Pyrocardan® interpositional arthroplasty for trapeziometacarpal osteoarthritis: a minimum four year follow-up

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Abstract

Background Pyrocardan® (Wright Medical-Tornier) is a pyrocarbon implant proposed in the treatment of trapeziometacarpal joint (TMCJ) osteoarthritis. Our aim was to assess the clinical and radiographic results after Pyrocardan® arthroplasty at midterm follow-up.

Methods In this prospective monocentric study, we enrolled 119 patients treated with Pyrocardan® for TMCJ osteoarthritis and followed up at a minimum of four years. The clinical outcome was assessed through the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire, the Visual Analog Score (VAS) for pain and the Kapandji score collected pre-operatively, at three, six and 12 months, then yearly. Hand radiographs were taken before surgery, at three months and every year. Complications and re-operations were also recorded.

Results The mean follow-up was 5.2 years (range, 4–9). DASH, VAS and Kapandji scores significantly improved at three (\(p < 0.001\) in all cases) and six months (\(p < 0.001\), \(p = 0.01\) and \(p < 0.001\), respectively), remaining stable over time. The dislocation and subluxation rates were 3.3% (4 cases) and 16.8% (20 patients), respectively. The two year, four year and seven year survivorship of the implant was 99%, 98% and 95%, respectively.

Conclusion Pyrocardan® arthroplasty provides a satisfactory clinical and radiographic outcome for treating TMCJ osteoarthritis, with a 97% survival rate at four years. We advocate comparative studies with more common techniques (i.e., trapeziectomy) to verify its cost-effectiveness.

Keywords Thumb · Arthritis · Pyrocarbon · Implant · Arthroplasty · Trapeziometacarpal joint

Introduction

Osteoarthritis of the trapeziometacarpal joint (TMCJ) may cause pain, weakness of the pinch, deformity and disability. When the conservative treatment fails, several surgical techniques have been proposed, but none has been proven superior to another [1–3]. Among them, trapeziectomy and its modifications are the most widely used, even if the proximal migration of the first metacarpal and the consequent loss of strength may represent an important drawback of the technique, particularly in young and highly demanding populations [1]. On the other side, joint replacement is an attractive option as a way to preserve the length of the first ray, resulting in a stronger pinch with a complete range of motion. Multiple implants have been described in literature, but to the best of our knowledge, no gold standard has been defined yet [4–6].

In 2011, Bellemère et al. introduced the Pyrocardan® (Wright Medical-Tornier) as a pyrocarbon implant which behaves as an intra-articular interposition [7] in the treatment of TMCJ osteoarthritis. While its biconcave surfaces would convert the saddle joint of the TMCJ into a cardan one, its structure in pyrocarbon would be theoretically advantageous given the elastic module similar to cortical bone [6, 8–10]. Encouraging results have been reported at over two years from surgery [11, 12], and only one study has documented a 96% survival rate at five years from surgery [13].
In this scenario, we set out to prospectively report the clinical and radiographic results of Pyrocardan® implant in the treatment of TMCJ osteoarthritis at a minimum follow-up of four years in order to confirm or disprove previous findings. We also focused on the complication and re-operation rates. Our hypothesis was that the clinical improvement in patients treated with Pyrocardan® would remain stable over time.

Methods

Study design

A prospective study was conducted for patients who received a Pyrocardan® implant between 2012 and 2017 at our institution. Surgery was performed by two experienced hand surgeons (levels 5 and 4, respectively [14]). Local ethical committee approval was not required for this observational study. No external funding was received for this study. Informed consent was obtained from all patients included in the study. Procedures were performed in accordance with the Helsinki declaration as revised in 2013.

Enrolling criteria

Inclusion criteria were as follows: patients aged 15–85 years, failure of non-operative treatment after at least six months, pain at the TMC joint and radiological staging II or III (according to Eaton-Littler [15]). Involvement of the scaphotrapezial-trapezoid (STT) joint was an exclusion criterion. In the timeframe selected, Pyrocardan® was used in 137 patients. Out of them, 119 (86%) were available at a minimum four year follow-up. Patient demographics are reported in Table 1.

Surgical technique

A Brachial plexus block was performed, and a high-arm tourniquet was inflated to 250 mmHg. A dorsal curvilinear incision was made in the TMCJ. The dorsal capsule was approached through the abductor pollicis longus and the extensor pollicis brevis. A trapezium-based flap was raised, and the joint was exposed subperiosteally to leave the capsule intact for direct closure.

