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Systematic Review

Facial Doppler ultrasound in minimally invasive procedures

Natalia Francesca Vidal Cofré[1]*, Victor Mercado Martinez[2], Ignacio Novoa Cornejo[3]

[1]Clinica Vida In, Reñaca, Valparaíso, Chile
[2]Instituto de reurorehabilitación y balance, Viña del Mar, Valparaíso, Chile
[3]Department of Rehabilitation Sciences, School of Public Health and Health Professions, State University of New York at Buffalo, Buffalo, NY, United States

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***Correspondence:**
Dr. Natalia Francesca Vidal Cofré,
E-mail: natalia.vidal.cofre@gmail.com

ABSTRACT

Color Doppler ultrasound (US) is an important ally in minimally invasive aesthetic procedures at the facial level. The three-dimensional images obtained make it possible to carry out a complete vascular mapping of the face, relate the different anatomical structures and observe the cutaneous and subcutaneous thickness. Knowing this information will make it easier for the professional to carry out safe planning in the injection of a "filler" in different dermal structures. Thus, this article intends to be a guide when carrying out such procedures, as well as in the management of possible complications. Knowledge of this information will allow the professional a safer procedure, with fewer possibilities of complications and clinical failures, making aesthetic and functional results compatible satisfactorily.

Keywords: Facial tissues, US, Hyaluronic acid, Orofacial

INTRODUCTION

Ultrasound (US) was first introduced in clinical dermatology in 1979. However, its use in aesthetic dermatology started much later, utilizing the US machine as a clinical imaging technique.[1,2] In recent years, dermatological US images have rapidly increased due to the development of high-resolution multifrequency transducers and multi-channel color Doppler equipment. As a result, the US has moved beyond the experimental phase and has reached a stage of daily use in different centers worldwide. Additionally, the number of publications in indexed literature has experienced exponential growth in the last decade.[2]

Currently, a wide variety of US devices can detect dermatological lesions, incorporating variable frequency transducers that work in ranges from 15 to 70 MHz and have color Doppler, allowing the detection of the type of capillary (arterial or venous) and blood flow velocity. The ability to vary the frequency of the transducer allows for penetration regulation according to the target structure. The use of the US is operator-dependent.[3]

In last decade, there has been an increase in minimally invasive facial aesthetic procedures worldwide.[2] Therefore, this article aims to compile available information to understand the current applications of the US in minimally invasive facial procedures, the basic principles of its use, and to generate a working guide.

Aim

This scoping review aims to provide a comprehensive overview of the potential applications of US as a complementary tool for minimally invasive aesthetic medical procedures. Specifically, this review aims to evaluate the benefits of US imaging in these procedures and to explore the potential uses of US technology by different accredited health professionals who perform such procedures. Additionally, the review aims to describe the safety standards and guidelines for both the operator and the patient while using the US in these procedures. Overall, this review seeks to provide detailed understanding of current and potential applications of US in minimally invasive aesthetic medical procedures, focusing on improving patient outcomes and safety.

LITERATURE SEARCH

We conducted a comprehensive systematic review by searching multiple health-oriented databases, including NIH/Pubmed (National Library of Medicine), Elsevier, Google Scholar, and Redalyc. The search was filtered by language (English and Spanish) and restricted to 10 years from January 2013 to January 2023. The search strategy included a combination of relevant keywords, and the following terms were used for the search: English: US dermal filler, ultrasonography facial hyaluronic acid, Doppler filler injection, US facial aesthetics. Spanish: ecografía facial, relleno dérmico Doppler, ultrasonografía facial, ácido hialurónico ecografía.

Studies related to the topic of interest were selected, including the use of US in facial aesthetic medicine, US and vascular complications associated with facial aesthetic procedures, and Doppler US and facial dermal fillers. All research article designs were included, while manual literature searches were excluded. Duplicate publications were also excluded.

