Cost-Effectiveness of Sonography-Guided Surgery

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KEYWORDS

• Percutaneous • Sonography • Surgery • Release • Cost-benefits • Carpal tunnel syndrome

KEY POINTS

- The surgical carpal tunnel procedure under sonography prevent intraoperative neurovascular injury.
- The sonography can also be used for carpal tunnel syndrome diagnosis and the surgical release.
- As a low-irradiation imaging technic, sonography can also be used for the trigger finger surgical procedure without skin incision.
- The percutaneous carpal tunnel procedure can be done without tourniquet and prevent from thromboembolism complication.

INTRODUCTION

Carpal tunnel syndrome (CTS) is the most frequent compressive neuropathy.[1] In Belgium, in 2018, there were 31,938 carpal tunnel releases (CTRs) performed with an annual direct reimbursement cost of 6,142,052 €. Most patients (64.4%) were women, and the median and average ages were 58 and 59.3 years, respectively. The vast majority of the operations (97.1%) were performed in an ambulatory day clinic.[2]

The classical surgical alternatives are Open and Endoscopic Carpal Tunnel Releases (OCTR and ECTR). In 2016, the American Academy of Orthopaedic Surgeons (AAOS) concluded that ECTR offers some benefits as compared to OCTR.[3] Sonography is now used more and more in CTS, for the diagnosis,[4] but also, by some physicians, during surgery. Already in 1997, Nakamichi suggested using sonography during CTR.[4] More recently, sonography has been proposed to guide the release of the transverse carpal ligament (TCL) using various endoscopic devices, or needles permitting sonography-guided percutaneous carpal tunnel release (PCTR). Several cadaveric studies have assessed the efficacy of PCTR.[5,6] Lecoq *and colleagues* reported in their series of 104 specimens, a total release of TCL in all cases. For 61 specimens, the complete release was obtained at first cutting movement.[6] In clinics, PCTR has been reported to be safe and could allow quicker return to daily activities and work.[7,8]

In 2017, PCTR has been introduced in our hospital. The operation is done in the operative room of the day clinic under local anesthesia. The first step of the procedure is a complete sonographic examination of the carpal tunnel region, to confirm the feasibility of the percutaneous sonography-guided release of TCL and to detect possible anatomic variations or abnormalities. Then, the upper extremity is prepared for an aseptic procedure and the release is performed using a bent catheter, under sonography guidance, with sterile gel and a sterile cover around the sonographic probe. At the end of the procedure, a metallic probe is used to confirm the completeness of the TCL release. The

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whole sonography-guided procedure takes about 10 minutes and then a compressive dressing is applied to prevent a postoperative hematoma. This dressing is removed on the first postoperative day and the patient can go back to his/her daily activities and resume light work. Note that during PCTR, no tourniquet is used, to allow good visualization of the vessels, particularly the ulnar artery and of the superficial volar carpal arch. Local anesthesia is also used because it is considered safer in this indication than general or regional anesthesia, the patient being able to describe a mechanical nerve stimulation during the procedure when the release motion is too close to it.

The aim of this study is to report the cost-effectiveness of PCTR as compared to OCTR and ECTR. The hypothesis was that PCTR was cheaper than OCTR or ECTR.

MATERIALS AND METHODS

This study is divided into 2 parts: an observational retrospective comparative study and a literature review. The research protocol has been approved by the Ethics Committee of the Erasme University Hospital (reference: P2019/571-CCB: B406201942256).

Part 1: Evaluation of Carpal Tunnel Surgery Direct Costs

All patients operated for CTS at our institution during the year 2019 were included in this study. One patient operated first by PCTR and later reoperated by OCTR in the same hand for persistent symptoms, 20 patients operated for CTS and concomitantly for another hand affection (ganglion, trigger finger, Dupuytren), and 4 patients with missing data were excluded in this study.

According to the preferences of patients and surgeons, 3 different techniques of surgery (OCTR, ECTR, and PCTR) were performed under 3 different techniques of anesthesia, general, regional (axillary or medio-ulnar block), and local. All PCTRs were performed under local anesthesia.

