OPEN

PRS GLOBAL OPEN

ORIGINAL ARTICLE

Craniofacial/Pediatric

Visualization of the Facial Nerve with Ultra-high–Frequency Ultrasound

Jeroen Poelaert, MD*
Renaat Coopman, MD, DDS, PhD*
Matthias Ureel, MD, DDS*
Nicolas Dhooghe, MD*
Eva Genbrugge, MD†
Tana Mwewa, MD‡
Phillip Blondeel, MD, PhD*
Hubert Vermeersch, MD, PhD*

Background: Profound variations in facial nerve branching, combined with the severe impact of facial palsy on the patient's quality of life, make surgery in this region challenging. Recent advancements in ultrasound (US) technology, including the improved visualization of small structures, have led to a sharp increase in its medical indications in various medical disciplines. We aimed to prove the feasibility of using ultra-high–frequency (UHF) US to visualize the facial nerve and to guide surgeons during surgery on and around the facial nerve.

Methods: A cadaveric study was performed on one hemi-face with a UHF US imaging system and state-of-the-art transducers. Firstly, a transcutaneous US was performed, and the facial nerve branches of interest (zygomatic, buccal, and marginal mandibular branches) were marked using US-guided color-injections of filler mixed with methylene blue. Skin and subcutaneous fat were then removed to simulate the intraoperative field. Secondly, an "intraoperative" US examination was performed, and the same branches were marked by US-guided color-injections of filler mixed with indocyanine green. Anterograde facial nerve dissection was performed, and the distance between the nerve branches and the injected filler was measured.

Results: All color-injections (mixed with both methylene blue and indocyanine green) were positioned right next to the nerve branches (<1 mm). The image quality of the US below the skin was observed to be far superior to that of the transcutaneous US.

Conclusion: UHF US can be used to visualize the facial nerve with high precision both transcutaneously and intraoperatively (after elevation of the skin flap).
(Plast Reconstr Surg Glob Open 2023; 11:e5489; doi: 10.1097/GOX.0000000000005489; Published online 19 December 2023.)

INTRODUCTION

The occurrence of facial palsy has a severe impact on the patient's quality of life, including significant alteration of facial appearance; emotional expression; exposure of the eye; and incompetence of the oral sphincter, resulting in drooling and alterations in vocal quality.

The face is one of the most surgically challenging areas in the human body, largely due to the variable anatomical course of the facial nerve. Its peripheral course starts when it leaves the stylomastoid foramen of the mastoid bone. After crossing the retromandibular vein laterally, the nerve divides into multiple branches (parotid plexus or pes anserinus-temporal, zygomatic, buccal, marginal mandibular, and cervical) during its course through the parotid gland. The profound variations in branching patterns of the facial nerve, combined with the severe impact of facial palsy (by iatrogenic damage or viral/oncological invasion) on the patient's quality of life, make surgery in the facial region very challenging.[1,2]

Over the past decades, intraoperative ultrasound (US) became widespread because it offers many advantages: safety, speed, high accuracy, wide applicability, and no ionizing radiation. During a US examination, a transducer both sends the sound waves and records the echoing (returning) waves. A computer instantly measures these returning waves (different pitch and direction) and displays them as real-time images on a monitor. The higher the frequency of the soundwaves, the higher the possible

*From the *Plastic, Reconstructive and Aesthetic Surgery, UZ Gent, Ghent, Belgium; †Radiology, UZ Gent, Ghent, Belgium; and ‡Radiology, UZ Brussel, Brussels, Belgium.*

Received for publication February 23, 2023; accepted October 18, 2023.

Presented at 14th International Facial Nerve Symposium and at GAPS (Ghent Academy for Plastic Surgery) meeting.