Four databases were consulted, resulting in 57,276 publications that included or associated the keywords; of these, only 45 articles were directly related to the topic of interest. After applying the inclusion and elimination criteria through a complete reading analysis, only 18 articles were included in this review (Figure 1).[4]

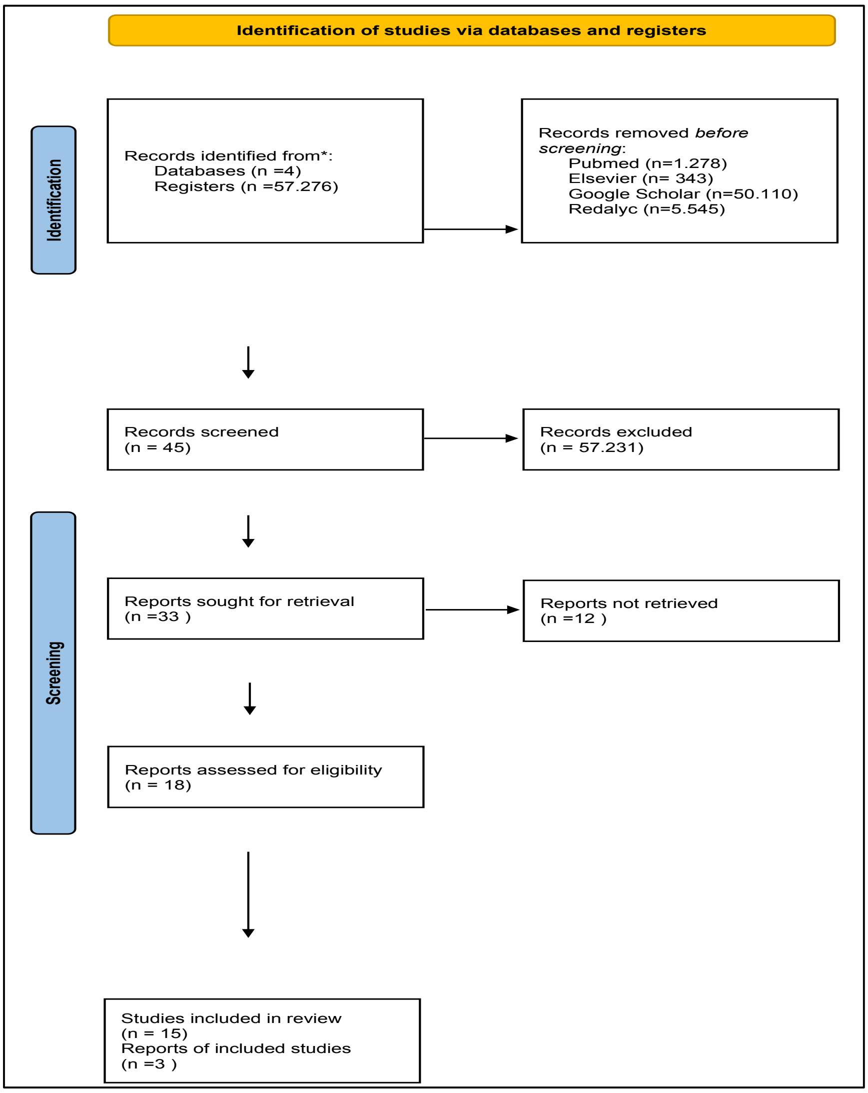

Figure 1: Flowchart of online literature search.

The results indicate that the vast majority of studies on the applications of the US in aesthetic procedures were conducted in Europe, followed by Asia and Brazil. The years with the most publications of interest were between 2015 and 2022. The majority of publications of interest found were on the application of the US as a tool for vascular mapping, followed by the use of the US to detect previously used dermal fillers.

TECHNICAL CONSIDERATIONS OF US

US is an imaging technique based on the emission and reflection of sound waves. It can easily capture the vertical axis of the skin, layers, and deeper tissues with a high definition without penetration problems. Currently, a wide variety of US devices can detect dermatological lesions. These devices may have variable frequency transducers that operate in their upper range of 15 to 70 MHz and also have color Doppler, which allows for the detection of capillary type and blood flow velocity.[5]

A US device consists of a transducer and a processor. The transducer will generate a sound wave that penetrates the body tissue. The sound waves interact with the tissue and become progressively weaker as waves are absorbed or scattered. Some of sound waves are reflected. The reflected sound waves, collected by probe and directed to the processor, are transformed into digital image.[5]

Several types of transducers include linear, convex and phased array antennas. For example, convex matrix transducer is used for abdominal exams since it has wide image area and focuses intensely. On other hand, linear transducer is recommended for aesthetic dermatology due to its superficial focus. Frequency is another characteristic of transducer. Higher frequency (HF) transducer provides more detailed images. However, its penetration depth is limited. Therefore, transducers with HF ranging from 10-22 MHz optimal for facial exams.[5]

US devices produce an image composed of various shades of gray. In summary, the absent reflection of sound waves is represented as black (anechoic), and the complete reflection as white (hyperechoic).