With the authorization of the billing department of our institution, all financial data related to these operations and anesthetics were recorded in an Excel file. All costs were expressed in Euro. The following parameters were collected: operating time duration (expressed in minutes), operating room occupation time (expressed in minutes), and direct costs related to the operation. These costs were categorized as:

- Costs of investment—corresponding to the hospital's investment for the acquisition of a tray of surgical instruments for OCTR and ECTR (including the endoscope for ECTR), the purchase of the ultrasound machine for PCTR, and the acquisition of the arthroscopy column for ECTR.
- Disposable costs—these costs correspond to all disposable equipment used during the procedure (needles, surgical drapes, sutures, gloves, etc).
- Pharmacy costs—all drugs used during the procedure were counted, as well as the sling given to the patient to elevate the hand after the operation.
- Costs of occupation of the operating room—in the internal billing system of our hospital, this cost is fixed, regardless of the technique and the duration of the operation. The cost of occupation of the surgical room includes the cost of sterilization of the surgical instruments, estimated to be 50€ per set.

We did not consider in this study, neither surgeon fees, as in Belgium, these fees are the same whatever technique is used, nor the compensation expenses for the days off work after the operation, as we could not access these data.

Part 2: Literature Review

The literature review was carried out between January and May 2020 by consulting different databases: primary (JBJS, HC, AANA, JHS, HUES, and SMAR), secondary (PubMed, Cible +, ScienceDirect, and Google Scholar), tertiary (UpToDate, Cochrane Library, and INAMI), and quaternary literature (AAOS Guideline). The first part consisted of finding articles on CTS, the second part, in the selection of the articles. We used the PICO [Patient, Intervention, Compare and Outcome] method to establish the search equations to increase the chance of finding relevant articles. Table 1 presents the equation research formulation. The combination of keywords (percutaneous, sonography, surgery, release, cost-benefits, and carpal tunnel syndrome) in the following Mesh term ((((“Surgical Procedures, Operative” [Mesh]) AND “Carpal Tunnel Syndrome” [Mesh]) AND “Cost-Benefit Analysis” [Mesh]) AND “Sonography” [Mesh]) yielded no result. We modified the equation to another, which consisted in the determination of the cost-benefit of carpal tunnel surgery independently of the procedure. To not deviate from the objectives of our study and in view of the results obtained by the modified search equation, we also constituted several other search equations without MESH term by integrating the Boolean operators in several databases. All articles retained were selected according to the Strobe endpoint, for writing and reading observational studies.[9] With

Table 1
Equation of research using PICO model

Problem	Carpal tunnel syndrome
Intervention	Percutaneous carpal tunnel release sonography-guided
Comparative	Open carpal tunnel release
Outcome	Cost-effectiveness, economical cost

this different research equation, 2411 articles have been founded, and the following were excluded:

- All articles without 2 of the following keywords: percutaneous, sonography, surgery, release, cost-benefits, and carpal tunnel syndrome,
- All articles about cadaveric studies, anatomic studies, and studies comparing 2 nonsurgical techniques (like corticosteroid injections and orthosis),
- All articles dealing only with the endoscopic technique, regardless of the purpose of the study,
- All articles whose cost-effectiveness assessment was not included in the abstract or the results.

Of the 2411 articles, 13 articles were finally selected for the comparison of results and 5 others for the discussion.

RESULTS

Comparative Analysis of the Costs

A total of 141 patients (143 hands) were operated for CTS at Erasme University Hospital in 2019. After exclusion criteria, 116 patients were included in the analysis: 35 men (mean age, 60 years) and 81 women (mean age, 54 years), 75 on the right side and 41 on the left side. Seventy-eight patients were operated by PCTR, 35 by OCTR, and 3 by ECTR. PCTR was performed by one single surgeon experimented in sonography (FM), OCTR and ECTR by multiple hand surgeons. Among the 116 operated patients, 29 were operated under regional anesthesia, 4 under general anesthesia, and 83 (including all PCTRs) under local anesthesia (Table 2). The average operative durations were similar for OCTR (15 $\pm$ 8 min) and PCTR (15 $\pm$ 6 min), inferior to those of ECTR (29 $\pm$ 10 min) (Fig. 1). The same difference was found for the total duration of occupation of the operating room (OCTR, 43 $\pm$ 17 min; PCTR, 47 $\pm$ 10 min; ECTR, 64 $\pm$ 34 min).

