INTRODUCTION

The technological advances made in recent years in the field of medical imaging by ultrasound have made it possible to considerably increase the performance of this tool, in particular with the development of very high frequency ultrasound probes which significantly improve the resolution and precision of the images obtained. This evolution makes ultrasound an increasingly important examination in daily medical practice for various disciplines.

For several decades, ultrasound has been used for diagnostic purposes by radiologists in the context of the development of tendon or ligament pathologies, vascular, neurological or even tumoral. Recently, this tool has been adopted by anaesthetists for locoregional anaesthesia or for the placement of ca- theters. More recently, ultrasound has begun to be used to guide therapeutic procedures such as corticosteroid infiltrations, which can be performed by radiologists, rheumatologists, anesthetists or surgeons.

The resolution of ultrasound images is proportional to the frequency of the probe used. The higher the frequency, the less likely it is that the waves will penetrate deep into the tissue. These characteristics make high-frequency ultrasound a tool that is perfectly adapted to the musculoskeletal system in general and more particularly to the field of hand surgery where the anatomical structures are fine and superficial.

The use of ultrasound during surgery has some potential advantages. Because ultrasound allows us to see the structures without making an opening, it allows us to perform less invasive or even percutaneous procedures, with the result that the patient's functional recovery may be faster. In hand surgery, the size of the wound determines the extent of the associated scarring fibrosis and therefore some of the postoperative stiffness. Finally, the dynamic image obtained with ultrasound allows the surgeon to have a better understanding of the normal biomechanics and the physiological and lesion mechanisms.

This article reviews the ultrasound-guided percutaneous procedures developed in recent years in the field of hand surgery.

MATERIALS AND METHODS

The instruments

Ultrasound-guided percutaneous surgery consists mainly of surgical release of tendon or nerve structures by means of ligament sections or tenotomies. Different types of instruments have already been described for this purpose. Some authors have described the use of two instruments for this purpose.

The use of bevelled puncture needles inserted one inside the other with a 180° rotation would allow percutaneous tenotomies to be performed in a precise and efficient manner[1] . Other authors describe the use of puncture needles of different sizes as is or modified by bending[2] , modified Kirch- ner pins[3] or dedicated instruments such as arthroscopy forceps[4] , cutting hooks[5-8] or specific cutting instruments[9,10]. Still other authors describe the use of an irregular wire to cut ligamentous structures with back and forth movements[12] .

Surgical techniques

These operations are performed under local anesthesia, which allows the surgeon to benefit from the patient's cooperation throughout the procedure.

Surgery on the protruding finger

With a prevalence of 2-3% in the general population, the protruding finger is due to fibro-cartilaginous metaplasia of the A1 ring pulley. Surgery is indicated for cases refractory to conservative treatments[13] .

Percutaneous surgery of the trigger finger is not new. Initially described in 1958 by Lorthioir[14] , the blind percutaneous technique nevertheless presents risks of partial sectioning of the A1 pulley and iatrogenic lesions of the tendons or adjacent vascular and neural structures[6] . The use of ultrasound allows continuous monitoring of the position of the sectioning instrument while avoiding structures at risk. Regardless of the instrument used, sectioning of the A1 pulley can be done retrograde (distal to proximal) or anterograde (proximal to dis- tal). Some authors describe a de- ining movement outside the tendon sheath (the so-called

Some patients use the *"intra-sheath"* method[6] , others use the *"extrasheath"* method[7] (Figures 1 and 2). Ultrasound is also used to check the completeness of the release, which is manifested by a harmonious sliding of the tenons in addition to the disappearance of the clinical protrusion.

Carpal tunnel surgery

Carpal tunnel syndrome is related to irritation of the median nerve, often by compression in this anatomical region. It is the most common compressive peripheral neuropathy with an incidence of 3.5 to 6.2% of the general population[11] . Most often idiopathic in origin, its treatment consists of transection of the transverse carpal ligament (TCL).

This procedure can be performed in an echo-guided percutaneous manner, with ultrasound allowing the identification of the structures at risk and the definition of a safe line that Nakamichi[4] describes as being located on the TCL at mid-distance between the ulnar border of the median nerve and the radial border of the ulnar artery. According to this author, it is at the level of this *"safe line"* that the transverse carpal ligament can be cut with a low risk of vascular or tendon lesion (Figures 3 and 4).

