision Dynamometer G200) : static and Rapid Exchange Grip Test method (REGT) (Hildreth et al.) *(5)*. The pinch strength was evaluated in two ways by a Precision Pinchmeter P200 : "Key" and "Three Jaw" positions (Goodson et al.) *(12)*.

Radiographic evaluation

On posterior-anterior radiographs, including the third metacarpal, we measured the carpal height and calculated the carpal height ratio (ratio carpal height - length of third metacarpal).

Kinematics

The three-dimensional quantified analysis of global wrist and forearm mobility was performed using the optoelectronic Vicon T40s system (©Vicon Motion Systems Ltd. 2011).

To allow kinematic evaluation, the patient was equipped by reflective markers placed on forearm and wrist on both sides allowing reconstruction of their trajectories and building of anatomical reference frames to further kinematical computation expressed in terms of range of motion and the envelope of circumduction (Salvia et al.) *(13)*. (Fig. 2a, 2b and 2c).

Next, the patient repeated a series of dorsal-palmar flexion (DPF), radio-ulnar deviation (RUD) and circumduction (CIRC) of the wrist. Forearm pronation-supination was not constrained and recorded. Each motion was performed using both speed modalities : "as well as possible without pain" and "as fast as possible, without pain". The studied kinematical parameters were RoM of DPF and RUD of the operated wrist as compared to the other side. For what concerns wrist circumduction, the mean polar radius, maximal DPF and RUD range and the form factor K ($K = length^2/4\pi.surface$) allowed to measure the difference of form between the envelope and a circle ($K_{circle} = 1$) (Salvia et al.) *(14)* was computed.

The statistical analysis was performed with a P value of .05 or less considered significant. The descriptive statistical analysis consisted in a non-parametric comparison of mean test and the percentage of loss between the operated wrists versus opposite normal wrists.

Correlations were determined with the Pearson linear correlation coefficient (r). A statistical test (*t* test) was used to determine if these correlations were significant.

The study protocol was reviewed and approved by our institutional review board.

RESULTS

Questionnaires

The DASH mean results were for the subscale sport/instrument 57 (SD 46), for the work 53 (SD 27) and for the total DASH 46 (SD 28). The PRWE mean was 49 (SD 27). The mean pain at rest and during an effort was respectively 2.5 (SD 2.4) and 6.5 (SD 2.7). Two patients had no pain at all at rest, three presented occasional pain and the last three had a continuous but tolerable pain. The pain localization was variable but four patients complained during ulnar deviation. Five patients used compensation strategies like laying down the hand on a support or on height, to relieve pain. The MAYO Wrist Score mean was 63, which is considered a satisfying score. We observed also a significant increase of the MAYO Wrist Score, the more the number of months postoperatively increased ($r_s = 0{,}731 – p < 0{,}05$).

Mobility

Average RoM of DPF and RUD reached a mean of 45° (SD 21) and 28° (SD 10) for the operated hand. For the non-operated wrist the mean RoM of DPF and RUD was 107° (SD 22) and 61° (SD 5), The mean RoM of DPF was 45° (SD 21) and 28° (SD 10) of RUD, estimated with the hand goniometer. The Kapandji score *(10)*, which estimates thumb opposition, was 9.75/10 for the operated hand and 9/10 for the other. We also calculated the mean percentage of preserved mobility of 64%.

Strength

We obtained a mean grip strength of 16 kg (SD 9) and a mean REGT of 15 kg (SD 9). The mean grip strength of the opposite wrist was 28 kg (SD 9) and a mean REGT of 22 kg (SD 10). The tested patients displayed lesser apprehension during REGT because the execution speed necessary for the good achievement of this test seemed to disinhibit them. This should justify the gap between Grip and REGT 57% (Grip) and 68% (REGT) of remaining strength compared to the opposite wrist (Hildreth et al.) *(11)*.

The mean “Key” and «“Three Jaw” positions were 3.7 kg (SD 1.7) and 3.4 kg (SD 1.2). Average “Key”and “Three Jaw” positions were 5.9 kg (SD 1.5) and 5.3 kg (SD 1.7) for the non-operated wrist.

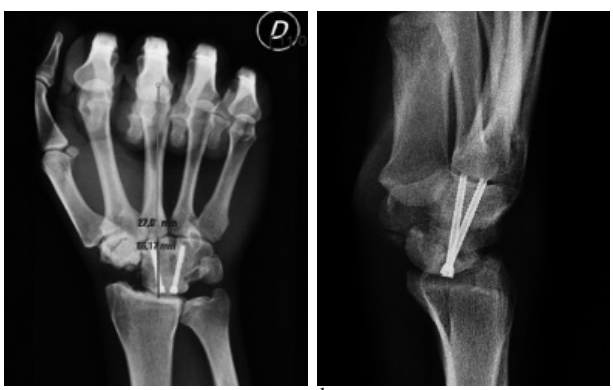
The grip strength reached a mean of 41% on the operated side and 77% on the opposite compared to normative standardized data (E-Link Biometrics Ltd) considering the age and the gender of the patient.