The echogenicity of a filler or its reaction in the tissue will be visualized as hyperechoic (white on the screen), hypoechoic (gray on the screen), and anechoic (black on the screen). Tissues are isoechoic if they show the same echogenicity as neighboring tissue, making these two tissues indistinguishable (Table 1).[7]

In consensus study on use of US in dermatology conducted by Worstman et al where 13 questionnaires from physicians in 9 countries (62% radiologists (n=8) and 38% dermatologists (n=5) completed and analyzed.[7] Min recommended frequency for dermatological exams was 15 MHz (62% (n=8). Use of 18 MHz as min was recommended by 38% (n=5) of participants. Routine use of color Doppler US recommended by 100%. Main dermatological applications of US raised by group were benign tumors (92%), skin cancer (92%), vascular anomalies (100%), aesthetics (85%), nail disorders (92%), and inflammatory diseases (92%).

Table 1: Consensus study.

Authors	Years	Title	Topics
Cral[1]	2022	Ultrasonography and facial aesthetics	Assessment
Haykal et al[2]	2022	The growing importance of ultrasonography in cosmetic dermatology: An update after the 23rd IMCAS annual world congress.	Diagnosis
Master[3]	2020	Hyaluronic acid filler longevity and localization: magnetic resonance imaging evidence	Assessment
Wortsman et al[5]	2016	Guidelines for performing dermatologic ultrasound examinations by the dermus group.	Diagnosis
Urdiales-Gálvez et al[6]	2021	Ultrasound patterns of different dermal filler materials used in aesthetics.	Diagnosis
Schelke et al[7]	2018	Ultrasound to improve the safety of hyaluronic acid filler treatments.	Treatment
Wortsman[8]	2021	Practical applications of ultrasound in dermatology.	Assessment
Wortsman[9]	2015	identification and complications of cosmetic fillers. j ultrasound med.	Diagnosis
Murray et al[10]	2021	Guideline for the management of hyaluronic acid filler-induced vascular occlusion.	Treatment
Schelke et al[11]	2019	Early ultrasound for diagnosis and treatment of vascular adverse events with hyaluronic acid fillers.	Diagnosis, Treatment
Tansatit et al[12]	2019	Anatomical and ultrasound-based injections for sunken upper eyelid correction.	Treatment
Cotofana et al[13]	2020	Anatomy of the superior and inferior labial arteries revised: an ultrasound investigation and implication for lip volumization.	Assessment
Constanza et al[14]	2022	Facial artery, an essential anatomy in different specialties: a review.	Assessment
Rocha et al[15]	2021	Description of a safe doppler ultrasound-guided technique for hyaluronic acid filler in the face-a method to avoid adverse vascular events.	Treatment
Velthuis et al[16]	2021	A guide to doppler ultrasound analysis of the face in cosmetic medicine. Part 1: standard positions	Assessment
Velthuis et al[17]	2021	A guide to doppler ultrasound analysis of the face in cosmetic medicine. Part 2: vascular mapping.	Assessment

For the technique per se, a large amount of gel is applied on top of the skin to adjust the depth according to the target's location. Then, the transducer is gently placed on top of the gel without compressing the skin. A recommendation to stabilize the hand is that the operator's pinky finger is located on the top of the perilesional skin.[8]

The ultrasonographic description of structures should include their shape, echogenicity, diameters in all axes, and vascularization patterns. The echogenicity of structures is defined by the intrinsic ability of tissues to reflect sound waves. Additionally, there are artifacts produced by the passage of sound through tissues. Some of these echoes allow for the recognition of lesions' solid or cystic nature and the discrimination of types of exogenous materials in the skin, such as cosmetic fillers.[8]