Figure 1

Illustration showing an example of echoguided percutaneous treatment of a third protruding finger (retrograde release, "intra-sheath" method). The ultrasound allows to distinguish the different anatomical structures and to cut precisely the A1 pulley (black spot) without damaging other structures through a single entry point (red spot).

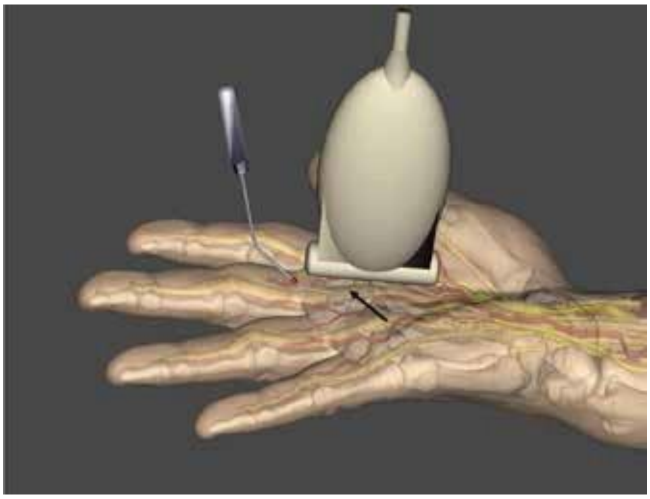


Figure 2

Photo of a hand three days postoperatively from percutaneous ultrasound-guided surgery of three resected fingers (index, middle, ring). The entry points are still visible at the base of each finger (blue lines).

Figure 3

Illustration showing an example of ultrasound-guided percutaneous surgery for carpal tunnel syndrome by dorsopalmar anterograde section of the transverse carpal ligament. Ultrasound allows to distinguish the different anatomical structures and to place the cutting instrument in the safety zone (black lick) in order to avoid damage to the vascular and nerve structures in the vicinity.

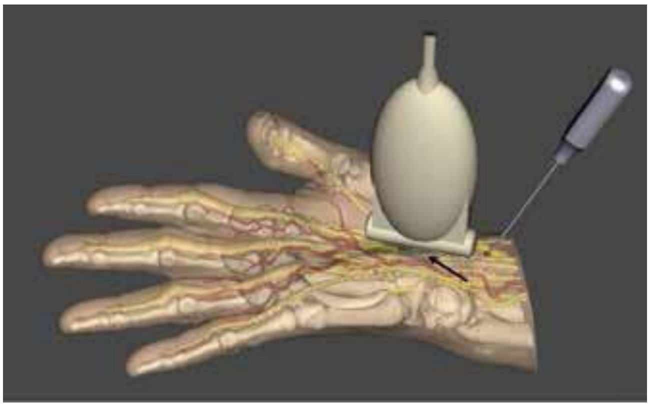
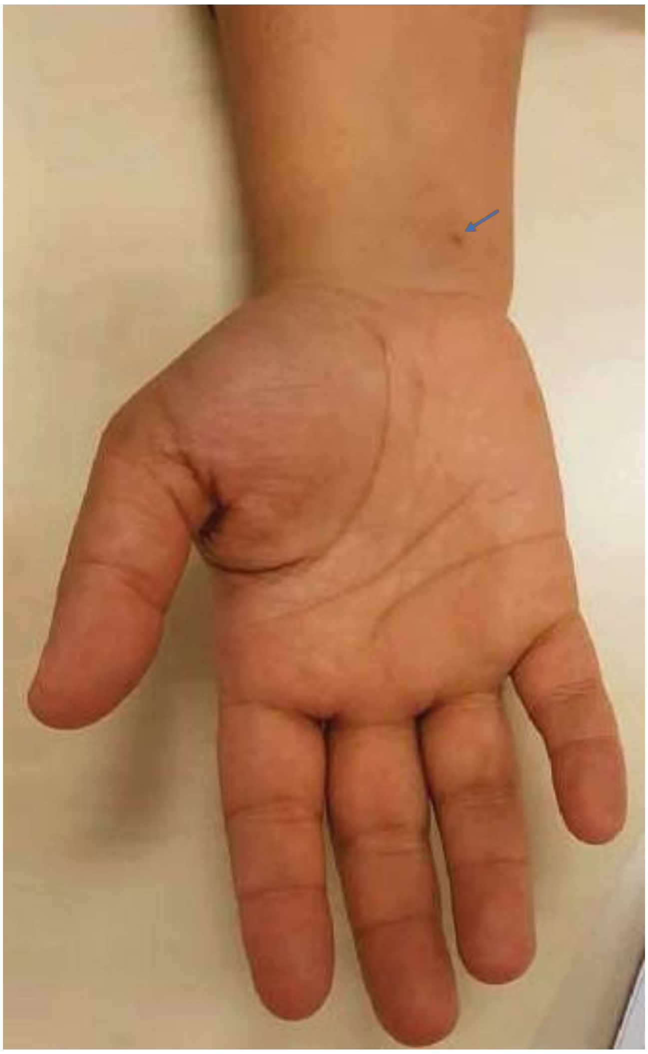