A sagittal saw was used to perform the minimal resection of the metacarpal base and trapezium. A meticulous resection of the osteophytes was performed, and the horns of the trapezium were resected. A spherical burr was used to reduce the irregularity and remodel the two surfaces. The trial implant was inserted and assessed using fluoroscopy. Finally, the size of the implant which fully covered the trapezium surface was chosen. The trial was replaced with a definitive implant. A suture of the capsule was performed with a transosseous suture on the first metacarpal base. Post-operatively, a thumb spica cast was applied. At two weeks post-operatively, the sutures were removed, and a removable splint was provided for gradual use of the hand. Rehabilitation was started at week three, and unrestricted activities were allowed after week six.

Clinical assessment

Patients were assessed pre-operatively (T0) and post-operatively at three months (T1, N=119), six months (T2, N=119), one year (T3, N=119), two years (T4, N=118), three years (T5, N=118), four years (T6, N=117), five years (T7, N=76), six years (T8, N=36) and seven years (T9, N=25). Patients completed the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire score (0 points no disability; 100 points complete disability) to assess the function of the upper limb [16]. Pain was assessed using a 10-cm VAS. The scale was graded from 0 to 10 cm, with 0 cm indicating no pain and 10 indicated maximum pain. Thumb motion was assessed using the Kapandji test [17], with 1 indicating incapacity of opposition and 10 indicating complete opposition and measuring radial and palmar abduction with the help of a goniometer. Key-pinç strength was measured with a Jamar pinch dynamometer (FEI, Irvington, NY, USA) on both the operated and non-operated hands. Clinical assessments were performed by a single orthopaedic resident with adequate training in hand surgery. Complications and re-operation rates were also recorded.

Radiographic assessment

Anteroposterior (AP) and lateral radiographic views of the TMCJ were obtained pre-operatively and during follow-up at three months and every year (Fig. 1), and the Eaton–Littler radiographic classification system [15] was used to stage thumb TMCJ osteoarthritis pre-operatively. Subluxation and dislocation were defined as a partial (more than one-fourth of
the metacarpal base displaced) or complete loss of positioning of the implant, respectively, as previously reported [9].

**Statistical analysis**

Normality of data was assessed using the Shapiro–Wilk test. Multi-comparison tests were performed with analysis of variance (ANOVA) test for repeated measures into groups, and the Bonferroni correction (B) of p-value was used in pairwise comparison into groups to assess differences in DASH, VAS, Kapandji score, ABD-P, ABD-R and key-pinches at different control points (T0, T1, T2, T3, T4, T5 and T6). Uni-variate analyses were performed to assess the association of age (Pearson’s correlation), sex and side (Wilcoxon rank sum analysis) and the position of the implant at the longest follow-up as normal, subluxed or dislocated (Kruskal–Wallis test) against the following continuous variables: (1) DASH, VAS, Kapandji score and key-pinches at different times (T0 and T6); (2) the improvement in DASH, VAS, Kapandji score and key-pinches at T6 (delta = T6–T0). Variables found to be independently significant in the univariate analyses were then included in a multivariable linear regression analysis to determine the predictors of clinical outcome. Kaplan–Meier survival curves were drawn, with the event of interest being any revision surgery, at one, two and four years of follow-up. The analysis was performed using the STATA statistical software package version 12.0 (StataCorp, College Station, TX, 2011). The p-value was set to 0.05.

**Results**

**Clinical outcome**

The mean follow-up in the study was 5.2 years (range, 4–9 years). DASH, VAS and Kapandji scores significantly improved at three (p < 0.001 in all cases) and six months (p < 0.001, p = 0.01 and p < 0.001, respectively), remaining stable at the longest follow-up. While palmar abduction improved at six months (p = 0.002), radial abduction and key-pinches showed a slower recovery trend that was significantly different from the immediate post-operative values only after 1 year (p = 0.006 and p = 0.005, respectively) (Table 2). Age and side did not significantly correlate with pre-operative values, last follow-up values and the improvement achieved in different scores. Conversely, males demonstrated a greater key-pinches at baseline (p < 0.001) and at the last follow-up (p < 0.001), with a more pronounced improvement after surgery (p = 0.02).

