Real-Time Ultrasound Imaging of the Tear Trough: Lessons Learned from Functional Anatomy

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Abstract

Background: The tear trough is one of the most challenging facial regions for soft-tissue filler injections. A thorough understanding of the underlying fascial, muscular, and vascular anatomy is crucial to perform safe and effective tear trough injectable treatments.

Objectives: To evaluate the location and function of the angular vein in the tear trough in three different facial expressions: repose, smiling, and max. orbicularis oculi contraction.

Methods: Twenty study participants with a mean age of 48.3 years and mean BMI of 24.5 kg/m^2 were investigated via functional ultrasound imaging. The diameter of the angular vein, the velocity, and direction of venous blood flow were analyzed in repose, smiling and during max. orbicularis oculi contraction.

Results: The angular vein was identified in 100% of the cases to travel inside the orbicularis oculi muscle (= intra-muscular course) within the tear trough whereas the angular artery was not identified in this location. The distance between the angular vein the inferior orbital rim was (lateral to medial): 4.6 mm, 4.5 mm, 3.9 mm, and 3.8 mm. The caudally directed blood flow was in repose 10.2 cm/sec and was 7.3 cm/sec at max. orbicularis oculi muscle contraction; however, no blood flow was detectable during smiling.

Conclusions: The diameter and the venous blood flow of the angular vein varied between the three tested facial expressions. Based on these anatomical findings, the deep injection approach to the tear trough is recommended due to the intramuscular course of the angular vein.

The medial infraorbital facial region, also termed the tear trough, is considered one of the most challenging locations for rejuvenation procedures. [1–4] While a plethora of algorithms using injectable soft tissue fillers and fat have been proposed, outcomes are inconsistent. [5–10] One challenge facing aesthetic practitioners is the underlying anatomy of this region. Recently, only three fascial layers were described for the tear trough consisting of skin, orbicularis oculi muscle (OOM), and periosteum.[11–13] This thin fascial arrangement lends itself to product visibility which can result in surface irregularities and discoloration.[3,14] Moreover, the physiologic function of the orbital and septal parts of the OOM, facilitating lymphatic outflow with contraction may be disrupted with soft tissue filler injections in the tear trough resulting in persistent edema.[15]

Another difficulty aesthetic practitioners face when performing filler injections in the tear trough is the underlying vascular anatomy. In 2017, Cotofana et al. found that the angular vein travels in the tear trough within the supraperiosteal plane at an average distance of 4.2 (0.7) mm from the inferior orbital rim based on computed tomographic (CT) contrast agent enhanced imaging of 72 fresh-frozen Caucasian body donors.[13] In 2018, Jitaree et al. described in a sample of 15 embalmed Thai body donors that the angular artery is the closest arterial branch to the tear trough and travels most frequently superficial to the OOM at a distance of 4.0 (2.3) mm to the inferior orbital rim.[16] These results were consistent with a recent study by Gombolevskiy et al. which confirmed in a sample of 156 facial contrast enhanced CT scans of healthy, procedure naïve Caucasian patients that the angular artery travelled in 82.7% of the cases superficial to the OOM.[17]

These previous publications have limitations, as data was either obtained from non-living individuals, or from embalmed tissue, or via a static and less precise technology which does not allow for detailed anatomic analyses or for functional assessment of the tear trough. Functional assessment of the tear trough includes the position of the arteries and veins during various facial expressions like smiling, maximal OOM contraction, or the change in position of the vessels in relation to anatomic landmarks.

Ultrasound technology can allow for dynamic imaging in live patients with accurate anatomic analyses both at rest and during motion. This study was designed to enhance the current understanding of the tear trough vascular and functional anatomy. It is hoped that the results will allow for safer aesthetic procedures when injectors seek to ameliorate the signs of aging in the infraorbital region.

