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GJOR
Global Journal of Orthopedics & Research

ISSN: 2687-816X
DOI: 10.33552/GJOR.2021.03.000568

Global Journal of Orthopedics Research

Iris Publishers

Review Article

Percutaneous Ultrasound-Guided Techniques for Carpal Tunnel Release: A Descriptive Review

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Received Date: August 27, 2021

Published Date: October 13, 2021

Abstract

Carpal tunnel syndrome (CTS) is a prevalent compressive peripheral neuropathy that often requires surgical treatment due to symptom severity or medical treatment failure. The recent popularity of ultrasound-guided (US) percutaneous surgery to treat these neuropathies has made this minimally invasive technique a good option over traditional open techniques. This review sought to identify, classify, and describe the minimally invasive percutaneous US-guided techniques reported in the literature for carpal tunnel release (CTR). Thirty reports were identified describing 22 different techniques. No systematic reviews addressing this topic were found. Of the 30 studies reviewed, only five (describing four techniques) were randomized controlled trials (RCT), three were non-randomized controlled trials, and 22 were uncontrolled studies. The technical characteristics most frequently described by the different authors were: 13 MHz US-probe, incisions 2 to 15 mm, section direction retrograde, incision orientation longitudinal, entry point carpal, with a single incision technique. As further characteristics, cutting instruments varied widely, few studies reported on the use of tourniquet and nearly all of them used local anesthesia. Our descriptive review shows that minimally invasive percutaneous US-guided surgery for CTR offers multiple technical possibilities. As only four of these techniques have been the focus of RTCs, more work is needed to assess the efficacy of this approach in improving the pain and hand functionality problems experienced by patients with CTS.

Keywords: Minimally invasive surgery; interventional ultrasound; percutaneous technique; carpal tunnel syndrome

Abbreviations: BCTQ: Boston carpal tunnel syndrome questionnaire; CT: Carpal tunnel; CTR: Carpal tunnel release; CTS: Carpal tunnel syndrome; DLA: Daily life activities; FR: Flexor retinaculum; MCID: Minimal clinical important difference; MeSH: Medical Subject Headings; MHz: Megahertz; MSN: Hanzhang miniscalpel-needle; NCV: Nerve conduction velocity; NoC: Studies without a control or comparison group; NoRCT: Non-randomized controlled studies; n.r: Not reported; PUSG: Percutaneous ultrasound-guided; Quick DASH: Quick–disabilities of the arm, shoulder, and hand questionnaire; RCT: Randomized controlled trial; SAPA: Superficial arterial palmar arch; SPA: superficial palmar aponeurosis; SR: Systematic reviews; TCL: Transverse carpal ligament; US: Ultrasound; WALANT: Wide awake local anesthesia no tourniquet

Introduction

Carpal tunnel syndrome (CTS) is the most common of all compressive peripheral neuropathies affecting some 88 men and 193 women per 100,000 [1]. While it is frequently idiopathic, it may be the consequence of increased carpal tunnel (CT) pressure, ischemic changes within the nerve, or compression of adjacent structures [2,3]. Clinically, CTS causes tingling, pricking, numbness, pain, swelling, or stiffness in the first three fingers of the hand. These symptoms will often awake the patient during the night and lead to hand weakness and atrophy of the thenar muscles [2,4]. The diagnosis is mainly clinical and confirmed by tests such as nerve conduction velocity (NCV), monofilament, and 2-point discrimination [3,5]. In milder cases, treatment for CTS can be conservative, but there is strong evidence to support the use of surgical treatment to improve symptoms [4]. The prognosis for surgically treated CTS is good, with a success rate of 86% [6].

Although open release of the CT is the most common surgical procedure, it has been associated with complications like postsurgical pain, dysesthesia and loss of grip strength [7]. To minimize these complications, new surgical techniques have been developed in the past 30 years for sectioning the flexor retinaculum (FR) and releasing the median nerve in the CT. These techniques can be open, mini-open, or percutaneous. The latter can be guided by ultrasound (US) or by endoscopic visualization [8]. The objectives of these newer procedures have been to reduce the length of the surgical incision, generating an ever-smaller scar associated with less postoperative pain and a sooner return to work. However, these approaches also have some shortcomings related to the compromised visualization of the median nerve and its terminal branches, the vascular structures around the wrist, and any anatomic variants that might be present, thereby increasing the risk of complications during CT release (CTR) surgery [9,10]. Several CTR procedures conducted under direct US-guidance have been described since, in 1997, Nakamichi and Tachibana described the first US-guided CTR technique [11]. These procedures have been classified according to the surgical access route (anterograde or retrograde), approach (palmar or wrist), and cutting instrument [8]. In this article, we review and update all percutaneous US-guided (PUSG) techniques described in the scientific literature that we were able to identify.

Materials and Methods

Eligibility criteria

The studies identified were those in which only a PUSG technique of CTR was examined. There were no filters on study design, comparison intervention, follow-up duration, or publication date or language (English, Spanish, German, or French). Participants were required to have primary CTS. Cadaveric studies were also included. Exclusion criteria were patient studies testing percutaneous techniques with endoscopic visualization, and participants of those studies with secondary CTS or undergoing repeat CTR surgery. Besides original articles, abstracts of presentations at conferences and articles only describing the surgical technique were also included.