**Radiographic outcome**

Dislocation and subluxation of the implant were found in four (3.3%) and 20 patients (16.8%), respectively (Fig. 2). Subluxed or dislocated implants were found to be associated with pain (VAS) and limited ROM as radial and palmar abduction and with a reduced improvement after surgery. In these cases, the change according to the Kapandji score was significantly lower than that in normally positioned implants (p = 0.03). Among these 24 patients, only three of them (all dislocated implants) required revision surgery and were treated with implant removal and trapeziectomy. After a follow-up of three, seven and eight years (for the 3 patients) from the revision procedure to trapeziectomy, DASH (17, 15 and 23 points, respectively) and VAS (1, 0 and 2, respectively) were satisfactory.

**Complication and re-operation rate**

None of the patients reported any intra-operative complications. Nine patients (7.5% of the population) experienced apraxia of the radial sensitive nerve which resolved within
Clinical parameter scores (mean) for all the patients at T0 (pre-operative), T1 (3 months), T2 (6 months), T3 (1 years), T4 (2 years), T5 (3 years), T6 (4 years), T7 (5 years), T8 (6 years) and T9 (7 years). Multi-comparison tests were performed with ANOVA test for repeated measures into groups, and the Bonferroni correction (B) of p-values was used in pairwise comparison into groups between two consecutive control points.

| Parameter       | T0 (N=119) | T1 (N=119) | T2 (N=119) | T3 (N=119) | T4 (N=118) | T5 (N=118) | T6 (N=117) | T7 (N=76) | T8 (N=36) | T9 (N=25) |
|-----------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| DASH score      | 59.6       | 37.6       | 25.3       | 19.8       | 17.8       | 16.6       | 15.9       | 16.2       | 21.7       | 16.3       |
| p-value         |            | T0 vs T1: <0.001 (B) | T1 vs T2: <0.001 (B) | T2 vs T3: 1 (B) | T3 vs T4: 1 (B) | T4 vs T5: 1 (B) | T5 vs T6: 1 (B) | T6 vs T7: 1 (B) | T7 vs T8: 1 (B) | T8 vs T9: 1 (B) |
| VAS score       | 8.4        | 4.1        | 2.9        | 2.3        | 2.2        | 2.2        | 2.2        | 2.4        | 3.1        | 2.4        |
| p-value         |            | T0 vs T1: <0.001 (B) | T1 vs T2: 0.01 (B) | T2 vs T3: 1 (B) | T3 vs T4: 1 (B) | T4 vs T5: 1 (B) | T5 vs T6: 1 (B) | T6 vs T7: 1 (B) | T7 vs T8: 1 (B) | T8 vs T9: 1 (B) |
| Kapandji test   | 8.7        | 7.8        | 8.9        | 9.1        | 9.1        | 9.2        | 9.2        | 9.2        | 9.2        | 9.2        |
| p-value         |            | T0 vs T1: <0.001 (B) | T1 vs T2: <0.001 (B) | T2 vs T3: 1 (B) | T3 vs T4: 1 (B) | T4 vs T5: 1 (B) | T5 vs T6: 1 (B) | T6 vs T7: 1 (B) | T7 vs T8: 1 (B) | T8 vs T9: 1 (B) |
| Palmar abduction| 57         | 54.5       | 59.2       | 60.8       | 61.3       | 61.3       | 61.5       | 63.2       | 64.3       | 64.7       |
| p-value         |            | T0 vs T1: 1 (B) | T1 vs T2: 0.002 (B) | T2 vs T3: 1 (B) | T3 vs T4: 1 (B) | T4 vs T5: 1 (B) | T5 vs T6: 1 (B) | T6 vs T7: 1 (B) | T7 vs T8: 1 (B) | T8 vs T9: 1 (B) |
| Radial abduction| 57.7       | 56         | 59         | 60.4       | 60.8       | 60.8       | 61.2       | 62.6       | 63.7       | 64.8       |
| p-value         |            | T0 vs T1: 1 (B) | T1 vs T2: 0.386 (B) | T2 vs T3: 1 (B) | T3 vs T4: 1 (B) | T4 vs T5: 1 (B) | T5 vs T6: 1 (B) | T6 vs T7: 1 (B) | T7 vs T8: 1 (B) | T8 vs T9: 1 (B) |
| Key-pin chase   | 2.8        | 2.9        | 3.4        | 3.5        | 3.6        | 3.6        | 3.6        | 3.6        | 3.7        | 4.3        |
| p-value         |            | T0 vs T1: 0.001 (B) | T1 vs T2: <0.001 (B) | T2 vs T3: 1 (B) | T3 vs T4: 1 (B) | T4 vs T5: 1 (B) | T5 vs T6: 1 (B) | T6 vs T7: 1 (B) | T7 vs T8: 1 (B) | T8 vs T9: 1 (B) |
three months without treatment. The Kaplan–Meier curve showed an implant survival rate of 99% at one year, 98% at two and five years and 95% at seven years (Fig. 3; Table 3).