METHODS

Study Setup

This interventional study investigated the course and the depth of the angular vessels in the tear trough by using real-time non-invasive ultrasound imaging and was conducted between May and July 2021 in Rio de Janeiro, Brazil. Participants for this study were recruited amongst consecutive, facial aesthetic procedure-naïve (no previous neuromodulator or soft-tissue filler injections) patients of Clinica Bravo, Rio de Janeiro, Brazil. Patients received pre-injection facial ultrasound scanning prior to their aesthetic treatment which is conducted on a regular basis for aesthetic patients in the participating clinic; pre-injection facial ultrasound scanning is not required standard of care according to board regulations or other authorities in the country where the data was generated (Brazil). The results presented in this study relied on the retrospective analysis of these previously obtained tear trough ultrasound scans and did therefore not require ethics committee approval. Ultrasound scanning data were not included in this analysis if patients were unwilling to participate in this study or if their aesthetic treatment did not include tear trough injections; tear trough ultrasound scanning was conducted only if the tear trough was targeted in the following aesthetic treatment.

Written and informed consent was obtained by all study participants prior to the inclusion into the study for the use of their images and personal data for research purposes. This study was performed in adherence to the Declaration of Helsinki (1996), and in accordance with regional laws and good clinical practice for studies in human subjects. [18]

Ultrasound Imaging

All ultrasound-based measurements were conducted by the same investigator (M.C.) to ensure consistency throughout the study. Repeated measurements were performed to evaluate the accuracy of the ultrasound measurements by calculating the interclass correlation coefficient (ICC) based on a two-way mixed effect model with absolute agreement; the results revealed a high rate of accuracy with ICC = 0.998 across all evaluated parameters. Patients were seated at a 45 degrees upright position during the ultrasound imaging and measurement process. The ultrasound device utilized in this study was a Logiq e, (GE Healthcare, Solingen, Germany) with a L8 – 18 MHz hockey stick transducer. The transducer was positioned in a thick layer of contact gel (Aquasonic Clear Ultrasound Gel, Parker Laboratories Inc., Fairfield, NJ, USA) without direct skin contact to avoid compression of the facial soft tissues and measurement artifacts. (Figure 1)

Conducted Measurements

In the medial infraorbital region (= tear trough), the parameters were measured in a vertical line relative to the following anatomical locations (Figure 2):

- P1: most medial location of the angular vein (distance measured in the horizontal plane)
- P2: medial canthus (distance measured in the vertical plane)
- P3: medial limbus (distance measured in the vertical plane)
- P4: midpupillary line (distance measured in the vertical plane)

All measured parameters per each of the four locations were evaluated in repose (= resting facial position), during Duchenne-type smiling[19], and during maximal OOM contraction. (Figure 2) Duchenne-type smiling includes the partial contraction of the OOM with additional contraction of the zygomaticus major muscle, whereas during maximal OOM contraction only the OOM contracted, not the zygomaticus major muscle.

The following measurements were conducted on both sides of the face for each study participant:

- Total thickness of the soft tissues i.e. distance between skin surface and periosteum
- Presence and location of angular arteries
- Distance between skin surface and angular vein (mm) (Figure 3)
- Distance between the angular vein and periosteum (mm) (Figure 3)
- Distance between the angular vein and the inferior orbital rim (mm) (Figure 3)
- Diameter of angular vein (mm) (Figure 4)
- Amount of blood flow in the angular vein (cm/sec) (Figure 4)
- Direction of blood flow (Figure 4)

The direction (cranial or caudal direction) and the velocity (given in cm/sec) of blood flow in the angular vein at the four measured locations were evaluated based on vascular elastographic measurements provided by the ultrasound device.

Statistical Analysis

Differences between measured locations and between facial expressions were calculated using non-parametric Friedman test due to the non-normal distribution of the data. Bivariate correlations relied on the calculation of Spearman's correlation coefficient whereas differences between genders were computed using Mann-Whitney-U testing. All calculations were run using SPSS Statistics 25 (IBM, Armonk, NY, USA) and differences were considered statistically significant at a probability level of ≤ 0.05 to guide conclusions. Results are presented as mean values and their respective 1x standard deviation (mean (SD)).