DOI: 10.1097/GOX.0000000000005489

Disclosure statements are at the end of this article, following the correspondence information.

spatial resolution of the obtained images, but the lower the penetration depth of the sound waves. This trade-off is favorable when small, superficial structures (like the facial nerve) need to be visualized.[3]

US of peripheral nerves is well established and is currently considered the primary imaging modality for anatomical assessment of the peripheral nerves in the extremities. The sonographic characteristics of large and small peripheral nerves have been extensively described.[3,4] In general, tendons are more echogenic than the nerve, and the nerve is more echogenic than the surrounding muscle. In an axial view, the nerves seem round to oval hyperechoic structures, resembling a honeycomb. Inside the honeycomb, the hypoechoic, round areas are the fascicles. In a transverse view, the nerves are cable-like, resembling a bundle of straws, wherein the straws represent the fascicles.[4–6]

The aim of this study was to prove the feasibility of using ultra-high–frequency (UHF) US to visualize the facial nerve and to help guide surgeons intraoperatively for surgery on or around the facial nerve.

METHODS

A proof of concept cadaveric study (one male fresh frozen hemi-face, informed consent by patient for scientific purposes was given) was performed with a UHF US imaging system and state-of-the-art transducers (Fujifilm VisualSonics, Toronto, Canada). The UHF system with a 46-MHz and a 71-MHz transducer has an axial resolution of 50 μm and 30 μm, and an image depth of maximum 23.5 mm and 10 mm, respectively. The intact hemi-face showed no obvious anatomical abnormalities. US examination was performed by an experienced radiologist (E. G.), specialized in head and neck radiology. The same pattern of examination was used for all the nerve branches, namely axial scanning of nerve structures, with careful rotation to the longitudinal view, making sure the nerve was kept in the middle of the image.

To visualize the branches of the facial nerve between the superficial and deep lobes of the parotid gland, the 46-MHz transducer was used. Distally from where the branches exit the parotid gland, they could be visualized using either the 46-MHz or the 71-MHz transducer.

As a first step, a transcutaneous US was performed and the facial nerve was marked via US-guided injections of filler (long-chain hyaluronic acid, Teosyal RHA 4, Teoxane laboratories) mixed with methylene blue (Fig. 1). The injections were performed with a 1 mL syringe and a 23G needle in an in-plane method. The average volume of injection was 0.05 mL.

The focus of the US examinations was the largest branches (as proof of principle), most relevant for facial reanimation surgery: more specifically the zygomatic, buccal, and marginal mandibular branches.

Subsequently, the skin and the subcutaneous fat were removed to simulate the intraoperative field over the superficial musculoaponeurotic system (Fig. 2).

A second US was performed, followed by a second round of US-guided injections to mark the facial nerve branches. This time, the filler was mixed with indocyanine green, to easily differentiate between the transcutaneous and intraoperative injections.

During both US examinations, the exact position of the injected filler in relation to the facial nerve was noted (superficial, superior, or inferior), depending on the volumetric effect of the filler on the surrounding tissue.

In the final step, the entire facial nerve was dissected using an anterograde technique (starting from the area of the stylomastoid foramen), with dissection of all except the cervical branches.

Takeaways

Question: Can ultra-high–frequency (UHF) ultrasound (US) be used to visualize the facial nerve?

Findings: In a cadaveric study, UHF US can be used to visualize the facial nerve, with high precision both transcutaneously and intraoperatively (after elevation of the skin flap).

Meaning: This study proves the concept that UHF US could be a useful aid in facial nerve surgery.

Fig. 1. Injection of filler with methylene blue during transcutaneous US.

Fig. 2. Position of US system during the intraoperative part of the experiment (after diversion of skin flap). Ultrasound is performed over the superficial musculoaponeurotic system.

Table 1. Location of the Injected Filler in Relation to the Nerve Branches

	Trifurcation of Upper Division	Zygomatic	Buccal	Marg. Mand.	Mean Distance to Nerve Branch
Methylene blue	0 mm, inferior	0.50 mm, superficial	0.50 mm, superficial	0 mm, posterior	0.25 mm
Indocyanine green	0 mm, superficial	0.50 mm, superficial	0.50 mm, superficial	0 mm, posterior	0.25 mm

Marg.Mand., marginal mandibular branch.