**Discussion**

The main finding of this study was that patients treated with Pyrocardan® for end-stage TMCJ osteoarthritis experienced a significant and long-lasting clinical improvement after surgery, with an overall low complication and re-operation rate. In the majority of patients, a satisfactory outcome remained stable over time, with a survivorship of Pyrocardan® standing at 95% at seven year follow-up. The instability of the implant, with subluxation or dislocation, was obviously associated with a poorer outcome, but in this series could be successfully tackled through a revision to trapeziectomy.

A few previous studies have investigated the efficacy of Pyrocardan® to treat TMCJ osteoarthritis [7, 11–13, 18–20] (Table 4). In these studies, authors have already outlined the advantages related to Pyrocardan®, i.e. the minimal resection of articular surfaces which prevents an excessive shortening of the first ray, the preservation of the range of motion (as compared to arthrodesis) and the possibility to

| Time (years) | Patients | Survivor function | [95% Conf. Int.] |
|-------------|----------|-------------------|-----------------|
| 1           | 119      | 0.99              | 0.94–0.99       |
| 2           | 118      | 0.98              | 0.93–0.99       |
| 3           | 118      | 0.98              | 0.93–0.99       |
| 4           | 117      | 0.98              | 0.93–0.99       |
| 5           | 76       | 0.98              | 0.93–0.99       |
| 6           | 36       | 0.95              | 0.84–0.98       |
| 7           | 25       | 0.95              | 0.84–0.98       |

Table 3 Data on Pyrocardan® survival rate
perform a revision to trapeziectomy in case of failure of the implant [7, 11–13, 18–20]. To date, the study, with the longest follow-up has been published by Gerace et al., who documented a significant improvement after pyrocarbon interposition arthroplasty in the pain level, QuickDASH and strength, with a 4% revision rate and a 96% survival rate at 5 years follow-up [13]. While the clinical results in our series confirm these findings, we believe that at least two important differences between this study and the one by Gerace et al. have to be outlined. First, the prospective design in our analysis allowed to overcome the biases inherently related to retrospective studies. Second, we were able to assess patients on a year-by-year basis, estimating the survivorship of the implant over time and reporting a 95% survival rate seven years after surgery, which to the best of our knowledge is the longest follow-up reported in literature. We believe that clinicians should explain these data to patients during the pre-operative counselling, in order to allow a correctly informed decision about the procedure.

With regard to re-operations, in this study, revision was necessary in 3% of cases, which is in keeping with values reported in previous literature (ranging from 0 to 18%) [7, 11–13, 18–20]. All patients needing revision presented with a dislocation of the implant, which in our opinion may be related to the instability inherently related to Pyrocardan®. In a series by Herren et al. [21], authors reported a less favourable outcome after revision surgery as compared to primary trapeziectomy. Conversely, it should be emphasized that in our series, patients who underwent trapeziectomy reported clinical results overlapping those reported after primary trapeziectomy (18.3 points for DASH as compared to 17–34 points reported in a recent systematic review about trapeziectomy [22]). Studies reporting data on larger cohorts of ‘revised’ patients are needed to confirm or disprove these findings.

For what concerns other treatment available in the treatment of TMCJ osteoarthritis, trapeziectomy remains the gold standard treatment. Since the clinical results reported in literature are similar to ours in terms of pain relief and function [23–29], a question arises about the cost-effectiveness of Pyrocardan® as compared to trapeziectomy which is intuitively a cheaper procedure. We advocate dedicated prospective comparative cost-analyses between these two treatments in order to shed light on the superiority of a technique over one other. On a different note, trapeziometacarpal arthrodesis still has a place in the armamentarium of hand surgeons, but it is not recommended as first-line option due to the significant loss of motion and the onset or progression of scapho-trapezial joint osteoarthritis [30, 31].