Figure 4

Photo of a hand at one week post-op of a percutaneous echo-guided release of the median nerve at the carpal tunnel. There is no surgical wound, only the scar at the entry point (blue lick).



Various techniques for percutaneous sectioning of the LTC have been described. In 1997, Nachamichi[4] was the first to describe a technique using a cutting forceps *(basket forceps)*, initially dedicated to arthroscopy, which he coupled to a trocar in order to avoid interposition of the tendons in the forceps. When used retrograde, this technique nevertheless required a small surgical approach to introduce the instruments. Rowe[5] in the early 2000's described the use of ultrasound coupled with a sharp instrument dedicated to endoscopic carpal tunnel release. In 2013, Markinson described the use of a cutting instrument requiring two entry routes, one proximal and one distal to the carpal tunnel[9] . This instrument allowed for sectioning of the LTC by back and forth movements once proper positioning was achieved under ultrasound control. Chern *et al.*[15] described in 2014 the use of a cutting hook to perform LTC section. Introduced proximally through a small 3-mm-long incision, a dilator initially created space on the extra-canal palmar portion of the LTC. The cutting hook was then introduced into the space thus created, corresponding to the conjunction of two *"safe zones"*, one transverse, located between the median nerve and the hook of the hamate, and the other longitudinal, extending no further distally than the junction between the base and the diaphysis of the metacarpal, thus preserving the superficial palmar arch. Ligamentous sectioning is done from palmar to dorsal by a retro-grade movement. Petrover in 2017 presented a technique similar to the previous one, also using a cutting hook but introduced intra-canal at the level of the longitudinal *"safe zone"* which he described as being located between the median nerve, the hook of the hammock, the LTC and the flexor tendons. Sectioning of the LTC was also done in a retrograde fashion[8] . In 2018, Hening *et al*. proposed the use of a dedicated ins- trument introduced through a small incision proximal to the carpal tunnel[11] . This instrument is equipped with a balloon that is inflated once introduced into the carpal tunnel to remove the structures at risk. Then, a cutting blade is deployed and allows the safe sectioning of the LTC. While the above-mentioned procedures are performed through a more or less small incision, Guo *et al.* proposed in 2016 a 100% percutaneous technique in which a striated wire is introduced through a catheter entering proximal and distal to the carpal tunnel, allowing the wire to be placed all around the LTC, with sectioning being performed by oscillating movements of the striated wire12.

Percutaneous ultrasound-guided surgery for Quevrain's disease

De Quevrain's tenosynovitis is a frequent pathology with a prevalence in the population of about 1.2%[16] . It is a stenotic tenosynovitis of the first compartment of the extensors of the thumb, thus affecting the long abductor and short extensor tendons of the thumb. Surgery is recommended in case of non-response to conservative treatment (rest, splinting, NSAIDs or corticosteroid injections)[17] . The surgery consists of sectioning the extensor retinaculum at the level of the first compartment. Lapègue *et al.* describe a technique for retrograde percutaneous ultrasound-guided section of the extensor retinaculum using a modified puncture needle16 , while Crouzet *et al.* propose the use of a specific blade introduced distally and also performing retrograde section of the retinaculum[18] . The major difficulty of this procedure is related to the disposition of the golden sensory branches of the radial nerve which run along the retinaculum at the height of the section zone and are therefore at high risk of iatrogenic injury.