The primary echogenicity and artifacts observed in US imaging are mainly attributed to the composition of the examined structure. The main component of the structure, such as liquid, collagen, adipose tissue, calcium, or exogenous synthetic materials, affects the echogenicity and produces characteristic artifacts. For example, structures containing liquid content tend to appear anechoic (primarily black) or hypoechoic (gray) and exhibit posterior acoustic enhancement. On the other hand, calcified structures display a hyperechoic pattern (primarily white) with posterior acoustic shadowing due to the sound waves being stopped by calcium.[8]

NORMAL SKIN ANATOMY ON US

On US, the epidermis appears as a bright, shiny, single-layered structure with high keratin levels, giving it a hyperechoic appearance. The dermis appears as a hyperechoic band due to its rich collagen content. In photoaged skin, a band of low echogenicity may be observed at the top of the dermis, known as the subepidermal low echogenicity band (SLEB), caused by the deposition of glycosaminoglycans.[8] This alteration is a hallmark of photoaging and can be detected non-invasively with US imaging.

PATTERNS OF DERMAL FILLERS ON US

US imaging can identify and distinguish cosmetic fillers based on their unique echogenicities, artifacts, and degradation properties. Fillers are typically located in the hypodermis rather than the dermis, making US an effective tool for their detection. Here are the four well-defined patterns established by Urdiales-Gálvez et al.[8]

Heterogeneous pattern: This pattern is typical in healthy skin and subcutaneous tissue, characterized by alternating hyperechoic and anechoic areas within tissue. It is often observed after integrating absorbable tissue materials, such as hyaluronic acid (HA) fillers (Figure 2).[6]

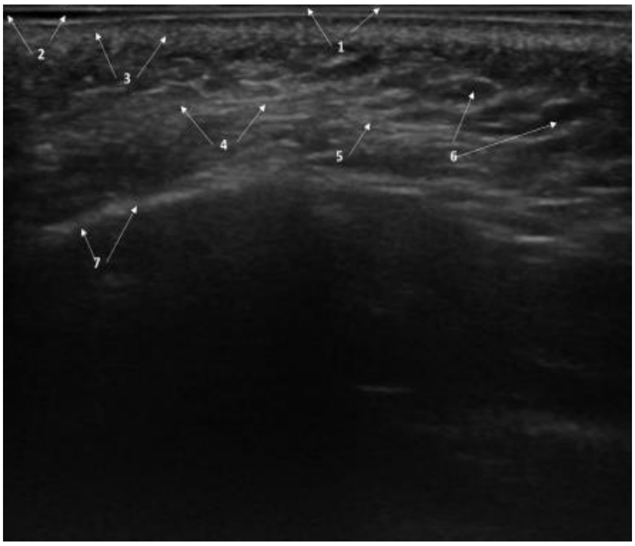

Figure 2: The heterogeneous pattern of healthy skin and subcutaneous cellular tissue. 1: Epidermis; 2: Subepithelial band of low echogenicity; 3: dermis; 4: subcutaneous cellular tissue; 5: hyperechoic image; 6: anechoic image and 7: periosteum.

Fine-grain snowstorm pattern: This pattern is typical of fillers based on silicone or biopolymers, characterized by alternating hyperechoic images with posterior echogenic shadows. It is frequently associated with lip injections due to its high echogenic density, making it challenging to visualize teeth (Figure 3).

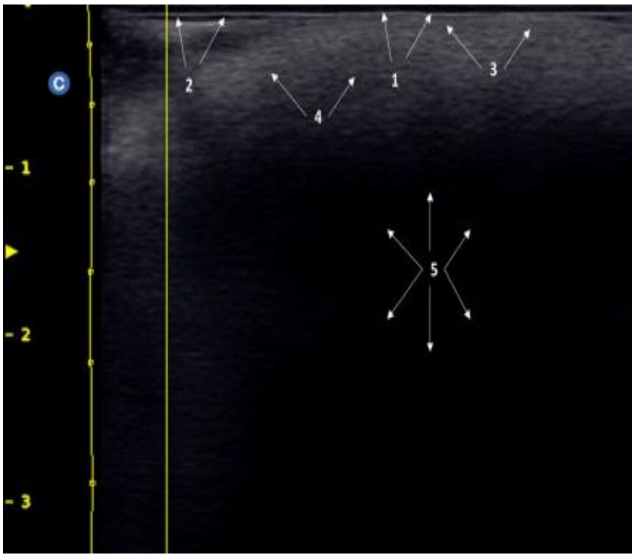

Figure 3: Fine-grain nevus pattern in patient injected with liquid silicone. 1: Epidermis; 2: subepidermal low echogenicity band; 3: dermis; 4: fine-grain nevus pattern and 5: posterior echogenic shadow.