The authors acknowledge some limitations of this study. First, lack of a group of control. Second, 14% of patients (18/137) did not reach the minimum four year follow-up originally set in the study protocol and were lost at

| Authors               | Year | Implant     | n     | Mean age (years) | Mean follow-up (years) | Quick-DASH or DASH | VAS Tip or key pinch (kg) | Grip strength (kg) | Satisfaction rate | Survival rate | Complication rate | Revision rate | Dislocation rate | Subluxation rate |
|-----------------------|------|-------------|-------|------------------|------------------------|-------------------|--------------------------|-------------------|-----------------|---------------|-----------------|---------------|----------------|------------------|
| Our study             | 2021 | Pyrocardan | 119   | 60               | 5                      | 16.3              | 2.4                      | 4.3               | NR              | 97%           | 7.5%           | 2.5%          | 3.3%          | 16.8%           |
| Gerace et al.         | 2020 | Pyrocardan | 103   | 59               | 5.5                    | 9                 | 0.6                      | 7                 | 27              | 96.2%         | 4.8%           | 3.8%          | 0%            | 100%            |
| Logan et al.          | 2020 | Pyrocardan | 40    | 58               | 2.5                    | 2.3               | 17                       | 5                 | 30              | 85%           | 100%           | 0%            | 3%            | 0%              |
| Erne et al.           | 2017 | Pyrocardan | 8     | 64.3             | 1.5                    | 1.5               | 1.7                      | 0.73              | NA              | 7.4/10         | 100%           | 0%            | 0%            | 12%             |
| Lauwers et al.        | 2016 | Pyrocardan | 28    | 59               | 2.5                    | 2.5               | 18                       | 5                 | 0.73           | 7.4/10         | 100%           | 0%            | 0%            | 18%             |
| Russo et al.          | 2016 | Pyrocardan | 40    | 58.5             | 2.5                    | 2.5               | 18                       | 5                 | 0.73           | 7.4/10         | 100%           | 0%            | 0%            | 12%             |
| Odella et al.         | 2014 | Pyrocardan | 25    | 55               | 1                      | 1                 | 5                        | 22.4              | 4               | 94.5%         | 88%            | 12%           | 8%            | 0%              |
| Belleme`re et al.     | 2011 | Pyrocardan | 27    | 58               | 1.5                    | 1.3               | 6.7                      | 10.1              | 6.7            | 100%          | 0%             | 0%            | 0%            | 0%              |
follow-up; although a formal power analysis was not carried out, we reckon that a final sample size of over 100 patients with a minimum follow-up of four years might be sufficiently informative to report midterm results of Pyrocardan®. Third, as discussed above, we did not perform a cost-effectiveness analysis, which would have provided paramount data in order to draw conclusions on the best surgical treatment for TMCJ osteoarthritis.

Conclusion

In conclusion, the use of Pyrocardan® in TMCJ osteoarthritis provides pain relief associated with a satisfactory functional outcome which persist over time. The estimated survival rate at 7 years from surgery stands at 95%. In case of failure, revision surgery with conversion to trapeziectomy can be performed with good results. We advocate further comparative studies in order to shed some light on the cost-effectiveness of the implant as compared to other common procedures such as trapeziectomy with or without ligament reconstruction.

Author contribution All authors contributed to the study conception and design. Material preparation and data collection were performed by Francesco Smeraglia, Giulia Famiglietti and Morena Anna Basso. Data analysis was performed by Francesco Smeraglia and Alessio Bernasconi. The first draft of the manuscript was written by Francesco Smeraglia, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability Yes.

Declarations

Ethical approval This is an observational study. The Local Ethics Committee, Università di Napoli Federico II, has confirmed that no ethical approval is required.

Consent to participate Informed consent was obtained from all patients included in the study.

Consent for publication Yes.

Competing interests The authors declare no competing interests.