RESULTS

The results of the various echo-guided percutaneous techniques are very encouraging. In a cadaveric study, Rojo-Manaute *et al.* described a complete sectioning rate of the A1 pulley of about 95.7%[6] . In a prospective study of 35 procedures on 25 patients over a 6-month follow-up period, Rajeswaran *et al.* using modified puncture needles to perform A1 pulley sectioning showed a complete resolution rate of 91% and complete resolution of pain in 86% of cases[2] .

In carpal tunnel surgery, Nakamichi[4] performed a prospective randomized controlled study comparing 50 percutaneous ultrasound-guided releases with 50 open releases. He observed a significant difference between the two procedures in terms of postoperative pain and tenderness at the surgical scar, which was less after the ultrasound-guided surgery until the thirteenth postoperative week. Hand strength was significantly greater in the ultrasound-guided group at three and six weeks. This author describes no neurovascular or tendon complications in either group.

Rowe[5] performed a cadaveric study showing complete sectioning and no iatrogenic injury to surrounding tissue. Chern *et al.* performed a cadaveric study showing a 90% complete section rate of the LTC. In a clinical study of 80 patients, these authors describe the absence of intra- and postoperative complications and no need for conversion to open surgery. Normalization of symptoms at 12 months was achieved in 100% of cases, although two cases had unsatisfactory results at 22.5 months postoperatively[15] . Petrover *et al.* report results on a series of 129 patients who benefited from echoguided percutaneous section of the LTC using a cutting hook introduced intracanally. In their series, a follow-up magnetic resonance scan was performed postoperatively and showed a 100% complete section rate of the LTC. In this series, the average surgical time was six minutes, the clinical results were described as good, and no neurological complications occurred.

was deplored[8] .

In the treatment of de Quevrain's tenosynovitis, Lapègue *et al.* described a 0% rate of complete sectioning of the retinaculum on 10 cadaveric specimens and the absence of vascular-nerve lesions. In their clinical study of 35 patients, these same authors describe the absence of neurovascular complications, a negation of Finkelstein's sign of 91.4% at one month and 77.1% of patients satisfied or very satisfied. These authors describe a need for revision surgery in 3 patients for whom no sign of retinaculum sec- tion was objectified during surgery. In their study of 14 cadaveric specimens, Crouzet *et al.*[18] observed a complete section rate of 13/14. The presence of a subcompartmentalization of the first extensor compartment was described as a factor favoring partial release. In their clinical study, these same authors show a success rate of 19/22 after three months without any neurovascular injury.

DISCUSSION

In the hand and wrist, ultrasound is currently used to assist percutaneous surgery of the trigger finger, carpal tunnel and de Quervain's tenosynovitis. A definite advantage seems to emerge from the ultrasound-guided percutaneous surgery of the trigger finger and the carpal tunnel. While the success of the procedure for the treatment of a protruding finger is easily measurable by the disappearance of the protrusion, the same cannot be said for the other procedures.

The classic carpal tunnel surgery is the open section of the transverse carpal ligament. However, this procedure has its share of undesirable effects such as the presence of a hypertrophic carpal tunnel, a decrease in hand strength, hand fatigue and pain on reaching the palm of the hand (*pillar pain*)[15] resulting in a prolonged convalescence time. These complications of surgery have been only partially reduced with endoscopic surgery, which has notably reduced the time required to return to work[9] . Nevertheless, endoscopic surgery, because of the blind insertion of its trocar and the restricted vision it offers, presents a risk of complications such as incomplete sectioning or neurovascular or tendon damage[9] .

Based on the various studies described, percutaneous ultrasound-guided carpal tunnel surgery is promising in terms of efficacy, but its advantage in terms of recovery time and postoperative complications remains to be defined. Percutaneous ultrasound-guided carpal tunnel surgery does have some contraindications. Absolute contraindications include the presence of a wrist deformity, the presence of a synovial cyst or elements responsible for a mass effect in the carpal tunnel, the presence of a muscular or tendinous anatomical va- riation contributing to the compression of the median nerve and a coexisting cubital tunnel syndrome[9] . Coagulopathies, the presence of a bifid median nerve, the absence of adequate space between the ulnar border of the median nerve and the hook of the hamate, and a persistent median artery occupying the ulnar part of the carpal tunnel are relative contraindications depending on the surgical technique used.