Investment costs

The investment costs were as follows: for PCTR, 42,129€ for purchasing the sonography device (42,000€), a needle holder (125€) and a buttoned stylus (4€); for OCTR, 1531.75€ corresponding to the purchase of a surgical hand surgery tray; and for ECTR, 68,052€ including the acquisition of an arthroscopy column (60,000€), the needed surgical instruments and endoscope (8052€).

Disposable costs

The common disposable to all CTS cases operated in our center, whatever surgical technique, included a surgical hand pack provided by Mölnlycke (Mölnlycke Healthcare, Göteborg, Sweden), which costed 35.37 €. For PCTR, the disposable cost was 6.23 € (cover for sonography probe 0.23 €, sterile ultrasound gel 3.5 €, 14G catheter 2 €, and Tuohy catheter 0.50 €); for ECTR, the

Table 2
Demographic data of patients grouped by anesthesia modality and surgical technique

Patients Recruited, N = 116				
Gender	Males: 35 (30.1%)		Females: 81 (69.9%)	
Surgical technique	PCTR: 78	ECTR: 3	OCTR: 35	
Side operated	Left: 41		Right: 75	
Anesthesia modalities	General: 4	Regional: 29	Local: 83	
Age	20–40 y: 15	41–60 y: 65	61–80 y: 26	81–90 y: 10

Distribution of Patients by Anesthesia Modalities and Surgical Technique, n = 116			
	PCTR	OCTR	ECTR
General anesthesia	—	4	—
Regional anesthesia	—	26	3
Local anesthesia	78	5	—

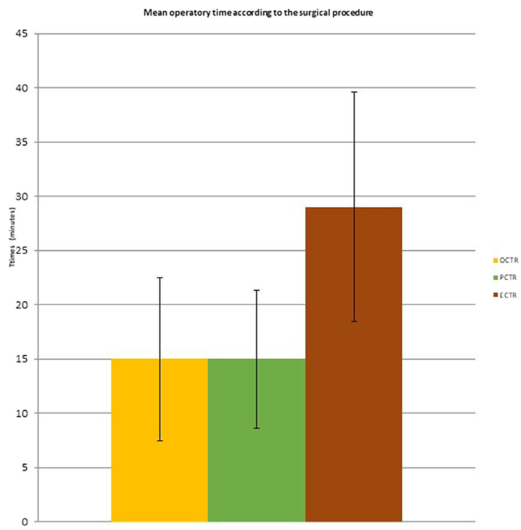

Fig. 1. Comparative operative durations.

cost of the disposable endoscopic knife was 201€.

Pharmacy costs

The costs of pharmaceutical drugs were on average 10.0 ± 2.9 € for PCTR, 23.2 ± 9.6 € for OCTR, and 19.0 ± 9.9 € for ECTR (Fig. 2). According to anesthesia modalities, the mean cost per patient was 10.55 ± 4.40 € under local anesthesia, 23.34 ± 8.79 € under regional anesthesia, and 29.36 ± 5.69 € under general anesthesia (Fig. 3).

Costs of occupation of the operative room

The costs for operative room occupation were the same in our institution, whatever surgical technique, despite the differences in room time occupation, 284.78€ per patient.

Instruments and disposable equipment used for percutaneous carpal tunnel release

Instruments and disposable equipment used in our hospital for performing PCTR are shown in Fig. 4. Two instruments (a needle holder and a buttoned probe), 3 needles, a 10 mL syringe, a probe cover, and sterile gel were needed to perform this surgery.