Search methods

The MEDLINE database was searched through Pubmed in December 2020 using the terms: (systematic [sb]) AND""Carpal Tunnel Syndrome / surgery"" [Mesh]. However, as no systematic review that met the inclusion criteria was found, we extended the search to: (Ultrasonography [Mesh]) AND "Carpal Tunnel Syndrome/ surgery" [Mesh]. We also revised the reference lists of the most relevant studies and also included one RCT by the present authors [12].

Studies were classified according to evidence level into systematic reviews (SR), randomized controlled clinical trials (RCT), non-randomized controlled studies (NoRCT), and studies without a control or comparison group (NoC). Due to the descriptive nature of this work, we did not assess the quality of the studies. To avoid further bias, we only consider the results obtained only in RCTs.

To describe the techniques used, we compiled data regarding: 1) the resolution of the US probe; 2) sonographer experience; 3) incision sizes; 4) anterograde or retrograde sections; 5) longitudinal or transverse incisions; 6) proximal or distal entry point; 7) number of incisions; 8) cutting instruments used; 9) use of tourniquet; and 10) anesthesia.

Result

Result of the search

Thirty studies meeting the inclusion/exclusion criteria were identified in our search. The results of the search are shown in (Figure 1).

Types of study

No SR comparing PUSG techniques of CTR with any other intervention were found. Only 5of the 30 studies reviewed here describing 4 different techniques were RCT [11–15]; a further 3 studies were NoRCT [10,16,17]; and 22 were NoC [18–39].

We considered the risk of bias of the study by Guo et al. [24] as high and classified it as NoC without taking into account its results. In this study, conducted in an initial series of 116 patients, 159 wrists were operated on. In the first 23 wrists (not specified how many patients), triamcinolone mixed with 0.5% lidocaine was used for hydro dissection. For the remaining 136 wrists, the authors no longer used steroids. After surgically treating 48 wrists, one step of their intervention was modified. The authors compared their results in 159 wrists (116 patients) with those of other authors [40] who reported on a group of 75 patients (96 wrists) who underwent endoscopic CTR, and on another group of 72 patients (95 wrists) who underwent open CTR surgery.

Furthermore, Buncke et al. and Markison [18,34] described in the same year the use of the same technique in a series of 3 patients, 2 men and 1 woman. Although we have considered them as different studies, we cannot be sure that this was really the case.

Publication years

The earliest study reviewed was the first to describe a PUSG technique [11]. A further 26 of the 30 studies included were published between 2013 and 2020.

Participants

Of the 30 studies identified, in 18 participants were patients with CTS. A further 9 were cadaver studies and the remaining 3 articles were descriptions of the surgical technique. In the 5 RCTs included, 378 patients were treated, mostly women (range 54% to 100%) of a mean age of 55.1 years (range 47 to 63 years). One NoC study [28] included patients with some disability (4 of the 10 patients).

Interventions

The 30 studies reviewed described 22 different surgery techniques. The technical characteristics described by the different researchers varied widely and are described in Tables 1, 2, and 3, for RCT, NoRCT, and NoC, respectively. The most used US-probe was 13 MHz (6 of the 25 studies reported on this), although frequencies ranged from 10 to 18 MHz. Only six reports considered sonographer experience, and this varied from 5 to 20 years. Incision size varied between 2 and 15 mm. With regard to section direction, 19 groups preferred retrograde, 8 anterograde, and two groups sectioned in the direction dorsal to volar. Incision orientation was preferably longitudinal (23 out of 29 studies). The most common entry point was carpal or proximal (24 out of 29 studies). Most surgeons opted for a single incision technique, 23 out of 30. Cutting instruments varied widely. In five reports, the US-guided technique was combined with the endoscopic one, and different types of endoscopes were used for the FR section [29,30,33,34,39]. Few studies reported on the use of a tourniquet while most used local anesthesia. Eight research groups reported they performed hydro dissection, and those of one study [20] reported they used the WALANT (wide awake local anesthesia no tourniquet) technique. Three studies by two groups [15–17] undertook steroid injection in the same surgical act as FR section.

Table 1: Details of the RCTs included in this review and their outcomes.