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References

1. Waigman A, Carr E, Edmunds I, Ada L (2009) Surgery for thumb (trapeziometacarpal joint) osteoarthritis. Cochrane Database Syst Rev (4): CD004631. https://doi.org/10.1002/14651858.CD004631.pub3
2. Vermeulen GM, Sliper H, Feitz R, Hovius SER, Moojen TM, Selles RW (2011) Surgical management of primary thumb carpometacarpal osteoarthritis: a systematic review. J Hand Surg Am 36(1):157–169. https://doi.org/10.1016/j.jhsa.2010.10.028
3. Berger AJ, Meals RA (2015) Management of osteoarthritis of the thumb joints. J Hand Surg Am 40(4):843–850. https://doi.org/10.1016/j.jhsa.2014.11.026
4. Degeorge B, Daganeux L, Andrin J, Lazerges C, Coulret B, Chammas M (2018) Do trapeziometacarpal prosthesis provide better metacarpal stability than trapeziectomy and ligamentoplasty? Orthop Traumatol Surg Res 104(7):1095–1100. https://doi.org/10.1016/j.otsr.2018.07.008
5. Cebrerón-Gomez R, Lizarra-Utrilla A, Sebastia-Forcada E, Lopez-Prats FA (2018) Outcomes of cementless joint prostheses versus tendon interposition for trapeziometacarpal osteoarthritis: a prospective study. J Hand Surg Eur 44(2):151–158. https://doi.org/10.1177/1753193417787151
6. Smeraglia F, Barrera-Ochoa S, Mendez-Sanchez G, Basso MA, Balato G, Mir-Bullo X (2020) Partial trapeziectomy and pyrocarbon interpositional arthroplasty for trapeziometacarpal osteoarthritis: minimum 8-year follow-up. J Hand Surg Eur 45(5):472–476. https://doi.org/10.1177/1753193420968085
7. Bellemère P, Gaisne E, Loubersac T (2011) Pyrocardan implant: free pyrocarbon interposition for resurfacing trapeziometacarpal joint. Chir Main 2:28–35. https://doi.org/10.1055/s-0035-1416885
8. Haubold AD (1994) On the durability of pyrolytic carbon in vivo. Med Prog Technol 20(3–4):201–208
9. Barrera-Ochoa S, Vidal-Tarrason N, Correa-Vázquez E, Revetre-Vinaixa MM, Font-Segura J, Mir-Bullo X (2014) Pyrocarbon interposition (PyroDisk) implant for trapeziometacarpal osteoarthritis: minimum 5-year follow-up. J Hand Surg Am 39(11):2150–2160. https://doi.org/10.1016/j.jhsa.2014.07.011
10. Mariconda M, Russo S, Smeraglia F, Busco G (2014) Partial trapeziectomy and pyrocarbon interpositional arthroplasty for trapeziometacarpal joint osteoarthritis: results after minimum 2 years of follow-up. J Hand Surg Eur 39(6):604–610. https://doi.org/10.1177/1753193413519384
11. Russo S, Bernasconi A, Busco G, Sadille F (2016) Treatment of the trapeziometacarpal osteoarthritis by arthroplasty with a pyrocarbon implant. Int Orthop 40(7):1465–1471. https://doi.org/10.1007/s00264-015-3016-z
12. Logan J, Peters S, Strauss R, Manzanero S, Couzens GB, Ross M (2020) Pyrocardan trapeziometacarpal joint arthroplasty – medium term outcomes. J Wrist Surg 9(6):509–517. https://doi.org/10.1055/s-0040-1714685
13. Gerace E, Royaux D, Gaisne E, Ardouin L, Bellemère E, Royaux D, Gaisne E, Loubersac T (2011) Pyrocardan implant arthroplasty for trapeziometacarpal osteoarthritis with a minimum follow-up of 5 years. Hand Surg Rehabil 39(6):528–538. https://doi.org/10.1016/j.hansur.2020.09.003
14. Tang JB, Giddins G (2016) Why and how to report surgeons’ level of expertise. J Hand Surg Eur 41(4):365–366. https://doi.org/10.1016/j.jhsur.2020.09.003
15. Eaton RG, Littler JW (1969) A study of the basal joint of the thumb. Treatment of its disabilities by fusion. J Bone Joint Surg Am 51(4):661–8
16. Hudak PL, Amadio PC, Bombardier C (1996) Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder and hand). The Upper Extremity Collaborative Group (UECG). Am J Ind Med 29(6):602–8. https://doi.org/10.1002/(SICI)1097-0274(199606)29:6<602::AID-AJIM4>3.0.CO;2-L