Literature Review

Postoperative functional improvement after percutaneous carpal tunnel release

In a study that included 194 patients, Logerlly *and colleagues* reported a mean postoperative functional and severity score of 13.8% in an OCTR group, compared to 14.2% in a minimally invasive group. The difference was not significant, both techniques were considered equivalent.[10] This score was established by a self-administered questionnaire whereby patients recorded the severity of their symptoms and functional status. Each patient scored the functional status and severity of their symptoms in the preoperative consultation and then in subsequent postoperative consultations (up to 3 postoperative recordings were possible). These scores were then converted to percentages: 0 representing normal functioning or no symptoms, 100 representing severely restricted functioning or very severe symptoms.

Rojo-Manaute *and colleagues* reported a better Q-DASH score at 6 months postoperatively, in a study comparing PCTR to OCTR. The difference of grip strength was not significant, except the first week after the surgery where the force was better after PCTR. In the PCTR group, the patients recovered 5.3 times quicker full wrist flexion compared to the OCTR group.[11]

Nakamichi *and colleagues* used a satisfaction score to compare open and percutaneous techniques. Three weeks after surgery the PCTR patients were more satisfied than those operated by OCTR. Later, there was no difference in terms of satisfaction. These authors also reported that the sensitive discrimination measured by Semmens-Weinstein monofilament test was similar in both groups, and that the recovering of grip strength was not optimal in both groups.[7]

According to Petrover *and colleagues* in a nonrandomized prospective trial comparing ECTR to OCTR, the Boston functional score improved significantly between 1 and 6 months in both groups.[12]

In 93 patients operated by PCTR, Chern *and colleagues* reported that the sensory disorder disappeared in 76.8% of patients 1 week postoperatively, and in 93.4% and 100% at 6 and 12 months, respectively, after the surgery.[13]

Effectiveness

In a study including 162 patients comparing OCTR to ECTR (one entrance portal), Saw *and colleagues* demonstrated a significant difference considering the return to work. In the ECTR group, the patients returned to work on average 8 days sooner (Confidence Interval (CI) 95%, 2-13 days). Considering the occupation time of the operating room, the tourniquet time and the time for the anesthesia, both techniques were similar. However, regarding the duration between skin incision and closure, ECTR was 2 minutes shorter than OCTR. In this study, there was no neurovascular lesion in either series.[14]

In 1997, Nakamichi *and colleagues* demonstrated in a prospective trial including 103 patients operated by PCTR or OCTR that there was no

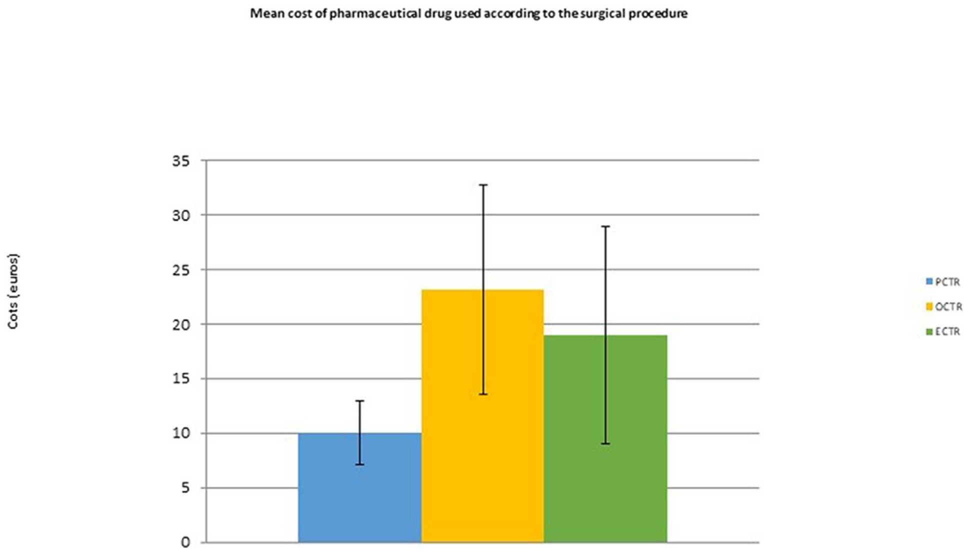

Fig. 2. Comparative pharmaceutical costs related to the surgery.