Radiographs

Seven of the eight patients examined reached fusion, after a mean delay of eighteen weeks (6 to 52 weeks – median 14 weeks). The mean carpal height was 25.8 mm (SD 5.1) for the operated side and 32.1 mm (SD 4.4) preoperatively, corresponding to a mean carpal height ratio of 0.39 and 0.50 before the operation. The DISI was radiographically corrected in all eight patients and no sign of radiolunate arthritis was found. (Fig. 3a and 3b).

Kinematic analysis

Average RUD and DPF were respectively of 29° (SD 6) and 54° (SD 14) for the operated wrist. The



a b

Fig. 3. — a and b.
Patient number four reached fusion after six weeks.

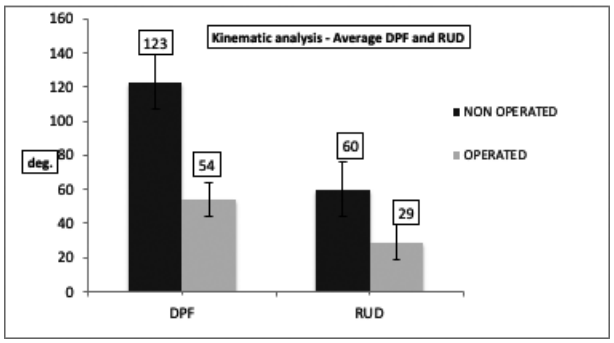


Fig. 4. — Average RUD and DPF for the operated wrist (grey) compared to the opposite wrist (black). DPF : Dorsal-Palmar Flexion ; RUD : Radial-Ulnar Deviation ; deg : degrees.

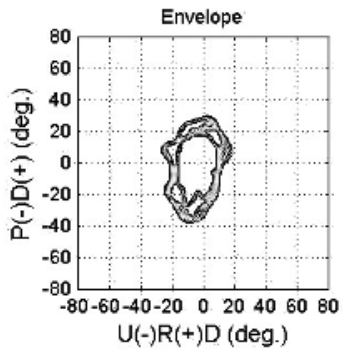


Fig. 5. — Envelope presentation of four circumductions of the operated wrist performed by patient nr. 2 with R = 20,6. P : palmar ; D : dorsal ; U : ulnar ; R : radial ; deg : degrees.

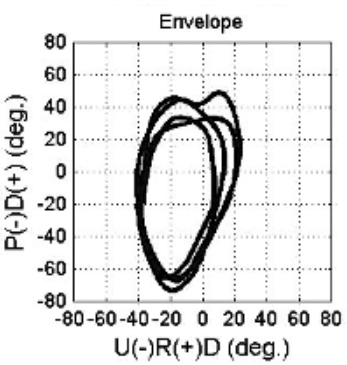


Fig. 6. — Envelope presentation of four circumductions of the non operated left wrist of patient nr.2 with R = 35,6. P : palmar ; D : dorsal ; U : ulnar ; R : radial ; deg : degrees. From the eight patients, the maximal range of motion (mean) of DPF was 93° (55°) and RUD was 45° (28°) for the operated wrist during circumduction.

mean percentage of DPF loss was 54% (SD 15) and 50% (SD 15) for the RUD. (Fig. 4).

The mean polar radius (R) reached a mean of 14.5° (SD 5.2) for the operated side and 34.2° (SD 7.6) for the non-operated side. For the operated wrist the mean K was 1.66 (SD 0.33) and 1.32 (SD 0.10) for the opposite wrist.

Maximal range of motion (mean) of DPF was 93° (55°) and RUD was 45° (28°) for the operated wrist during circumduction. For the opposite wrist, the highest range of motion for DPF was 144° (116°) and 69° (54°) for RUD. (Fig. 5 and 6).

DISCUSSION

The goal of the treatment of SLAC wrist is to relieve pain and to improve function, including joint motion amplitudes and hand strength. In the absence of a prosthetic arthroplasty that could achieve these goals and would be sufficiently durable in young, manual workers, other surgical options are usually offered to the affected patient. The most frequent operations are FCA and PRC. Another less known option is TCA. PRC is not complicated by nonunion but the joint contact is not physiological, between the head of the capitate and the radius lunate fossa, which may generate on the long-term osteoarthritis (Ashmead et al.) *(15)*. It is contra-indicated in case of capitate head cartilage degeneration, though resurfacing has been proposed (Fowler et al.) *(16)*. After PRC, the carpal height is markedly reduced which can affect the finger function. On the other hand, both FCA and TCA are supposed to offer better grip strength as they maintain the carpal height, at the price of a loss of mobility generated by the arthrodesis - Brumfield and Champoux *(17)* observed that it is indeed not essential to keep the whole range of wrist motion for the activities of daily life. Both intercarpal arthrodeses may be complicated by nonunion, less likely however after TCA. TCA is easier to perform than FCA because the shortening permits better alignment correction in the transversal and sagittal planes. A variant of TCA has been published by as Alnot *(18)* and Calandruccio *(19)* with resection of the scaphoid and triquetrum like TCA, but with a fusion only between lunate and capitate, without including the hamate to the arthrodesis. Delattre felt it important to incorporate the hamate, because it facilitates the

re-alignment of the carpus, and because the majority of wrists are type II according to Viegas *(20)*, that is with a hamate-lunate joint facet.