The distance between the nerve branches and the injected filler was measured with a caliper.

RESULTS

All injections of the methylene blue fillers (transcutaneous) and the indocyanine green fillers (intraoperative) were found to be accurately placed right next to the zygomatic, buccal, and marginal mandibular branches within 1 mm of the nerve and positioned (superficial, superior, or inferior to the nerve) as noted during both US examinations (Table 1; Figs. 3 and 4).

Figure 5 shows the facial nerve after it was completely dissected. The deposited colored filler can be seen along the mandibular branch, buccal branch, and zygomatic branch, as well as the trifurcation of the upper division of the facial nerve in the parotid gland.

The image quality of the US after removal of the skin was subjectively observed to be far superior to the transcutaneous US. This effect could not be quantified, as the

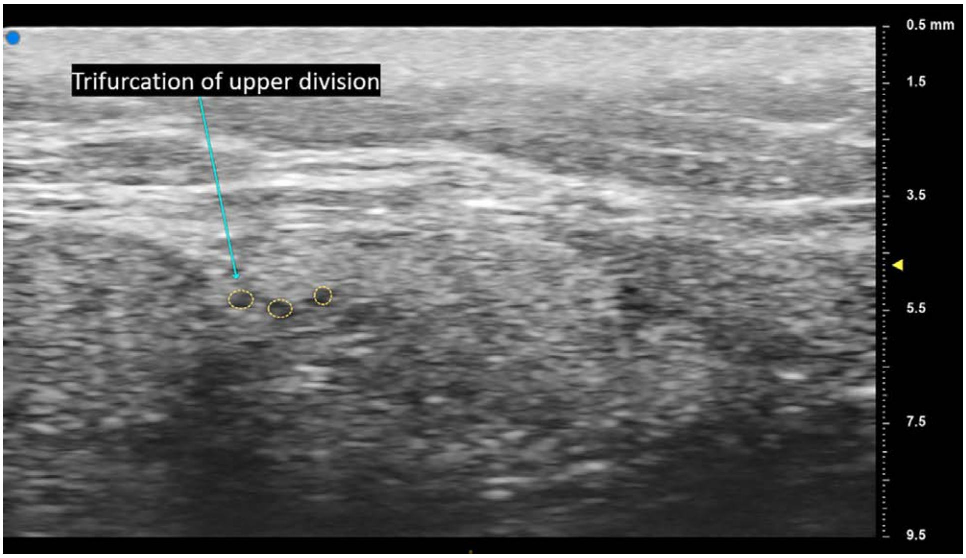

Fig. 3. Axial US visualization of trifurcation of the upper division of the facial nerve. Firstly, axial scanning of nerve structures was performed, followed by careful rotation to the longitudinal view, making sure the nerve was kept in the middle of the image (dynamic nature of US).

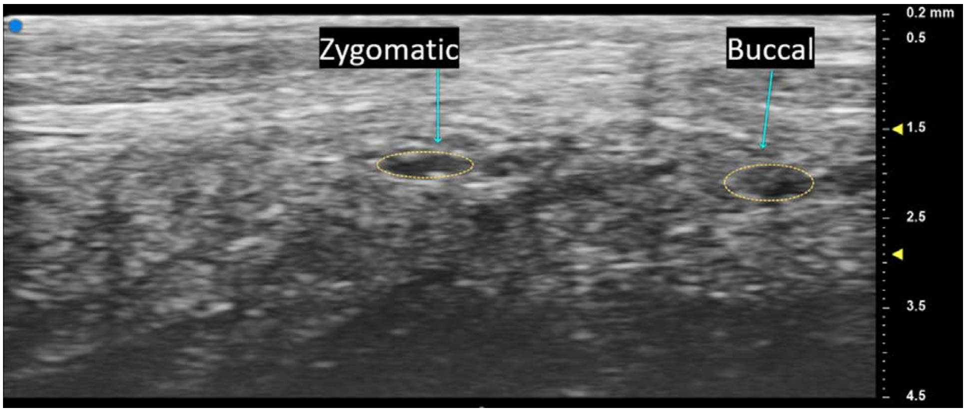

Fig. 4. Axial US visualization of the zygomatic and buccal branch of the facial nerve.