Course-grain snowstorm pattern: This pattern is specific to particle-based fillers, such as calcium hydroxyapatite and polycaprolactone fillers. It gives snowstorm appearance but with coarser grain, more defined, brighter grains than fine-grain snowstorm pattern (Figure 4).

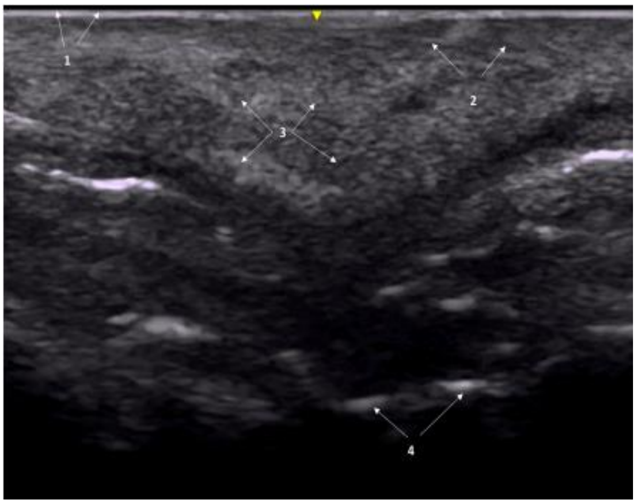

Figure 4: Coarse snowstorm pattern in a patient injected with calcium hydroxyapatite-based filler. 1: Epidermis; 2: dermis; 3: coarse snowstorm pattern and 4: periosteum.

The globular pattern is characterized by a typical cystic image with anechoic areas indicating the presence of liquid content. This pattern creates a robust echogenic reinforcement due to the presence of semi-liquid cysts, resulting in a distinct hyperechoic image (Figure 5). This pattern is commonly associated with polyalkylimides, polyacrylamides, and non-absorbable materials that mimic endoprostheses. Furthermore, fillers containing hyaluronic acid may exhibit this pattern immediately after injection. In contrast, polymethylmethacrylate appears as hyperechoic deposits with hyperechoic focal points that generate a comet tail artifact.

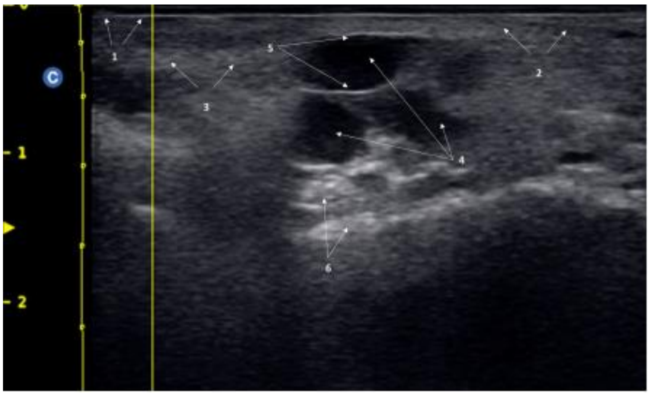

Figure 5: The globular pattern in a patient undergoing treatment by injection with polyacrylamide and polyacrylamides. 1: Epidermis; 2: dermis; 3: subcutaneous cellular tissue; 4: cysts; 5: cystic wall and 6: posterior echogenic reinforcement.