significant difference considering the sensitive discrimination and recovery of strength of abductor pollicis brevis muscle at 104 weeks after the surgery. However, in the PCTR group, there was significantly better grip and pinch strength after PCTR at 3, 6, and 13 weeks.[15]

In another nonrandomized study including 65 women operated either by PCTR or OCTR, Nakamichi *and colleagues* observed healing of the surgical wound on average after 1.4 days (IC 1–4 days) in the PCTR group, whereas it was on average 7.5 days (IC 6–10 days) in the OCTR group.[7]

Mc Shane *and colleagues* reported in a prospective study of 17 PCTR patients that the cross-sectional area of the median nerve diminished from 0.15 cm^2 preoperatively to 0.14 cm^2 in postoperative—the difference was statistically significant. In the same study, these authors found that the distal diameter of the median nerve increased significantly, from 0.14 cm to 0.21 cm postoperatively.[16]

In a prospective study on 129 patients operated by minimally invasive surgery using a groove probe, Benquet *and colleagues* reported that the mean duration of off work was 22.6 days and varied much from one patient to another (2–75 days). In the same study, these authors found that 90% of patients returned to work 3 weeks after the operation. The off-works duration was longer in

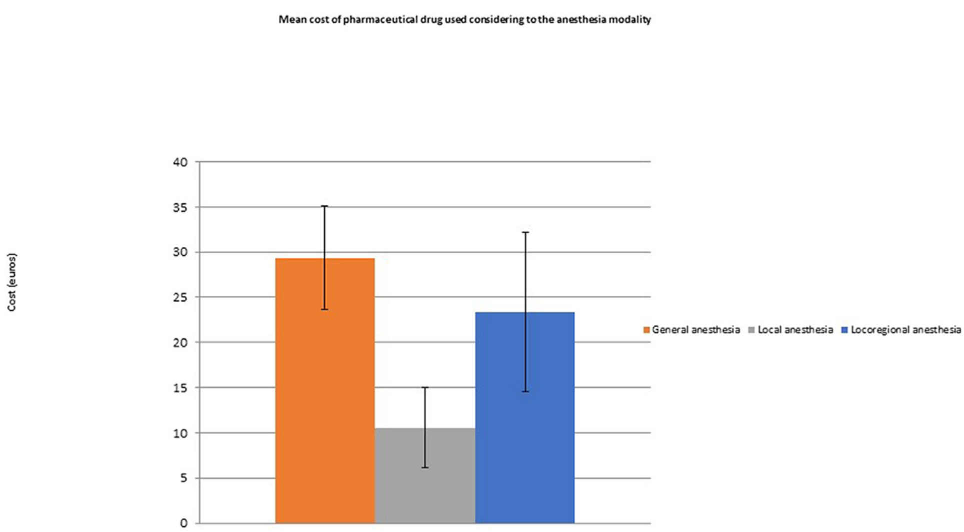

Fig. 3. Comparative pharmaceutical costs related to the anesthesia.

the hands worker group than in the nonhands worker group (23.2 ± 11.5 days vs 15 ± 7.8 days).[8]

Postoperative pain and complications

Nakamichi *and colleagues*[15] observed neither neurologic nor vascular complication after PCTR in their first study.