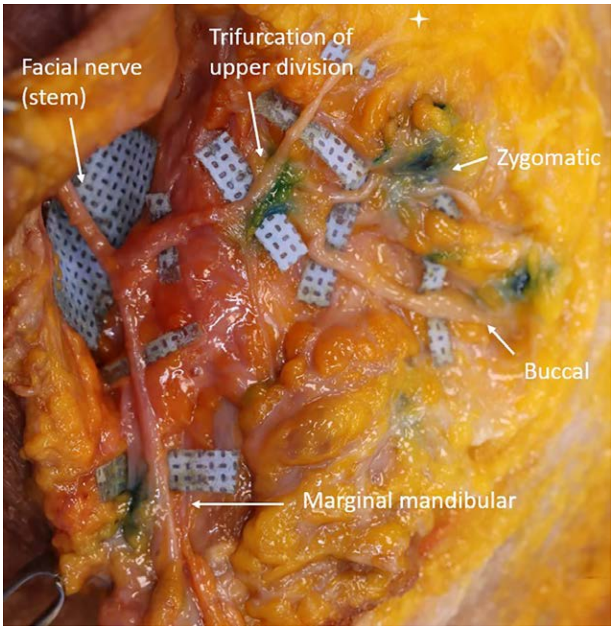

Fig. 5. Close-up of completed dissection, showing the injected filler (indocyanine green/methylene blue) right next to the most important nerve branches. The white star in the top right marks the two small temporal branches crossing the zygomatic arch.

facial nerve branches could already be adequately visualized using transcutaneous US, and the first round of injected filler was as accurate as the second round.

DISCUSSION

A precise anatomical knowledge is needed to operate in the facial region to prevent or surgically repair facial nerve damage and its clinical consequences. In our opinion, there are two main techniques to locate the facial nerve and its branches intraoperatively.

Firstly, various anatomical landmarks have been proposed with different degrees of consistency. The main branch of the facial nerve can be found by defining local anatomical landmarks (anterior margin of the sternocleidomastoid muscle, cartilage of the external hearing canal) and is located superficial of the posterior belly of the digastric muscle and the styloid process. The innervating branch (zygomatic/buccal) to the major zygomatic muscle can be found at the Zucker point (midway point between the root of the helix and the lateral commissure of the mouth).[7] The temporal branch crosses the zygomatic arch at the Pitanguy line (connecting the lobule to the midway point between the lateral canthus and the superior border of the external auditory meatus).[8]

Secondly, electrophysiological monitoring or facial nerve monitoring (FNM) can be used. This provides monitoring of facial muscle activity by electromyography (EMG), both continuously tracking facial muscle activity during surgery (passive monitoring) and sensing for electrically evoked EMG responses from an internal pulse generator (active monitoring).[9,10] Repetitive stimulation at 4 Hz using a pulse duration of 100 ms is most common. FNM during parotid surgery greatly benefits from four recording channels: the frontal (temporal branch of facial nerve), orbicularis oculi (zygomatic branch), orbicularis oris (buccal), and mentalis (marginal mandibular) muscles. This allows for more accurate mapping, as the dissection proceeds peripherally. Stimulus intensity can be adjusted according to the procedure and purpose of stimulation. A rule of thumb can be that a low current (eg, 1 mA) locates the peripheral facial nerve in close vicinity of the stimulation probe (1 mm environment), whereas a high current (eg, 4 mA) locates it at a higher distance (4-mm environment).