Authors year	N Population	Intervention characteristics	Comparison	Follow-up	Outcomes
Capa-Grasa et al., 2014 [13]	40 patients: 20 in the PUSG group (mean age 63 years), 20 in the comparison group (mean age 58 years)	US probe resolution: 5–11 MHz.Sonographer experience: n. r.Incision size: ≤ 1 mm Section direction: retrograde Incision direction: longitudinal or transverse Anesthesia: n. r.	Mini-open technique with 2 cm incision	3 months	QuickDASH better (lower score) in PUSG group (differences 28, 21 and 14 points for the first, third and sixth weeks, respectively). No significant differences in week 12.
de la Fuente et al., 2020 [12]	92 patients: 54% women, 47 in the PUSG group (mean age 47 years), 42 in the open surgery group (mean age 49 years)	US probe resolution: 13–7.5MHz Sonographer experience: more than 20 years Incision size: 5-10mm.Section direction: anterograde Incision direction: transverse	Open technique	12 months	Symptoms: no significant differences in BCTQ. The number of patients showing an MCID was significantly higher in the PUSG group.
Nakamichi and Tachibana 1997 [11]	103 women, mean age 58 years, 50 years in the PUSG group, and 53 years in the open technique group	US probe resolution: 10 MHz Sonographer experience: n.r. Incision size: 1-1.5 cm Section direction: retrograde Incision direction: longitudinal or transverse Entry point: palmar Incision number: single Cutting instrument: for the distal section basket punch (2.7 mm external diameter) with direct vision and for the proximal section an metal tube (3.5 mm external diameter). Upper jaw of basket fully open with a height of 2.8 mm. Tourniquet: yes Anesthesia: local	Open technique	Up to 26 months	No significant differences
Rojo Manaute et al., 2016 [14]	92 patients, 60% women, mean age 58 years: 46 in the PUSG group and 46 in the open technique group.	US probe resolution: 6–15-MHz Sonographer experience: n. r. Incision size: 1 mm Section direction: retrograde Incision direction: longitudinal or transverse Entry point: carpal, first available antebrachial skin crease 2 cm proximal to the pisiform Incision number: single Cutting instruments: mini retractors, surgical scissors and Kocher guide Tourniquet: n. r. Anesthesia: n. r.	Open technique with 2 cm incision	12 months	QuickDASH score better in the PUSG group at 12 months (1.6 vs 5.3 points). Faster discontinuation of oral analgesics in the PUSG group (2 vs 13 days). Faster return to DLA in the PUSG group (5 vs 25 days).
Zhang et al., 2019 [15]	51 patients, 46 with complete follow-up. 72% women. 25 (23 with complete follow-up) in the PUSG group + US-guided betamethasone infiltration, 26 (23 with complete follow-up) in the US-guided betamethasone infiltration group. Mean ages 49 and 53 years respectively.	US probe resolution: 8-12 MHz Sonographer experience: n. r. Incision size: 1 mm just enough to introduce the MSN Section direction: anterograde Incision direction: not applicable Entry point: carpal Incision number: single Cutting instruments: MSN, and 25 G needle Tourniquet: n. r. Anesthesia: local, 2.0 ml of 1% lidocaine. In addition, in the two groups, 1.0 ml of betamethasone (2 mg of betamethasone sodium phosphate and 5 mg of betamethasone dipropionate) were injected around the median nerve together with 1.0 ml of 1% lidocaine	US-guided betamethasone infiltration	3 months	In both groups, all parameters improved significantly compared to baseline data. BCTQ results, for both symptoms and function significantly better in the PUSG plus infiltration group, 1.8 vs 2.1 points. NCV test results significantly better in the PUSG group plus infiltration.

Table 2: Details of the non-randomized controlled studies included in this review.

Authors year	N Population	Intervention characteristics	Authors year	N Population	Intervention characteristics
Guo X. et al., 2017 [17]	52 patients: 8 male, 44 female, 56 wrists.28 wrists in the group US-guided steroid injection plus PUSG with needle. 28 wrists in the group with only one US-guided steroid injection.	US probe resolution: 5–12 MHz Sonographer experience: n. r. Incision size: to accommodate a 22 G needle Section direction: anterograde Incision direction: not applicable Entry point: carpal, in the space of the 3rd and 4th flexor tendons, transverse to the proximal plane of the pisiform bone. The needle was used repeatedly to section the TCL from proximal to distal in a direction parallel to the median nerve under continuous US guidance. Incision number: single Cutting instruments: standard 22 G needles, hypodermic needle and 5 ml syringe Tourniquet: n. r. Anesthesia: local, 4.0 ml of 2% lidocaine and 0.9% sodium chloride in a 1:1 ratio. US-guided injection with the tip of the hypodermic needle introduced in common flexor sheath and flexor pollicis longus tendon sheath with mixture of 1 ml of 2% lidocaine, 1 ml of 0.9% sodium chloride and 0.5 ml betamethasone	Guo X. et al., 2017 [17]	52 patients: 8 male, 44 female, 56 wrists.28 wrists in the group US-guided steroid injection plus PUSG with needle. 28 wrists in the group with only one US-guided steroid injection	US probe resolution: 5–12 MHz Sonographer experience: n. r.Incision size: to accommodate a 22 G needle Section direction: anterograde Incision direction: not applicable Entry point: carpal, in the space of the 3rd and 4th flexor tendons, transverse to the proximal plane of the pisiform bone. The needle was used repeatedly to section the TCL from proximal to distal in a direction parallel to the median nerve under continuous US guidance. Incision number: single Cutting instruments: standard 22 G needles, hypodermic needle and 5 ml syringe Tourniquet: n. r. Anesthesia: local, 4.0 ml of 2% lidocaine and 0.9% sodium chloride in a 1:1 ratio. US-guided injection with the tip of the hypodermic needle introduced in common flexor sheath and flexor pollicis longus tendon sheath with mixture of 1 ml of 2% lidocaine, 1 ml of 0.9% sodium chloride and 0.5 ml betamethasone.
Guo X. et al., 2018 [16]	49 patients: 12 males and 38 females, 50 wrists. 25 wrists in the US-guided steroid injection plus PUSG with needle group, and 25 wrists in the group with only one US-guided steroid injection	The same as in Guo X. et al., 2017 [17]	Guo X. et al., 2018 [16]	49 patients: 12 males and 38 females, 50 wrists. 25 wrists in the US-guided steroid injection plus PUSG with needle group, and 25 wrists in the group with only one US-guided steroid injection	The same as in Guo X. et al., 2017 [17]
Nakamichi et al., 2010 [10]	49 patients: 12 males and 38 females, 50 wrists. 25 wrists in the US-guided steroid injection plus PUSG with needle group, and 25 wrists in the group with only one US-guided steroid injection	US probe resolution: n. r. Sonographer experience: n. r. Incision size: 4 mm Section direction: retrograde Incision direction: not applicable Entry point: palmar, at the intersection of the SAPA with a line midway between the ulnar margin of the median nerve and the radial margin of the ulnar artery. The section was extended 5 to 10 mm proximal to the wrist crease. Incision number: single Cutting instruments: angled scalpel (single use) with guide and holder Tourniquet: no Anesthesia: local	Nakamichi et al., 2010 [10]	65 women, 74 wrists, mean age 58 years, 29 women (35 wrists) in the PUSG group and 36 women (39 wrists) in the open technique group	US probe resolution: n. r. Sonographer experience: n. r. Incision size: 4 mm Section direction: retrograde Incision direction: not applicable Entry point: palmar, at the intersection of the SAPA with a line midway between the ulnar margin of the median nerve and the radial margin of the ulnar artery. The section was extended 5 to 10 mm proximal to the wrist crease. Incision number: single Cutting instruments: angled scalpel (single use) with guide and holder Tourniquet: no Anesthesia: local