USES OF US IN AESTHETIC DERMATOLOGY

Following the IMCAS 2022 world congress, Haykal et al propose the potential uses of US (US) in aesthetic dermatology: detecting previous filler injections, vascular mapping, filler localization, and as a guide for hyaluronidase injection. Currently, the US is considered a first-line imaging technique in the use of different fillers, as well as in the management of their possible complications. The preventive concept of US prior to injection of a product involves the anatomical inspection study of the area to be treated, detecting vessels, mainly arterial, that is in the injection trajectory, as well as the presence of anatomical variations.[2]

MANAGEMENT OF COMPLICATIONS ASSOCIATED WITH THE USE OF FILLERS

Not only HA, but all fillers can be detected using US. Patients who have received filler treatments previously may only sometimes remember the type of material used, location, and injection plane. However, different filling substances can produce unwanted side effects when mixed. Using US before filler treatment can help distinguish between different types of fillers previously used, preventing complications.

Although there are successful reports on using fillers for aesthetic purposes, the number of complication reports has increased in recent years. These adverse reactions are more commonly observed when the patient has a history of injections of one or more synthetic or non-degradable fillers and is injected with a new degradable or synthetic type, especially in the same region. With silicone oil, these adverse reactions are usually delayed in their onset, appearing 8 to 10 years after injection, producing severe aesthetic and functional alterations that are extremely visible at the facial level, resulting from a severe foreign body reaction.[9]

Severe complications of filler treatments include intravascular injection or vascular compression of the filler material, which can lead to skin necrosis or, in sporadic cases, blindness due to compromise of the central retinal artery.[10] As these vessels are not clinically visible, prevention is essential. Guidelines advise using different techniques to minimize the risks of intravascular injection (use of cannulas, slow injections, aspiration, and more minor to larger product quantities, among others). However, anatomical knowledge of the face and the course of veins and arteries is crucial. Unfortunately, there may be individual variations in the anatomy of the facial artery. US allows visualization of the facial arteries and veins, making it a beneficial non-invasive imaging technique for pre-procedural vascular mapping.[7]

In the case of complications related to HA fillers, hyaluronidase can be placed with US -guided injections precisely in the filler deposit.[2]

Within the past 15 years, hyaluronidase has been used in aesthetic medicine to dissolve cross-linked hyaluronic acid. Hyaluronidase breaks down complex hyaluronan glycosaminoglycan polysaccharides by a hydrolysis reaction. Its primary function within aesthetic medicine is to dissolve cross-linked HA dermal fillers; however, it can also be used to improve resistant edema, given its ability to increase capillary and tissue permeability.[10] In this study, the recommendations are not using concentrations of less than 1,500 units in 5 ml to electively dissolve cross-linked HA. In case of emergency reversal, it is recommended reconstituting 1,500 units of hyaluronidase with 1 ml bacteriostatic NaCl 0.9% or 1-2% lidocaine over the couse of the affected artery and the wider area of ischaemia.[9]

In a study by Schelke et al 35-50 IU of hyaluronidase were injected under US guidance into the hyaluronic acid deposits responsible for vascular occlusion, resulting in the immediate restoration of blood circulation, compared to high-dose hyaluronidase (>500 IU) with a non-guided protocol.[11] Therefore, using the US in managing vascular complications associated with using hyaluronic acid fillers proves to be a precise and efficient contribution.

Vascular structures appear anechoic in black due to their liquid content, linear when the transducer is in the same line as the vessel, or circular when the transducer is positioned in a section of the vessels. B-scan duplex ultrasound combined with color Doppler US helps distinguish structures with movement, such as blood moving inside the vessels. Blue vs. red color Doppler can also be used to determine the direction of blood flow when necessary.[7]

VASCULAR MAPPING

Several researchers perform vascular mapping of important facial arteries to establish injection protocols and ensure treatment safety, thus avoiding complications. For example, using US, Tansatit et al studied the course of the terminal branches of the ophthalmic artery. They reported that the terminal branches of this artery follow two vascular courses from the emergent point: the supratrochlear artery (diameter, 0.80±0.38 mm, n=59/60) and the supraorbital artery (diameter, 0.71±0.25 mm, n=58/60). The supratrochlear artery runs vertically from the medial orbital rim passing through the medial end of the eyebrow and continuing towards the forehead. The supraorbital artery could be identified laterally to the supratrochlear artery, starting at the medial eyebrow halfway between the medial limbus and the vertical line of the medial pupil. Then, the artery moved obliquely towards the temporal crest.[12]