This experiment shows that the intraoperative use of UHF US is not only feasible but could aid in the visualization and localization of the most important facial nerve branches. These findings are supported by recent cadaveric studies suggesting that it is possible to visualize the extratemporal facial nerve and its branches along their course to the facial muscles of expression using high-resolution US (MyLabOne, Esaote Group, Genoa, Italy, 13–22 MHz transducers). In 2019, Wegscheider et al found only four published reports describing an attempt to image the extratemporal part of the facial nerve with high-resolution US. None of those studies, nor the studies published since then (including Wegscheider) use the US intraoperatively.[11]

A prospective longitudinal study by Baek et al shows that ultrasonography could be a useful tool for the evaluation of the facial nerve in Bell palsy. Preliminary results even show that to predict the outcome of Bell palsy, ultrasonographic evaluation was superior to facial nerve conduction studies and blink reflex studies (Philips HD15 Ultrasound System, 5–12 MHz transducers were used).[12–15]

The visualization of the cervical branches was not attempted, and the temporal branches were found to be very small when crossing over the zygomatic arch. We suspect this is the reason these branches were not found during this anatomical US study (Fig. 5).

The use of US as an adjunct for facial nerve localization has some advantages.

Firstly, US as an imaging modality is safe, has high accuracy, and provides real-time images with no substantial side effects or danger. Secondly, UHF US could be used to minimize iatrogenic damage to surrounding tissues and nerve branches, especially in the hands of less-experienced surgeons. On the other hand, there is also the question of whether less-experienced surgeons should be performing these procedures.

Thirdly, not only could UHF US be used intraoperatively, but it could also be used preoperatively and transcutaneously by the surgeon (as shown by Wegscheider et al[11]) to determine the location of incision, allowing for a minimally invasive surgery by knowing the exact location of the nerve. For example, in a patient who has wrinkles in the facial skin, the incision could be positioned exactly over the facial nerve branch in the nasolabial fold or wrinkle, instead of the traditional face-lift incision and full dissection over the parotid gland, ultimately leading to a reduced operating time and less morbidity of the surrounding tissues. This could also be beneficial to pediatric patients, where the position of the facial nerve could be more superficial (and prone to iatrogenic damage) because of underdevelopment of surrounding structures.[16]

Potential disadvantages include a substantial learning curve, limited depth of US penetration and the cost of the device and UHF US probes.

As the use of US is currently not part of the standard training curriculum for facial surgeons, it will take time to get the appropriate training and experience to use the UHF US with confidence during an operation.

The increased spatial resolution comes at the cost of limited penetration depth of US waves when using UHF US probes. The scan depth, when using the highest frequency probe (71 MHz), is limited to 10 mm.[17] This limitation may be relevant when the thickness of the overlying tissue of the facial nerve is increased, such as cases involving parotid tumors, soft tissue edema, or hematoma.

The initial cost of purchasing a US device with UHF probes may be seen as a hurdle by the surgeons or their departments. However, the versatility of UHF US can justify its initial cost by serving multiple clinical needs. UHF US can be used for many different purposes in clinical practice, such as imaging of peripheral nerves, presurgery mapping of perforators, planning surgery for vascular malformations in the skin, and visualizing lymphatic vessels and lymphatic fluid motion.[18–20] Spinal cord and brain imaging by UHF US are closely following.

Economic factors and resource availability may hinder the early adoption of UHF US technology in certain centers. We are certain that future advancements and increased adoption of UHF US technology will contribute to cost reductions, further enhancing its cost-effectiveness.

In contrast to computed tomography and magnetic resonance imaging, UHF US offers the real-time location of the facial nerve "on demand" intraoperatively. Furthermore, computed tomography can only infer pathology of the facial nerve by visualization of erosion or destruction of the adjacent bony facial nerve canal. Although new sequences of magnetic resonance imaging are currently being validated for visualization of the facial nerve (3D Cranio, Casselman et al, and Van Der Cruyssen et al[21,22]), visualization of distal nerve branches is still not possible in this preoperative static imaging modality. Further studies will need to determine the preferred facial nerve imaging modalities.

In this study, US examinations were performed by an experienced radiologist and experienced maxillofacial surgeon to minimize the possibility of operator-dependent mistakes. In this early stage of experimental use of the UHF US, it is advisable to work together with a US specialist. This will be a logistical challenge, but it enables the surgeon to gain more information in a safe and relatively fast manner intraoperatively.