Abbreviations: TCL: Transverse carpal ligament; PUSG: Percutaneous ultrasound-guided; n.r.: Not reported; SAPA: Superficial arterial palmar arch; US: ultrasound.

Table 3: Details of the uncontrolled studies included in this review.

Authors year	N Population	Intervention characteristics
Buncke et al., 2013 [18]	3 patients: 2 male, 1 female (ages: 42, 72 and 82 years)	US probe resolution: 10 MHz Sonographer experience: n. r. Incision size: 5 mm Section direction: dorsal to volar Incision direction: longitudinal or transverse Entry point: carpal, 2 cm proximal to the distal crease of the wrist, exit point intersection of the Kaplan cardinal line in line with the web of the third and fourth fingers Incision number: double Cutting instruments: MANOS CTR ™, 14-gauge blunt synovial dissector Tourniquet: no Anesthesia: n. r.
Burnham et al., 2017 [19]	14 lightly embalmed cadaveric distal forearm and hand specimens, 12 male, 2 females, 7 right, 7 left, mean age 83 years	US probe resolution: 6-15 MHz Sonographer experience: 5 years Incision size: to accommodate an 18 G needle Section direction: retrograde Incision direction: not applicable Entry point: carpal Incision number: double Cutting instruments: 5 mL of saline solution for hydrodissection, two Quincke tip 18 G needles Tourniquet: not applicable Anesthesia: not applicable
Candelier and Apard, 2016(Candelier and Apard, 2016)	100 patients: 85 female, 15 male, mean age 62 years	US probe resolution: 6-15 MHz Sonographer experience: n. r. Incision size: n. r. Section direction: n. r. Incision direction: n. r. Entry point: n. r. Incision number: single Cutting instruments: Kemisy knife (NewClip Technics™) Tourniquet: no Anesthesia: WALANT
Chern et al., 2015 [21]	80 patients: 62 female, 18 male, 91 wrists, mean age 51 years	US probe resolution: 5-10 MHz Sonographer experience: n. r. Incision size: 2 mm for an 18 G needle on the carpal wound and 1 mm on the palm Section direction: anterograde Incision direction: not applicable Entry point: carpal, 1 cm proximal to the flexor crease of the wrist and 5 mm distal to the metacarpal shaft-base junction Incision number: double Cutting instruments: specially designed probe, easily fashioned using an electric grindstone from a 1.8 mm Kirschner wire and two different custom made hook knives Tourniquet: no Anesthesia: 3 mL of 1% lidocaine
de la Fuente et al., 2013 [22]	10 fresh cadavers: 6 male, 4 female, 20 wrists	US probe resolution: 7.5-13 MHz Sonographer experience: more than 20 years Incision size: 1.5 cm Section direction: anterograde Incision direction: transverse Entry point: carpal, at the most distal skin fold of the wrist, starting at the palmaris longus tendon and incising in an ulnar direction Incision number: double Cutting instruments: metallic surgical probe with a "U"-shaped trough, scalpel with a V-shaped blade of distance between blade points 5 mm Tourniquet: not applicable Anesthesia: not applicable
Dekimpe et al., 2019 [23]	14 wrists of unembalmed cadavers	US probe resolution: 18 MHz Sonographer experience: one radiologist with 5 years, another one with no experience Incision size: to accommodate a 21 G needle Section direction: retrograde Incision direction: longitudinal or transverse Entry point: carpal, on the skin fold of the wrist Incision number: single Cutting instruments: Acufex 3 mm hook knife (010600; Smith & Nephew), scalpel 11 blade, 21 G needle, 10 mL syringe, 1% lidocaine for hydrodissection Tourniquet: not applicable Anesthesia: not applicable