Cotofana et al investigated the location of the superior and inferior labial arteries using US for safe injection in lip volume augmentation procedures with HA. They observed that the most frequent location of the superior and inferior labial arteries was in the submucosal plane (58.5%), followed by the intramuscular (36.2%) and subcutaneous planes (5.3%). The depth of the superior labial artery in the upper lip was 5.6±0.13 mm, while the inferior labial artery in the lower lip was 5.2±0.14 mm. Both arteries were most frequently located within the vermillion border: upper lip (83% vs. 18.7%) and lower lip (86.2% vs. 13.8%). In the midline, the artery was inserted into the vermillion in all investigated volunteers.[13]

Constanza et al search that one study analyzed FA (Facial artery) by Doppler US at the base of the mandible in front of the masseter muscle, obtaining a mean diameter of 2.7 mm; another using the same methodology had a mean diameter of 2.14 mm. However, computed tomography found a mean diameter of 2.83 mm; these variations may be due to the methods used. However, both tests play in favor of correct pre-surgical planning.[14]

VASCULAR MAPPING TECHNIQUES

Several researchers perform vascular mapping of important facial arteries to establish injection protocols and ensure treatment safety, thus avoiding complications. For example, Tansatit et al used US to study the course of the terminal branches of the ophthalmic artery. They reported that the terminal branches of this artery follow two vascular courses from the emergent point: the supratrochlear artery (diameter, 0.80±0.38 mm, n=59/60) and the supraorbital artery (diameter, 0.71±0.25 mm, n=58/60). The supratrochlear artery was traced vertically from the medial orbital edge, passing through the medial end of the eyebrow and continuing towards the forehead. The supraorbital artery could be identified laterally to the supratrochlear artery, starting at the medial brow halfway between the medial limbus's vertical line and the medial pupil's vertical line. Then, the artery moved obliquely towards the temporal crest.[12]

Cotofana et al investigated the location of the upper and lower labial artery using US for safe injection in lip volume augmentation procedures with HA. They observed that the most frequent location of the upper and lower labial arteries was in the submucosal plane (58.5%), followed by the intramuscular plane (36.2%) and subcutaneous plane (5.3%). The upper lip's upper labial artery depth was 5.6±0.13 mm, while the depth of the lower labial artery in the lower lip was 5.2±0.14 mm. Both arteries were most frequently located within the vermilion: upper lip (83% vs. 18.7%) and lower lip (86.2% vs. 13.8%). In the midline, the artery was inserted into the vermilion in all investigated volunteers.[13]

GUIDED FILLER APPLICATION TECHNIQUES USING US

Rocha et al described a safe technique for HA injection in the face using Doppler US to avoid vascular complications. The technique consists of three steps[15]

Prior arterial mapping, only in the injection area

Objective was to map area, identifying trajectory of vessels and plane in which they are located. It is essential to place transducer in area receiving filler to identify responsible arteries that supply area rather than mapping entire zone. Any prev filler should also be made evident, identifying material used. This is important to avoid injections in same plane as other materials (polymethyl methacrylate, silicone oil)/ in areas it is impossible to inject in different planes (lips, periorbital area).

Real-time US-guided filling

After inserting the cannula and before injecting the filler: The objective is to verify that the cannula is placed in the correct plane (not in the plane where the arteries are located). If the artery is more superficial, the cannula should be positioned in a deeper plane and vice versa. Once the cannula is in the correct plane, the US is removed, and the AH can be safely injected with the bevel upwards without needing prior aspiration.

Evaluation of vascular perfusion after injecting filler

Objective here is to verify continuous vascular perfusion of the area.