17. Kapandji A (1986) Clinical test of apposition and counter-apposition of the thumb. Ann Chir Main 5(1):67–73. https://doi.org/10.1016/d0753-9053(86)80053-9
18. Odella S, Querenghi AM, Sartore R, Felice DE, Dacatra AU (2015) Trapeziometacarpal osteoarthritis: pyrocarbon interposition implants. Joints 2(4):154–158
19. Lauwers TMAS, Brouwers K, Staal H, Hoekstra LT, van der Hulst RRWJ (2016) Early outcomes of Pyrocardan® implants for trapeziometacarpal osteoarthritis. Hand Surg Rehabil 35(6):407–412. https://doi.org/10.1016/j.jhsur.2016.09.004
20. Erne HC, Schmauß D, Cerny M, Schmauß V, Ehrl D, Löw S, Deiler S (2017) Lundborg’s resection arthroplasty vs. Pyrocarbon spacer (Pyrocardan®) for the treatment of trapeziometacarpal joint osteoarthritis: a two-centre study. Handchir Mikrochir Plast Chir 49(3):175–80. https://doi.org/10.1055/s-0043-115220
21. Herren DB, Ishikawa H, Rizzo M, Ross M, Solomons M (2022) Arthroplasty in the hand: what works and what doesn’t? J Hand Surg Eur 47(1):4–11. https://doi.org/10.1017/17531934211017703
22. Liu Q, Xu B, Lyu H, Hyup J (2021) Differences between simple trapeziectomy and trapeziectomy with ligament reconstruction and tendon interposition for the treatment of trapeziometacarpal osteoarthritis: a systematic review and meta-analysis. Arch Orthop Trauma Surg 141(4):4–11. https://doi.org/10.1007/s00402-020-03707-w
23. Gangopadhyay S, McKenna H, Burke FD, Davis TRC (2012) Five- to 18-year follow-up for treatment of trapeziometacarpal osteoarthritis: a prospective comparison of excision, tendon interposition, and ligament reconstruction and tendon interposition. J Hand Surg Am 37(3):411–417. https://doi.org/10.1016/j.jhsa.2011.11.027
24. Raven EEJ, Kerkhoffs GMMJ, Rutten S, Marsam AJ, Marti RK, Albers GHR (2007) Long term results of surgical intervention for osteoarthritis of the trapeziometacarpal joint: comparison of resection arthroplasty, trapeziectomy with tendon interposition and trapezio-metacarpal arthrodesis. Int Orthop 31(4):547–554. https://doi.org/10.1007/s00264-006-0217-5
25. Gibbons CE, Gosal HS, Choudri AH, Magnussen PA (1999) Trapeziometacarpal basal thumb joint osteoarthritis: 3- to 19-years follow-up. Int Orthop 23(4):216–218. https://doi.org/10.1007/s002640050354
26. Brennan A, Blackburn J, Thomson J, Field J (2021) Simple trapeziectomy versus trapeziectomy with flexor carpi radialis suspension: a 17-year follow-up of a randomized blind trial. J Hand Surg Eur 46(2):120–124. https://doi.org/10.1177/1753193420952966
27. Lane JCE, Rodrigues JN, Furniss D, Burn E, Poulter R, Gardiner MD (2020) Basal thumb osteoarthritis surgery improves health state utility irrespective of technique: a study of UK Hand Registry data. J Hand Surg Eur 45(5):436–442. https://doi.org/10.1177/175319342099753
28. Singer MS, Kandel WA (2016) Slip abductor pollicis longus suspension tendinoplasty for management of trapezo-metacarpal joint osteoarthritis. Int Orthop 40(5):765–9. https://doi.org/10.1007/s00264-015-2904-6
29. Yeoman TFM, Stone O, Jenkins PJ, Mceachan JE (2019) The long-term outcome of simple trapeziectomy. J Hand Surg Eur 44(2):146–150
30. Rizzo M, Moran SL, Shin AY (2009) Long-term outcomes of trapeziometacarpal arthrodesis in the management of trapeziometacarpal arthritis. J Hand Surg Am 34(1):20–26. https://doi.org/10.1016/j.jhsa.2008.09.022
31. Smeraglia F, Soldati A, Orabona G, Ivone A, Balato G, Pacelli M (2015) Trapeziometacarpal arthrodesis: is bone union necessary for a good outcome? J Hand Surg Eur 40(4):356–361. https://doi.org/10.1016/j.jhsa.2011.11.027

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