Guo D. et al., 2015 [26]	20 patients: 34 wrists, 12 female, 8 male, mean age 53 years	US probe resolution: 12 MHz Sonographer experience: n. r. Incision size: to accommodate an 18 G needle Section direction: retrograde Incision direction: not applicable Entry point: carpal, 2 cm proximal to the distal crease of the volar wrist and between the median nerve and the ulnar artery. Exit point at the intersection of Kaplan's line and the radial aspect of the third finger extension Incision number: double Cutting instruments: 18 G 90 mm-long spinal needle; dividing thread; powered hand tool; protective tube. Dividing thread GuoPercutaneousWire™ (Ridge & Crest Company): medical grade thread with friction coefficient of 0.22; thread ends stiffened by inserting 0.5 mm-diameter, 95 mm-long tubes. Tourniquet: n. r. Anesthesia: local and hydrodissection in 17 patients, general in 3 patients
Guo D. et al., 2016 [25]	11 unembalmed cadaveric wrists	US probe resolution: n. r. Sonographer experience: n. r. Incision size: to accommodate a 27 G needle Section direction: anterograde Incision direction: not applicable Entry point: palmar, 5 mm distal to the SAPA, distal edge of the TCL division determined sonographically in the "duck's beak" described by Rojo Manaute et al.(38)a previously reported sonographic zone was defined as the space between the median nerve and the closest ulnar vascular structure. Axially, the safest theoretical cutting point for carpal tunnel release was set by bisecting this zone. Magnetic resonance imaging was used for axially determining the limits of the sectors (origin at the cutting point. Needle exit point determined as the proximal edge of TCL located 2 cm proximal to the distal crease of the wrist. Needles followed a distal to proximal course within the "safe zone" between the median nerve and ulnar artery. Incisions number: double Cutting instruments: 1.5 inch 27 G needles, 3.5 inch 18 G spinal needles; 0.9% saline solution for hydrodissection and surgical dissecting thread (Loop&Shear, 0.009 inch in diameter; Ridge & Crest Company) Tourniquet: n. r. Anesthesia: n. r.
Guo D. et al., 2017[24]	116 patients: 159 wrists, 77 female, 39 male, mean age 55 years, 17 patients diabetic The first 48 patients operated on by step 3, and the remaining patients by a modified step 3, preserving the SPA	US probe resolution: n. r. Sonographer experience: n. r. Incision size: to accommodate an 18 G needle Section direction: anterograde Incision direction: not applicable Entry point: palmar, same as in Guo D. et al., 2016(25) Incision number: double Cutting instruments: 1 inch 30 G needle, 1.5-inch 27 G needle, 2 x 3.5 inch 18 G spinal needles, 0.009 inch surgical dissecting thread (Loop&Shear™, Ridge & Crest Company) Tourniquet: n. r. Anesthesia: local and hydrodissection, with 5 mL of 1% lidocaine and 10 mL of 0.5% lidocaine
Hebbard et al., 2018 [27]	10 frozen cadaver wrists	US probe resolution: 6–13 MHz Sonographer experience: n. r. Incision size: to accommodate diameter of micro i-Blade Section direction: retrograde Incision direction: not applicable Entry point: carpal, just proximal and on the ulnar side of the appearance of the median nerve from the depth of the flexor digitorum superficialis Incisions number: single Cutting instruments: micro i-Blade (Summit Medical Products) Tourniquet: n. r. Anesthesia: n. r.
Henning et al., 2018 [28]	14 patients: 18 wrists, mean age 64 years, 10 patients without disabilities, 1 with post-polio syndrome, 1 with multiple sclerosis and 2 with paraplegia. The first 8 patients, 12 wrists, operated in the operating room, the rest in an outpatient setting	US probe resolution: 6-15 MHz and 5-18 MHz Sonographer experience: more than 8 years Incision size: 4-5 mm Section direction: retrograde Incision direction: longitudinal Entry point: palmar Incision number: single Cutting instruments: SX-One MicroKnife®, 2 x 25G 50 mm needles, hydrodissection of the median nerve of the flexor tendons and the TCL using 10 mL 0.9% saline solution, # 15 scalpel blade, Steri-Strips or 4-0 nylon sutures Tourniquet: n. r. Anesthesia: patients treated in the operating room with general anesthesia, those in the outpatient room with local anesthesia, 8 mL of 1% lidocaine without epinephrine