In a prospective randomized trial of 128 patients, Rojo-Manaute *and colleagues* observed that the mean duration of postoperative use of analgesics was shorter in the PCTR group than in the OCTR group. They also reported that the first- and third-week postoperative pains were 3 times less in the PCTR group than in the OCTR group.[11] Nakamichi *and colleagues* reported that postoperative pain was less in the PCTR group than in the OCTR group at 3 and 6 weeks. The postoperative sensitivity of the surgical wound was also less in the PCTR group at 3 weeks.[7] In the study of Chern *and colleagues*, there was moderate pain in 24.2% of patients 1 week after PCTR, the rate decreased to 6.6% after 2 months, and 1.1% after 12 months.[13]

Economic studies

Logerlly reported that the cost of CTS surgery varied between 65.23£ and 3971£, with an average of 800£ per patient. The mean cost of OCTR was 801.23£, the mean cost of minimally invasive surgery was 779.36£, the difference was not statistically significant.[10] Saw *and colleagues* compared the cost of ECTR and OCTR and reported higher costs with the first technique, 6482£ to purchase endoscopic devices and 82£ to purchase the single-use blade. However, according to the Confederation of British Industry, 1 day of off works costs on average 67£. Because ECTR had shorter return to work (8 days), the final gain for the society was 536£ per patient.[14]

Nakamichi *and colleagues* reported in their prospective study on 103 patients that the operative time duration was 54 minutes in the PCTR group and 48 min in the OCTR group. The mean cost of each surgery was 513$ in the PCTR group and 487$ in the OCTR group. The difference was mainly due to the particularity of the instruments used for PCTR surgery (26$ for the sonographic gel and the retractor).[15]

Rojo-Manaute *and colleagues*[11] used a blade hook, which costed 56.35 $ and can be reused several times.

Koehler *and colleagues*[17] reported that ECTR is 44% more expensive than OCTR (2759.70$ vs 1918.06$), and the difference is mainly related to the endoscopic blade. In the same study, they reported that the operative time was 44.8 minutes in the ECTR group and 40.5 minutes in the OCTR group.

DISCUSSION

Only one patient in the PCTR group had to be reoperated by OCTR for persistent symptoms, all others were markedly improved by the operation. Postoperative conversion of PCTR to OCTR is indeed quite low in all series. This high success rate is related to the excellent preoperative visualization of the anatomic structures offered by sonography.[4,18,19] Indeed, for the surgeon experienced in sonography, all structures are perfectly observed, including the location of the thenar branch and of the Berrettini medio-ulnar anastomosis, so sonographically guided surgery could be safer than open surgical dissection, especially by mini-open technique, and especially safer than endoscopy where only the TCL is seen from its deep surface. PCTR under sonography without tourniquet is in the opinion of the authors safer than ECTR and even safer than OCTR, provided that the surgeon master's sonography. The high success rate can also be attributed to the very minimally invasive technique that induces the least possible operative damage—only the TCL is sectioned, all other tissues are preserved.

Our hypothesis that PCTR is not only a safe and efficient method, but also cost-effective, has not been demonstrated, neither in our economic study nor in the literature review. However, it may still be cheaper, but only a prospective comparative trial including work compensation costs could demonstrate if it is the case.

The first source of costs is the investment needed to perform PCTR. PCTR compares unfavorably to OCTR, because of the cost of acquisition of the sonograph, but favorably to ECTR as the cost of the arthroscopy column and endoscope is higher. However, in some countries like Belgium, a medical fee code of sonography can be added to the medical fee code of the surgery and can allow reimbursing the investment. Another point to consider is that sonographs are already present in the operation rooms—to allow the anesthetists to perform sonography-guided nerve blocks, for example, so the equipment is frequently already available and financially amortized by other acts. Indeed, if in our study we had not considered the costs of acquisition of a sonography, considered in the study only for ECTR, but in fact used in our hospital for the 3 types of operations, PCTR for the surgeon and ECTR/OCTR for the anesthesiologists, then PCTR is the cheapest method. The same consideration applies to the arthroscopy column, used for wrist, shoulder, and knee arthroscopic procedures. It is also the case for the set of surgical instruments for hand surgery, used for other indications of hand surgery. For ECTR, a special fragile endoscope must be purchased, that cannot be used for other surgeries. This endoscope can break and then needs to be replaced. However, cheap portable sonographs are nowadays available on the market, but the authors insist that there should be no trade-off in the quality of sonographic imaging (high frequency) to allow perfect visualization of the hand tissues. If there is already a good sonograph in the operation ward, then the only investment necessary for PCTR is in our technique a buttoned stylus (see **Fig. 4**). Note that other surgeons use other instruments, for example, Petrover and Chern a sharped hook, Benquet a grooved director, and Markinson the Manos CTR system.[4,8,16,20,21]