RESULTS

Patient Demographic Data

The sample investigated in this study consisted of n = 20 study participants of which 8 were males and 12 were females. The mean age of the total sample was 48.3 (13.6) years [range: 26 – 76] and the mean body mass index (BMI) was 24.5 (3.5) kg/m^2 [range: 19.0 – 32.1].

Presence and Location of Angular Artery

In the investigated sample, no artery was identified with ultrasound imaging at the midpupillary line, at the medial limbus, or at the medial canthus. However, in 100% of the cases, the angular artery was identified to travel in vertical orientation medial and parallel to the angular vein.

Course of the Angular Vein

The angular vein was identified to travel inferior (caudal) to the inferior orbital rim at a mean distance of 4.6 (0.5) mm in the midpupillary line, of 4.5 (0.5) mm at the medial limbus, of 3.9 (0.6) mm at the medial canthus, and of 3.8 (0.6) mm at the most medial location evaluated. No statistically significant differences were detected between genders with p > 0.202.

Soft Tissue Thickness

The total soft tissue thickness at repose decreased statistically significantly moving lateral to medial (p < 0.001) from the midpupillary line 11.0 (0.9) mm to the medial limbus 10.7 (0.9) mm, to the medial canthus 6.6 (0.7) mm, and to 5.9 (0.6) mm measured at the most medial location of the angular vein.

Medial to the medial limbus (= at the locations P2 and P1) no statistically significant relationship was detected between higher values of BMI and the total soft tissue thickness with r_s = 0.130; p = 0.423 for P2 and r_s = 0.121; p = 0.456 for P1.

Depth of Angular Vein

The depth of the angular vein at repose was at the midpupillary line 5.1 (0.8) mm, whereas at the medial limbus it was 5.0 (0.8) mm, at the medial canthus it was 3.4 (0.6) mm, and at the most medial location of the vein it was 2.9 (0.6) mm; this represents a statistically significant decrease in the depth of the angular vein as it courses medially, with $p < 0.001$.

At repose the distance between the periosteum of the maxilla and the angular vein was at the midpupillary line 4.1 (1.1) mm, at the medial limbus it was 3.9 (1.0) mm, at the medial canthus it was 1.5 (0.3) mm, and was at the most medial location of the vein it was 1.2 (0.3) mm; this represents a statistically significant decrease in the distance between angular vein and the periosteum as it courses medially, with $p < 0.001$.

Venous Blood Flow

The venous blood flow was in 100% of the investigated cases directed from cranial to caudal both in repose and during maximal OOM contraction; no flow was detectable during smiling.

In repose, the blood flow did not differ between the four measured locations ($p = 0.105$) and averaged 10.2 (2.5) cm/sec. During smiling, no venous blood flow was detectable at any of the investigated locations with 0.0 cm/sec across all study participants. During maximal OOM contraction, the average venous blood flow in the caudal direction was 7.3 (1.9) cm/sec representing a statistically significant reduction from repose, with $p < 0.001$. (Figure 5)

Diameter of Angular Vein

At repose the diameter of the angular vein was at the midpupillary line and at the medial limbus 2.72 (0.3) mm, at the medial canthus it was 2.71 (0.4) mm, and at the most medial location of the vein it was 2.70 (0.4) mm. There was no statistically significant difference in the diameter between genders in any of the four locations with $p > 0.469$.

During smiling, the diameter of the angular vein increased in all four measured locations and was at the midpupillary line 2.96 (0.4) mm, at the medial limbus it was 2.99 (0.4) mm, at the medial canthus it was 2.98 (0.4) mm, and at the most medial location of the vein it was 2.93 (0.4) mm. There was no statistically significant difference in the facial vein diameter between genders in any of the four locations with $p > 0.525$.

During maximal OOM contraction, the diameter of the angular vein was at the midpupillary line 2.82 (0.4) mm, at the medial limbus it was 2.86 (0.3) mm, at the medial canthus it was 2.87 (0.4) mm, and at the most medial location of the vein it was 2.82 (0.4) mm. There was no statistically significant difference in the diameter between genders in any of the four locations with $p > 0.481$.