Lecoq et al., 2011 [30]	107 cadaver wrists	US probe resolution: 15 MHz Sonographer experience: n. r. Incision size: 5 mm Section direction: retrograde Incision direction: transverse Entry point: carpal, 1 cm proximal to the proximal wrist flexion crease Incision number: single Cutting instruments: 5 mm arthroscope trocar with sheath and retrograde knife Tourniquet: n. r. Anesthesia: n. r.
Lecoq et al., 2015 [29]	39 patients: 15 male, 24 female, aged 21 to 86 years	US probe resolution: 13 MHz Sonographer experience: n. r. Incision size: 5 mm Section direction: retrograde Incision direction: transverse Entry point: carpal, 1 cm proximal to the proximal wrist flexion crease Incision number: single Cutting instruments: 5 mm arthroscope trocar with sheath and retrograde knife Tourniquet: no Anesthesia: local with 10 to 20 mL of lidocaine
Markison, 2013 [31]	3 patients, 2 male, 1 female, aged 65 to 76 years	US probe resolution: 6-13 MHz Sonographer experience: n. r. Incision size: 3 mm Section direction: dorsal to volar Incision direction: transverse Entry point: carpal, 1.0-1.5 cm proximal to the distal crease of the wrist and just ulnar to the palmaris longus, exit point on Kaplan's cardinal line Incision number: double Cutting instruments: MANOS CTR ™, MANOS Hand Board, 3-4 mm Hegar Uterine Dilator Tourniquet: yes to 250 mmHg Anesthesia: local, 1% xylocaine with epinephrine just below the dermis at the entry and exit points
Mittal et al., 2019 [32]	16 lightly embalmed forearm and hand specimens, 8 right, 8 left. Mean age 77 years	US probe resolution: 10-15 MHz Sonographer experience: over 5 years Incision size: 1 mm Section direction: retrograde Incision direction: n. r. Entry point: carpal, 2-3 cm proximal to the distal wrist crease Incision number: single Cutting instruments: Acufex 010600 (Smith & Nephew PLC) 3 mm hook knife, 18 G needle, 1.5 mm blunt K wire Tourniquet: n. r. Anesthesia: n. r.
Ohno et al., 2016 [33]	20 patients: 8 male (9 wrists), 12 female (13 wrists). Mean age 70 years (range 45–84 years)	US probe resolution: 12-MHz Sonographer experience: n. r. Incision size: minimum to insert arthroscope Section direction: retrograde Incision direction: n. r. Entry point: carpal Incision number: single Cutting instruments: arthroscope (Karl-Storz GmbH & Co.), tube has an outer diameter of 6 mm, inner diameter of 4 mm, a bevel-shaped barrel with a length of 175 mm and retrograde hook knife Tourniquet: no Anesthesia: local, 10 mL of 1% lidocaine solution with epinephrine 1:1OO,OOO applied to the skin over the palmaris longus tendon, 3 cm proximal to the distal transverse carpal crease and into the carpal tunnel
Ohuchi et al., 2016 [34]	Only technique described	US probe resolution: 6-13 MHz Sonographer experience: n. r. Incision's size: 1 cm Section direction: retrograde Incision direction: longitudinal or transverse Entry point: carpal, entry point on the ulnar side of the palmaris longus tendon at the level of the proximal wrist flexor crease, exit point on palm surface (0.5-0.75 cm in length) on the bisect line of the angle formed from the distal border of the fully abducted thumb and the third web space and approximately 1 cm proximal to the junction of these lines, locating the SAPA with the Doppler and respecting a safety zone Incision number: double Cutting instruments: arthroscope ECTRA 2 Carpal Ligament System curved dissector, slotted cannula, and 3 types of knives: probe, triangle and retrograde (Smith & Nephew Endoscopy) Tourniquet: n. r. Anesthesia: n. r.

Petrover et al., 2017 [35]	129 patients: 69.8% female, mean age 61.5 years	US probe resolution: 18 MHz Sonographer, experience:12 years, Incision size: 2-5 mm Sections direction: retrograde Incision direction: n. r. Entry point: carpal Incisions number: single Cutting instruments: # 16 scalpel, 3.0 mm Acufex hook knife, 26 G needle for subcutaneous anesthesia and 22 G for carpal tunnel Tourniquet: n. r. Anesthesia: 3 mL
Petrover et al., 2018[36]	Only technique described	US probe resolution: n. r. Sonographer experience: n. r. Incision size: as needed for the 3.0 mm diameter of the Acufex hook knife Sections direction: retrograde Incision direction: n. r. Entry point: carpal Incisions number: single Cutting instruments: # 15 scalpel, 3.0 mm Acufex hook knife (010600; Smith & Nephew PLC), 25 G and 21 G needles Tourniquet: no Anesthesia: local subcutaneous and hydro dissection of the median nerve with 10 mL of 1% xylocaine
Rajeswaran et al., 2016 [37]	Only technique described	US probe resolution: high frequency without further specification Sonographer experience: n. r. Incision size: 5 mm Section direction: retrograde Incision direction: transverse Entry point: carpal, transverse incision in the antebrachial skin crease slightly ulnar to the median nerve and 2 to 3 cm proximal to the pisiform Incision number: single Cutting instruments: scalpel, McDonald elevator, 3 mm retrograde hook knife (Smith & Nephew), 10 ml Luer lock syringe Tourniquet: n. r. Anesthesia: local, lidocaine with epinephrine
Rojo-Manaute et al., 2013 [38]	10 formaldehyde-preserved upper limbs detached from the body 25 cm above the elbow	US probe resolution: 11 MHz Sonographer experience: n. r. Incision size: 1 mm Section direction: retrograde Incision direction: longitudinal or transverse Entry point: carpal Incision number: single Cutting instruments: blunt 1.5-mm Kirschner wire, Acufex 3.0 mm hook knife (010600; Smith & Nephew PLC) Tourniquet: not applicable Anesthesia: not applicable
Rowe et al., 2005 [39]	6 fresh frozen/thawed cadaver upper extremities	US probe resolution: 10 MHz Sonographer experience: n. r. Incision size: 6 mm Section direction: retrograde Incision direction: transverse Entry point: carpal, on the ulnar side of the palmaris longus tendon at the proximal volar wrist crease Incision number: single Cutting instruments: standard single-port endoscope/cutting device (Carpal Tunnel Release System, MicroAire) with sectioning instrument Tourniquet: not applicable Anesthesia: hydro dissection with 5-10 mL of saline solution

Abbreviations: n. r.: Not reported; SAPA: Superficial arterial palmar arch; SPA: Superficial palmar aponeurosis; TCL: Transverse carpal ligament; WALANT: Wide awake local anesthesia no tourniquet

The technique encompassing the most used characteristics of the interventions described in the articles reviewed would be one carried out with a 13 MHz transducer, involving a 3 mm longitudinal incision, with a single carpal entry point, involving a retrograde section, and performed under local anesthesia (Figure 2).