The second source of costs, and one of the most important ones, is the duration of occupation of the surgical room. In our internal hospital billing system, these costs which include sterilization of the surgical instruments are the same, whatever the duration of CTS surgery (284.78€ per patient). A 2005 study of 100 US hospitals found that the costs of operating room occupation were on average $62/min (range, $22–$133/min), so a reduction of this duration, even by a few minutes, has a marked influence on the total costs of the operation.[22] The duration starts when the patient enters the room and ends when the patient leaves the room. We observed that the duration of occupation of the operative room was 43 min for OCTR, 47 min for PCTR, and 64 min for ECTR (the latter evaluated in only 3 patients). Lecoq *and colleagues*[6] reported an operative time from 10 to 15 min in their cadaver PCTR study; Petrover *and colleagues,*[4] an operative mean time of 19 minutes and a mean time of occupation of the operating room of 38 min; Nakamichi *and colleagues,*[15] a mean operative time of 54 min in their PCTR group and 48 min in their OCTR group. So, the duration of occupation of the operative room seems to be similar in the published studies, and even slightly higher for PCTR than OCTR.

Can we reduce the duration of occupation of the operation room? In our study, the duration of the surgery itself was similar, 15 min on average, whether for PCTR or OCTR. These 15 min include in PCTR the local anesthesia. The nonoperative time is used, for PCTR, for the installation of the ambulant patient, for a preoperative nonsterile sonographic evaluation of the carpal tunnel region, and for accompanying the ambulant patient to the changing room, after completion of the dressing. In OCTR, the nonoperative time is used for the bringing of the regionally anesthetized nonambulant patient and installation in the operation room (at our institution, regional blocks are done in advance in a separate room), for the induction of general anesthesia, if this is the modality of anesthesia, then after the operation for wakening the patient and bringing him/her on a stretcher to the recovery room. For PCTR, the nonsterile part of the procedure could possibly be shortened, if sonography is only done under sterile conditions.