However, the concept of point-of-care US is not new and has been shown to improve diagnosis and reduce the need for other examinations.[23] It is very well possible that in the future, surgeons will train to perform specific US examinations themselves (nerves, perforator flaps, lymphatics). Facial surgeons could start using this intraoperative technique comparable to the work of the anesthesiologists for local anesthetics application (eg, brachial plexus).

Concerning the US images, the observation of subjectively poorer visualization transcutaneously is probably due to artifacts from anatomical structures in the skin (namely, the hair follicles). The temporal branches were not found using the UHF US. However, localizing these would have no direct clinical implications in the current concept of facial reanimation as of the time of writing. The aim of most facial reconstructive surgery remains restoration of eye sphincter function, smile, and depressor functions.[24]

The filler, Teosyal RHA 4, was chosen because of its cohesive and viscous properties, allowing the color-injections to be precise and preventing spreading of the colored fluid.

In clinical cases, there is also the possibility to inject filler with a colorant (methylene blue for example) in patients to guide dissection to the specific nerve branch. Although both filler and colorant are nontoxic and biodegradable, this would not be advisable, especially on the healthy side of the face, as the risk of nerve damage due to sharp needle injection cannot be eliminated. Methylene blue and indocyanine green can be distinguished after injection, but the final colors in the cadaver lie close together. In the future, it will be best to choose two colors that are easier to differentiate after injection.

The reason a cadaveric study was chosen was to prove the level of accuracy with which UHF US can localize the facial nerve and its branches using US-guided color injection and subsequent dissection. An obvious limitation of this study is the fact that only one hemi-face was used to perform the US with color injections and subsequent dissection.

To our knowledge, no studies have tried to use US to guide facial nerve surgery intraoperatively. In a recent study, UHF US was used to visualize lymphatic vessels intraoperatively.[25]

UHF US might aid us in the future to avoid nerve damage in surgery around the facial nerve and give information about the positional relation to tumors. It can help us in the preoperative evaluation of facial reanimation to localize the specific branches to the zygomaticus major muscle, orbicularis oris muscle, and depressor anguli oris muscle. During surgery, it can be used to further guide the surgeon toward the desired nerve branch, while minimizing iatrogenic damage.

UHF US is not yet recommended for intraoperative use in clinical practice. More research is required to further establish its added benefit in facial nerve surgery, concerning reduction in operating time and prevention of iatrogenic damage to nerve branches.

CONCLUSIONS

This study proves the concept that UHF US could be a useful aid in facial nerve surgery. Although FNM remains invaluable during operating procedures, this experiment does suggest that intraoperative use may become one of the indications for this new technology.

Jeroen Poelaert, MD
Resident in Plastic Surgery
Corneel Heymanslaan 10
9000 Gent, Belgium
E-mail: poelaertjeroen@gmail.com

DISCLOSURES

The authors have no financial interest to declare in relation to the content of this article. Funding for this study was provided internally by the Department of Plastic, Reconstructive and Aesthetic Surgery, UZ Gent.

ETHICAL APPROVAL

Approved by Internal Ethics Committee of the UZ Gent (study no.: 4176).