Few series of TCA have been published in the literature. Indeed, even Delattre *(21)*, initiator of the technique, reported on only thirty cases. Regarding pain, most patients experienced less pain after the operation, though none was painless. Regarding mobility, our study demonstrates that functional wrist motion amplitudes can be achieved after TCA (average 45° of DPF and 28° of RUD), similarly to the modification of Alnot *(18)* and Calandruccio *(19)* and to FCA. Delattre *(21)* however reported better amplitudes after TCA. We also found acceptable strength after TCA (average grip strength 57% as compared to normal side). Thus, despite carpal shortening, sufficient strength can be achieved. This rejoins the clear pain relief and strength improvement of 70% compared to the non-operated wrist according to Delattre *(3)*. These authors believed that the residual strength after TCA could improve with time, like after PRC. The patient motivation may also interfere in this recovery process. Indeed, our study revealed a favorable evolution of grip strength with time; the same was noted for the MAYO Wrist Score.

The kinematic part of our study allowed a better understanding of the arthrodesed wrist motion. The movement most affected by the intercarpal fusion was radial deviation (64% of RD loss). For the non-operated wrist, we obtained a mean of 123° of DPF (SD 22) and 60° of RUD (SD 10), what is comparable to Salvia's study by electrogoniometrics with six degrees of freedom (Salvia et al.) *(13)*. Obtaining a mean of mean polar radius (R) of 34.2° (SD 7.6) for the non-operated wrist, we found a value close to Salvia's study (35.9° (SD 4.5) (Salvia et al.) *(14)*. To evaluate the most natural movement we didn't constrained pro-supination. This underlines the sturdiness of the VICON approach. We did not measure the speed motion, and a future perspective could be to evaluate the speed loss after wrist partial fusion, possibly providing interesting knowledge concerning the ease of mobility.

Postoperative nonunion remains an important complication of all types of intercarpal wrist fusions. We report bone healing in seven out of eight of our cases. These results are comparable to those published after FCA (Vance et al. *(22)* ; Voche and Merle *(23)*) and capitate-lunate arthrodesis (Alnot et al. *(18)* ; Calandruccio et al. *(19)*). TCA induces a carpal height reduction, of 6.3 mm on average in our series, comparable to the data reported by Alnot *(18)* of 6.4 mm. According to Delattre *(3)*, when advanced levels of degenerative arthritis are reached and that the carpal collapse is important, it makes no sense to restore a normal carpal height, like Saffar and Fakhoury *(24)* advocated. It can also be deleterious, as going back to the "original" carpal height, after TCA, could result in joint amplitude reduction and increased contact stresses at the radiolunate joint. On the contrary, on demand carpal height reduction helps in correcting the DISI deformation.

In conclusion, TCA provides acceptable results, similar to FCA. It is technically easier. A question arises, is it worth keeping the triquetrum, usually not affected by the arthritis processes? Resection of the triquetrum could increase the loss of strength. We know however that the triquetrum resection doesn't influence carpal stability when a PRC is conducted (Calandruccio et al.) *(19)*. The cancellous bone from the triquetrum is used during TCA to promote bone healing at the site of the arthrodesis. According to Jorgensen *(25)*, triquetral resection, added to that of the scaphoid, doesn't disturb the global ligament balance of the wrist. The triquetrum resection could also improve RUD and DPF (Sood et al.) *(26)* and avoid later ulno-carpal impingement.

We recognize the limitations of this study. We have a limited number of patients not allowing statistical significant results. The use of load during the quantified analysis wasn't performed, allowing us to measure the functional losses more representative of the real-life conditions.

CONCLUSIONS

TCA is a good treatment option of SLAC/SNAC wrist, technically easier than FCA but providing similar results. Indeed, we found that TCA improves strength while providing pain relief. PRC is another option, relatively contra-indicated in young patients with demanding hand activities. PRC is also contra-indicated in SLAC/SNAC type

III, with chondral degeneration of the proximal pole of the capitatum. Therefore, the indication of TCA depends on the degree of advancement of articular degeneration and on the age and level of activity of the patient (Fassler et al. *(27)* ; Krakauer et al. *(28)*). Further research about carpal posttraumatic arthritis is necessary to advance our knowledge for better care of our patients.

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