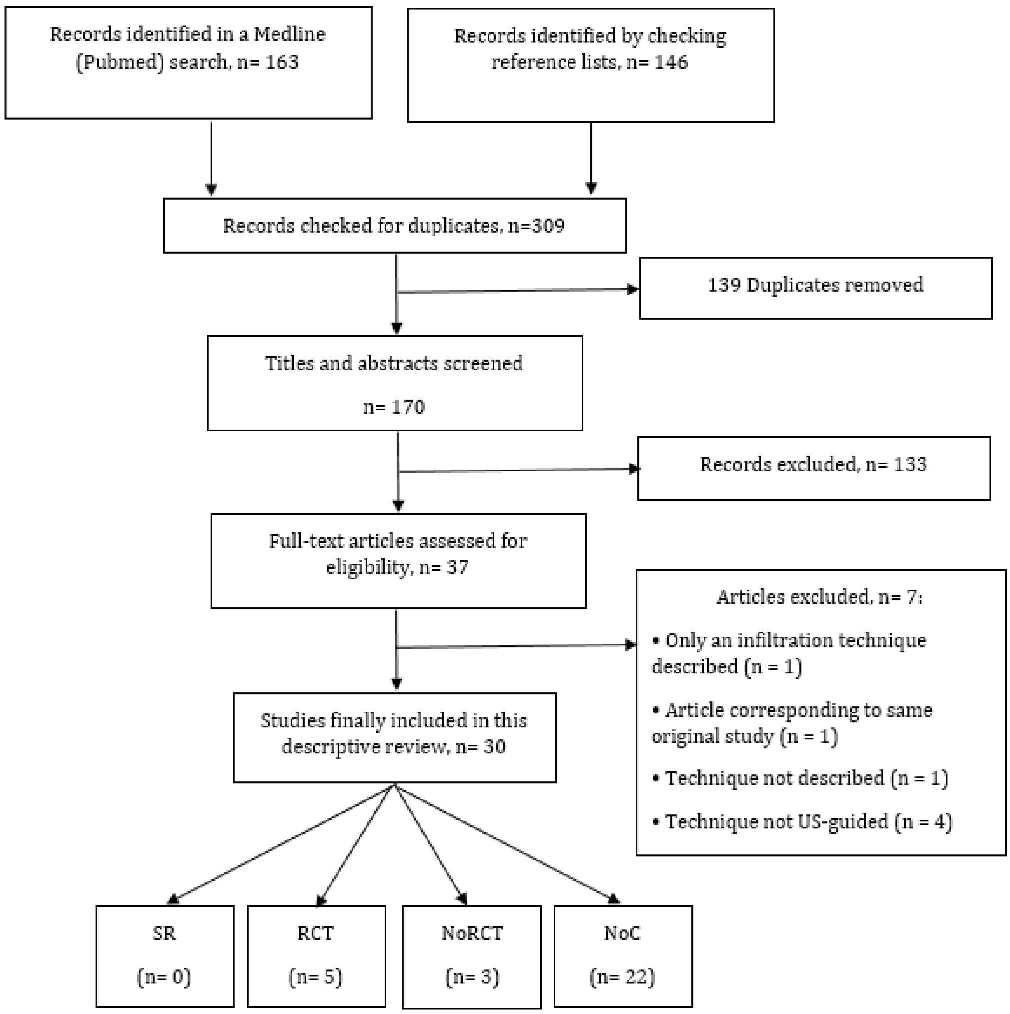

Figure 1: Study flow diagram.
Abbreviations: SR: Systematic reviews; RCT: Randomized clinical trials; NoRCT: Non-randomized controlled studies; NoC: Studies with no control or comparison group; US: Ultrasound

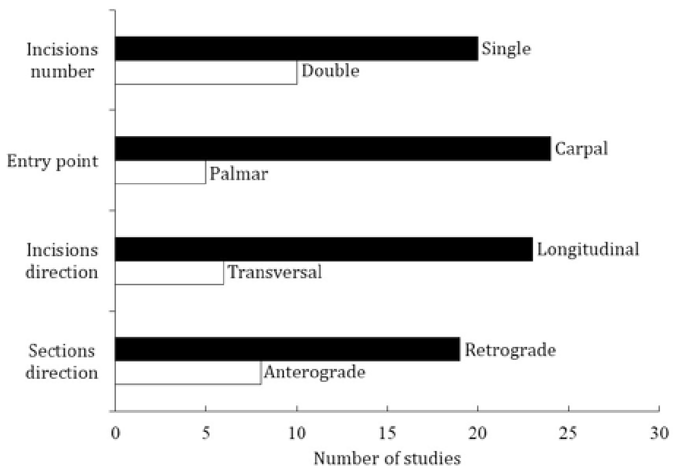

Figure 2: Frequency in the use of some characteristics of the techniques described in the studies included in this review.

The instruments used to section the FR were essentially different in each group and included different types of scalpels with various tips and blades, sectioning instruments of the endoscopes used, sectioning instruments designed ad hoc for this purpose, even with a built-in electro stimulator, surgical section threads and different types of needles.

Comparison intervention in the randomized controlled trials

Four of the RCTs included [11-14] used a comparison group subjected to one open technique. In contrast, in their comparison group, Zhang et al. [15] infiltrated betamethasone under US-guidance.