REFERENCES

1. Alomar OSK. New classification of branching pattern of facial nerve during parotidectomy: A cross sectional study. *Ann Med Surg (2012)* 2021;62:190–196.
2. Tzafetta K, Terzis JK. Essays on the facial nerve: part I microanatomy. *Plast Reconstr Surg.* 2010;125:879–889.
3. Machi J, Oishi AJ, Furumoto NL, et al. Intraoperative ultrasound. *Surg Clin N Am.* 2004;84:1085–1111.
4. Kele H. Ultrasonography of the peripheral nervous system. *Perspect Med.* 2012;1:417–421.
5. Lawande A, Warrier S, Joshi M. Role of ultrasound in evaluation of peripheral nerves. *Indian J Radiol Imaging.* 2014;24:254.
6. Bianchi S, Becciolini M, Urigo C. Ultrasound imaging of disorders of small nerves of the extremities: less recognized locations. *J Ultrasound Med.* 2019;38:2821–2842.
7. Dorafshar AH, Borsuk DE, Bojovic B, et al. Surface anatomy of the middle division of the facial nerve: Zuker's point. *Plast Reconstr Surg.* 2013;131:253–257.
8. Babakurban ST, Cakmak O, Kendir S, et al. Temporal branch of the facial nerve and its relationship to fascial layers. *Arch Facial Plast Surg.* 2010;12:16–23.
9. Guntinas-Lichius O, Eisele DW. Facial nerve monitoring. In: Bradley PJ, Eisele DW, eds. *Advances in Oto-Rhino-Laryngology.* 78. S. Karger AG; 2016:46–52.
10. Kartush JM, Rice KS, Minahan RE, et al. Best practices in facial nerve monitoring. *Laryngoscope.* 2021;131:S1–S42.
11. Wegscheider H, Volk GF, Guntinas-Lichius O, et al. High-resolution ultrasonography of the normal extratemporal facial nerve. *Eur Arch Otorhinolaryngol.* 2017;275:293–299.
12. Baek SH, Kim YH, Kwon YJ, et al. The utility of facial nerve ultrasonography in Bell's palsy. *Otolaryngol Head Neck Surg.* 2020;162:186–192.
13. Li S, Guo RJ, Liang XN, et al. High-frequency ultrasound as an adjunct to neural electrophysiology: evaluation and prognosis of Bell's palsy. *Exp Ther Med.* 2016;11:77–82.
14. Tawfik EA, Walker FO, Cartwright MS. A pilot study of diagnostic neuromuscular ultrasound in Bell's palsy. *J Neuroimaging.* 2016;25:564–570.
15. Lo YL. High resolution ultrasound in the evaluation and prognosis of Bell's palsy. *Eur J Neurol.* 2010;17:885–889.
16. Farrior JB, Santini H. Facial nerve identification in children. *Otolaryngol Neck Surg.* 1985;93:173–176.
17. FujiFilm VisualSonics. Available at Https://Www.Visualsonics.Com/Content/Browse-All-Transducers.
18. Izzetti R, Vitali S, Aringhieri G, et al. Ultra-high frequency ultrasound, a promising diagnostic technique: review of the literature and single-center experience. *Can Assoc Radiol J.* 2020;72:418–431.
19. Cartwright MS, Baute V, Caress JB, et al. Ultrahigh-frequency ultrasound of fascicles in the median nerve at the wrist. *Muscle Nerve.* 2017;56:819–822.
20. Forte AJ, Boczar D, Oliver JD, et al. Ultra-high-frequency ultrasound to assess nerve fascicles in median nerve traumatic neuroma. *Cureus.* 2019;11:e4871.
21. Casselman J, Van der Cruyssen F, Vanhove F, et al. 3D CRANI, a novel MR neurography sequence, can reliable visualise the extraforaminal cranial and occipital nerves. *Eur Radiol.* 2022;33:2861–2870.
22. Van der Cruyssen F, Croonenborghs TM, Hermans R, et al. 3D cranial nerve imaging, a novel MR neurography technique using black-blood STIR TSE with a pseudo steady-state sweep and motion-sensitized driven equilibrium pulse for the visualization of the extraforaminal cranial nerve branches. *AJNR Am J Neuroradiol.* 2021;42:578–580.
23. Oni G, Chow W, Ramakrishnan V, et al. Plastic surgeon–led ultrasound. *Plast Reconstr Surg.* 2018;141:300e–309e.
24. Terzis JK, Konofaos P. Experience with 60 adult patients with facial paralysis secondary to tumor extirpation. *Plast Reconstr Surg.* 2012;130:51e–66e.
25. Hayashi A, Visconti G, Yamamoto T, et al. Intraoperative imaging of lymphatic vessel using ultra high-frequency ultrasound. *J Plast Reconstr Aesthet Surg.* 2018;71:778–780.