With regard to percutaneous surgery for de Quevrain's tenosynovitis, clinical studies have combined surgical release with corticosteroid injection in at least some of the patients treated. This does not distinguish the efficacy of percutaneous release, which may be questioned because of a significant rate of incomplete release in cadaveric studies[16,18] . Further clinical studies involving more patients and using only one therapeutic modality at a time seem necessary to confirm the efficacy of percutaneous ultrasound-guided procedures in this indication. The table summarizes the different percutaneous techniques described above. Percutaneous ultrasound-guided surgery techniques are also being developed elsewhere in the upper limb, notably in the elbow, where surgery for epicondylitis can also be performed percutaneously with ultrasound guidance, consisting of a tenotomy of the common extensor tendon[19] . In addition, techniques for ulnar nerve release at the elbow have been described[20] on cadavers with encouraging results in terms of learning curve and precision in the sec- tion of compressive structures, but their clinical application has not yet been described.

Table

Summary of percutaneous ultrasound-guided techniques described according to the pathology treated. Most of the techniques described are not completely percutaneous but require a small surgical approach to be performed.

SNAP FINGER					
Authors	Instrument used	Technique	Direction of the section	Approach	Type of study
Chern *et al* (2005)[7]	Cutting hook	Extra-sheath	Anterograde	Small incision	Cadaveric and clinical
Rojo Manaute *et al.* (2010)[6]	Cutting hook	Intra-sheath	Anterograde	Small incision	Clinic
Rajeswaran *et al.* (2009)[2]	Needles	Intra-sheath	Retrograde	Percutaneous	Clinic
CARPIEN CANAL					
Authors	Instrument used	Technique	Direction of the section	Approach	Type of study
Nakamichi *et al.* (1997)[4]	Basket clip	Intra and extra-root canal	Retrograde	A small incision	Cadaveric and clinical
Rowe *et al* (2005)[5]	retractabl e blade	Intra-channel	Retrograde	A small incision	Cadaveric
Markinson (2013)[9]	Cutting hook	Extra-ductal	Back and forth	A small incision	Clinic
Chern *et al* (2014)[15]	Cutting hook	Extra-ductal	Retrograde	Two small incisions	Cadaveric and clinical
Guo *et al* (2016)[12]	Grooved wire	Intra and extra-root canal	Back and forth	Percutaneous	Cadaveric and clinical
Petrover *and al.* (2017)[8]	Cutting hook	Intra-channel	Retrograde	A small incision	Clinic
Hening *et al.* (2018)[11]	Specific instrument with retractable blade	Intra-channel	Retrograde	A small incision	Clinic
DE QUERVAIN TENOSYNOVITIS					
Authors	Instrument used	Technique	Direction of the section	Approach	Type of study
Lapègue *et al.* (2018)[16]	Needles	Intra-channel	Retrograde	Percutaneous	Cadaveric and clinical
Croutzet *and al.(2019)*[18]	Blade specific	Intra-channel	Retrograde	Percutaneous	Cadaveric

CONCLUSION

Percutaneous ultrasound-guided surgery is a promising technique. Percutaneous procedures offer a potential economic advantage for the patient and for society by shortening the convalescence time and reducing the time to return to work. Some techniques can also be performed in the office, further reducing the cost to society. The good resolution obtained with high frequency ultrasound probes makes them a very precise tool to guide these procedures and to reduce complications related to surgery. Because all structures in the hand are superficial, percutaneous ultrasound-guided surgery is likely to develop as part of a less invasive hand surgery. It is likely that in the future the use of ultrasound by surgeons for therapeutic purposes will become more widespread with a progressive increase in indications and percutaneous ultrasound-guided techniques that will be stimulated by improved instrumentation and standardization of procedures. This percutaneous ultrasound-guided surgery constitutes today a crossroads where surgeons, radiologists and rheumatologists are walking the same path.

Conflicts of interest: Prof. Schuind is founder and CEO of Spirecut SA (2020).

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