Outcomes of the randomized controlled trials

The outcome measure in the two RCTs by Rojo-Manautes' group [13,14] was the Quick-Disabilities of the Arm, Shoulder, and Hand Questionnaire (QuickDASH). In their reports, they described improved results of this questionnaire, which were more significant in the first weeks after surgery. We are unaware of the clinical relevance of these improvements, as minimal clinically important differences (MCID) were not reported [41]. In both papers, a greater number of complications were described for the group subjected to the open surgery technique.

Nakamichi and Tachibana [11] observed no significant differences in numbness, paresthesia, electrophysiological, or sensory test results between their PUSG and open technique groups. Although small in magnitude, they found significant differences in pain and scar sensitivity, both measured on a 4-point Likert-type scale (maximum difference 0.7 points at 13 weeks for both variables). Significant differences also emerged in hand grip strength (maximum difference 3.1 kg at 3 weeks) and key-pinch strength (maximum difference 0.53 kg at 3 weeks). No complications were detected in either of the two groups.

To assess symptoms and functionality, Zhang et al. [15] used the Boston Carpal Tunnel Syndrome Questionnaire (BCTQ). These investigators noted significant differences, albeit small in magnitude, in symptoms, function, compound muscle action potentials, sensory conduction velocity, and median nerve cross-sectional area, all in favor of the PUSG technique.

In our RCT [12], we detected no significant differences in symptom severity as assessed through the BCTQ. However, the number of patients showing a minimal clinically important difference (MCID) [42] following surgery in the PUSG surgery group was significantly higher. In contrast, when we assessed functionality also using the BCTQ, the differences were significantly greater in the PUSG group. However, numbers of patients showing MCID were not different between the two groups, and neither were their differences in complications between the groups.

Discussion

To our knowledge, this is the first study to describe and classify all PUSG techniques of CTR. Of the 30 articles reviewed, 22 are descriptive works with no comparison group, three are non-randomized controlled studies, and five are randomized controlled trials. This paper allows a quick review and update of the PUSG techniques of CTR described in the literature and should help surgeons choose the technique that best suits their needs, skills, and preferences. Contrary to the case of endoscopic CTR techniques, for which numerous publications exist allowing for detailed SRs of more than 20 original studies [43,44], we were unable to find any SR that analyzes and synthesizes the efficacy of PUSG techniques for CTR.

Besides enabling the localization of possible anatomical variants, US offers the possibility of marking the safety zones of the CT. In effect, US visualization can be adapted to all percutaneous techniques, providing an expanded field of view and therefore offering greater safety. According to the study by Dekimpe et al. [23], the learning curve for the US-guided CTR is short. In this cadaver study, two radiologists with different experience were able to perform a complete section of the FR after only two previous attempts. We would thus encourage young physicians to acquire skills in this technique, which, as already mentioned, has benefits both in terms of diagnosis and treatment.

Every medical procedure has its contraindications. Henning et al. proposed the following for the PUSG technique of CTR: 1) inability to adequately visualize structures at risk, including the thenar motor branch and recurrent motor branch of the median nerve, the palmar cutaneous branch of the median nerve, ulnar vessels, superficial palmar arch, and median and ulnar palmar digital nerves; 2) presence of anatomical variants that would make it impossible to create a safe transverse zone; and 3) presence of a mass or other event that would require treatment other than a FR section [28].

A limitation of our review is that its design does not allow for any conclusions regarding the effectiveness of the different PUSG techniques for CT section. While we provide the results of the five RCTs described to date, there is still a need for a comprehensive SR, including a more complete bibliographic review, peer assessment of the relevance and quality of the original articles, an analysis of heterogeneity and, if appropriate, a meta-analysis of the extracted data.

Considering the reports by Huisstede et al. and Zhang et al. (Huisstede et al., 2010; Zhang et al., 2019), another topic of future investigation would be to explore whether irrigation or steroid infiltration of the median nerve before skin closure after percutaneous RF section has any added effect to exclusively that of mechanically releasing the CT. To establish whether any of the techniques described here is more effective than another, there is also a need for adequately designed RCTs, preferably considering MCID. The conclusions to be drawn from our descriptive review are that: 1) PUSG surgery for CTR offers multiple technical possibilities;

2) no technique has been shown to be more effective than another in a RCT; 3) SRs are needed to establish whether PUSG are better than open techniques in reducing symptoms and improving hand functionality in patients with CTS; and 4) more RCTs are needed to establish the most effective PUSG techniques.

Conclusion

The present review shows that minimally invasive percutaneous US-guided surgery for CTR offers multiple technical possibilities. As only four of these techniques have been the focus of RTCs, more work is needed to assess the efficacy of this approach in improving the pain and hand functionality problems experienced by patients with CTS.

Acknowledgement

The authors thank Maria del Mar Ubeda and Eukene Ansuategi from the Donostia University Hospital Library for their help in the literature search.

Conflict of Interest

The authors declare that they have neither conflict of interest nor any disclosure to declare.

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Citation: Javier de la Fuente*, Jose F Aramendi, Davila Fernando, Balius Ramon and Marc Blasi. Percutaneous Ultrasound-Guided Techniques for Carpal Tunnel Release: A Descriptive Review. Glob J Ortho Res. 3(4): 2021. GJOR.MS.ID.000568. DOI: 10.33552/GJOR.2021.03.000568.