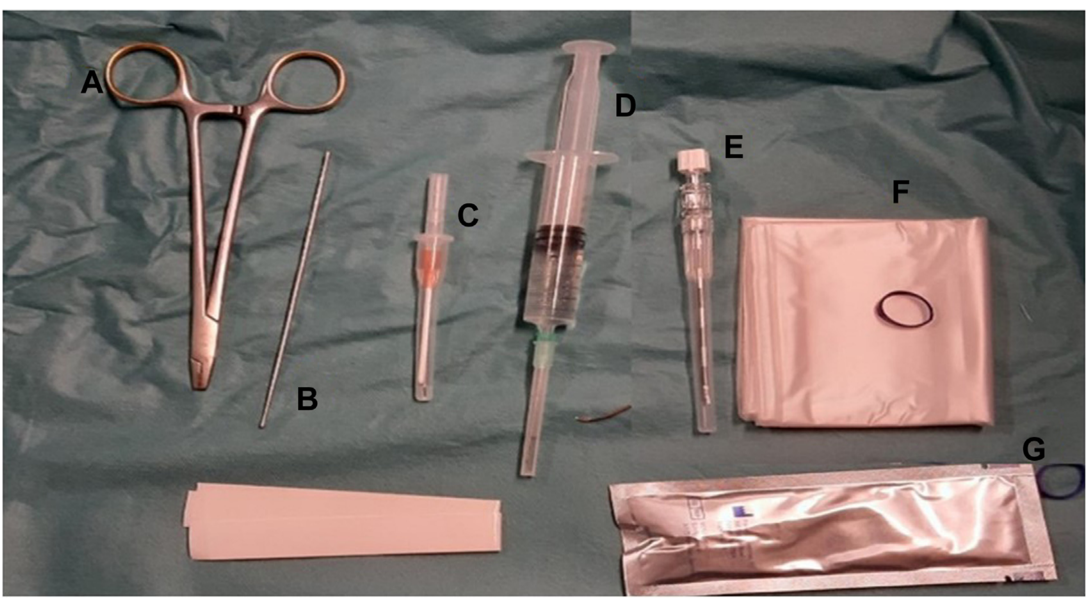

Fig. 4. Instruments used for PCTR in our center: (*A*) needle holder, (*B*) buttoned stylus, (*C*) 14G catheter, (*D*) syringe with anesthetic product, (*E*) Tuohy catheter, (*F*) cover for sonography probe, and (*G*) sterile ultrasound gel.

What would much change the operative costs would be to operate the patient in an outpatient clinic instead of in an operative room, which is perfectly possible given the fact that PCTR is done under pure local anesthesia with limited instrumentation, which is not possible for other techniques. We did not consider in this study another direct operative cost. PCTR can be performed by a single surgeon, without assistant, and even, if he/she opens sterile all material in advance, without a nurse. Obviously, OCTR and ECTR need at least a nurse in the operation room and if the anesthesia is not local, an anesthetist. Even though the OCTR can be done without an assistant, this is relatively unsafe and less efficient (longer operative time). In any case, PCTR, performed under local anesthesia, allows also to spare the costs of recovery room after regional or general anesthesia, frequently used for OCTR and ECTR—these costs were not considered in the present study.

The costs of the disposable and pharmaceutical products are in favor of PCTR, though the difference is modest with OCTR. We use two catheters (Tuohy and 14G). McShane *and colleagues* use an 18G needle,[4] Guo *and colleagues* use a metallic thread.[4] However, if for PCTR, a more sophisticated single-use instrument is used (eg, the Indiana Tome of Zimmer Biomet [cost: 225$]), then OCTR becomes cheaper. For Nakamichi *and colleagues*, PCTR surgery is more expensive because of the author using of many tools like sonographic gel and self-locking retractor.[15] We also observed that the pharmaceutical costs for local anesthesia are less than those for other anesthesia modalities.

The main source of reduction of costs of PCTR is probably for those patients still professionally active, the reduction of days off work. We could not study these indirect costs, and it is our experience in our academic hospital that most patients operated for CTS are not anymore working—active patients tend to choose private hospitals for CTS surgery. In this group of active patients, going back to work soon after the surgery can make a huge economical difference. However, there is no evidence yet in the literature that PCTR patients resume earlier their working occupations, but it can be assumed, as for ECTR, it has been demonstrated.

We recognize the limitations of our study. The size of our sample of patients was limited. The treatments were not randomized. Our protocol did not allow to measure the costs of recovery room nor the duration of days off work after the operation. Another limitation of the study is the low evidence level of the papers selected for the literature review. As there were few articles comparing PCTR to OCTR, we included also articles comparing ECTR to OCTR, and surgical technique to a nonsurgical technique.

SUMMARY

Our observational study does not show an economic advantage of PCTR. However, the lack of data on postoperative outcomes prevented us from determining a possible economic advantage in terms of earlier return of the patients to their professional activities, and we considered that a sonograph was needed only for PCTR, while actually a sonograph is also used for the anesthesiology in OCTR and ECTR. We anticipate also fewer iatrogenic complications after PCTR; neurovascular complications are reported after PCTR and ECTR and are costly. Further economic studies are needed, optimally through prospective randomized trials comparing functional results, complications, and costs between OCTR and PCTR.

We believe that PCTR will become quite popular in the coming years, as the morbidity is minimal, and the patient can resume his/her daily activities on the next day. The economic gains remain to be demonstrated.

AUTHOR CONTRIBUTIONS

R. Kinanga, F. Moungondo, and F. Schuind contributed to this article. The authors thank Frederic Schuind, MD, PhD (Past Head of the Department of Orthopaedics and Traumatology, Erasme University Hospital) for his contribution to the review of the paper and the acceptance of protocol.

CONFLICT-OF-INTEREST

The authors have nothing to disclose.

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