Authors suggest that if no artery is visible on US in step, there is no need to perform steps 2 and 3.[1] It should be noted that the device used does not visualize all vessels in face, only those with diameter of 0.1 mm or more. Since 27G cannula has a diameter of 0.4 mm, using any cannula above 27G will provide injector with additional safety.[15]

GUIDE FOR FACIAL ANALYSIS USING DOPPLER US

Velthius et al propose a guide for facial analysis using Doppler US, in which they suggest standard transducer positions at the facial level (Figure 6).[8,16,17]

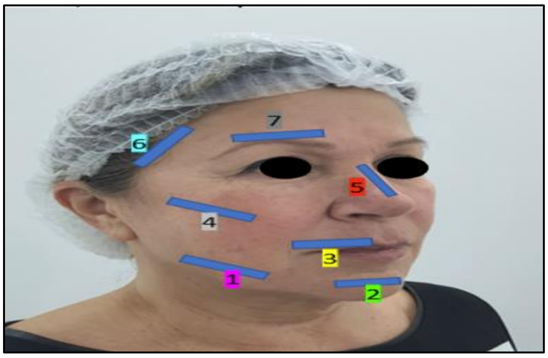

Figure 6: Transducer positions proposed by Velthius et al. 1: Mandibular border; 2: chin and lower lip; 3: upper lip; 4: midface; 5: nasal dorsum; 6: temporal area and 7: forehead.

Position 1: Mandibular border

Transducer position: Sliding anteriorly and cranially in the middle third of the mandibular border.

Reference point: Masseter muscle.

Vascular structures: Facial vein, facial artery, submental artery, external carotid artery (the facial vein and artery can be identified at the medial border of the masseter muscle).

Position 2: Chin and lower lip.

Transducer position: Axial from the midline of the chin laterally, sliding and rotating to identify structures.

Reference point: Depressor anguli oris muscle.

Vascular structures: Inferior labial artery, submental artery, mental artery.

Position 3: Upper lip

Transducer position: Axial on the vermillion part of the upper lip with a cranial sliding motion towards the nose.

Reference point: Orbicularis oris muscle and teeth.

Vascular structures: Superior labial artery, columellar artery.

Position 4: Mid-facial third

Transducer position: Semi-sagittal from the zygomatic bone to the corner of the mouth, sliding towards the nose.

Reference point: Zygomatic major muscle.

Vascular structures: Transverse facial artery, infraorbital artery, angular artery, lateral nasal artery.

Position 5: Nose

Transducer position: sagittal from glabella to the tip of the nose, sliding movements up and down and to both sides of the nose. o

Landmark: Nasal bone and cartilages.

Vascular structures: Dorsal nasal artery, intercanthal vein, external nasal artery.

Position 6: Temporal area

Transducer position: Sagittal at the hairline, sliding upward and medially to the eyebrow.

Landmark: Temporal muscle.

Vascular structures: Superficial temporal artery, zygomatic-orbital artery, the frontal branch of the superficial temporal artery.

Position 7: Forehead

Transducer position: Axial at the glabella and upper orbital rim, medial/lateral and cranial sliding.

Landmark: Frontal bone and muscle.

Vascular structures: Supraorbital artery and supratrochlear artery.

DISCUSSION

Currently, the US is considered a first-line technique for professionals who perform minimally invasive procedures for cosmetic purposes. Among the applications of the US in cosmetic dermatology, the ability to visualize anatomical structures and facial stratigraphy in real-time stands out as an advantage and complement to the primarily cadaver-based dissection techniques used thus far. Another substantial advantage of using US in clinical practice is the ability to visualize different types of fillers, whether long-standing or newly applied dermal fillers. Thus, US is a monitoring tool for ensuring proper filler placement, integration and identifying vascular complications. As Schelke et al point out, the US can serve as a percutaneous guide for injecting hyaluronidase and intralesional steroids, with as little as 35-50 units of hyaluronidase being sufficient to resolve a vascular occlusion and restore blood circulation immediately, compared to the protocol described by Murray et al which requires infiltrating 1,500 units with a needle or cannula in the course of the affected artery and the broader ischemic area, followed by monitoring and potentially requiring the use of even more units.[7,10]

However, one limitation of using the US is the high requirement for anatomical knowledge of the facial layer, which necessitates training and experience. Additionally, it is a tool that involves a relatively high investment to supplement daily practice in the clinic. Finally, due to the importance of this technique, it is essential to have more clinical research studies to objectively assess the results and establish precise protocols for its use.

CONCLUSION

The US represents a valuable contribution to minimally invasive facial procedures. Obtaining three-dimensional images of different anatomical structures allows for a safer performance, resulting in good outcomes and minimal risks.

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