The three investigated facial expressions (repose vs. smiling vs. maximal OOM contraction) resulted in a highly statistically significant change in the diameter of the angular vein with all $p < 0.001$. (Figure 6)

DISCUSSION

This ultrasound-based investigation of the functional anatomy of the tear trough provides novel insights that can help guide aesthetic practitioners seeking to ameliorate the signs of facial aging. Of particular interest, no major arterial vessel was detected in the midpupillary line, at the medial limbus, or at the most medial measurement location (P1). When conducting measurements at the most medial location of the angular vein, in 100% of the cases, the angular artery was identified to travel in vertical orientation medial and parallel to the angular vein. This is consistent with the expected course of the angular artery which has connections to the ophthalmic and to the paracentral arteries of the forehead. [20–22]

The angular vein was consistently identified within the tear trough and our ultrasound-based results are in line with a CT-based investigation by Cotofana et al. which identified that the angular vein travels an average distance of 4 mm to the inferior orbital rim. [13] However, due to the sample selected (live patients) and due to the methodology applied (high frequency ultrasound imaging) the present study expands on the anatomic evaluation of the tear trough. The total soft tissue thickness was shown to decrease from 11 mm at the midpupillary line to 6 mm in the most medial aspect of the tear trough confirming clinical observations of reduced soft tissue thickness moving laterally to medially. Subsequently in this location autologous fat or soft tissue fillers should be injected with a goal of under correction, as thin soft tissues are less likely to camouflage injectate-induced surface irregularities. Interestingly, no statistically meaningful relationship was found between increasing BMI and the total soft tissue thickness, confirming anatomic observations that in the tear trough no superficial and no deep fat could be identified.[11–13] Having any layer of fat in the tear trough may have resulted in an increase in total soft tissue thickness with increasing BMI, but this trend was not observed.

The depth of the angular vein was identified to reduce statistically significantly between midpupillary line (5.1 mm) and the most medial location of the vein (2.9 mm). Therefore, clinicians performing superficial injections in the tear trough should exercise caution to avoid entering the vein due to its increasingly superficial course. Similarly, the depth between the periosteum and the vein reduced statistically significantly from 4.1 mm in the midpupillary line to 1.5 mm at the level of the medial canthus. This means that when performing deep supraperiosteal injections the space for safe product is reduced moving from lateral towards the tear trough. The identified course of the angular vein also favors the deep injection approach as there is a safer plane for product administration which is deep to the angular vein and allows for product deposition into a physiologic room. Whether a needle or a cannula is favored for the deep approach, it should be tailored to the utilized product [23,24], the size of the used needle/cannula and to the injection angle. [25] Previous reports have indicated that intra-venous injections of volumizing materials can cause pulmonary embolism which have occurred following genital or gluteal procedures.[26–29] However, one case report showcased that forehead and cheek filler injections resulted in non-thrombotic pulmonary embolism caused most likely by intra-venous product administration.[30] To date and to the best knowledge of the authors, no cases of injection related visual compromise following intra-venous product administration have been reported. Whether needles or cannulas pose a greater risk for intra-venous product application following tear trough injections is currently subject to speculations; future studies will need to investigate this topic similar to previously published data on arteries.[31]

The performed investigations revealed a novel course of the angular vein in the tear trough which is different from previous anatomic descriptions. [13,32] The angular vein does not travel deep to the OOM in the tear trough but inside the muscle. This is novel and was confirmed by anatomic dissections (Figure 7) but also during the visualization of the venous pathway in this study (Figure 3). The intra-muscular course of the angular vein in the tear trough gives additional justification for a deep injection approach to avoid the more superficially located than previously expected vein inside the OOM. This is consistent with clinical observations where the deep injection approach in the tear trough volumized the local soft tissues without intra-venous product application.[33–35] Previous reports have described venous vascular events following filler injections, but the occurrence of this adverse event does not correlate with the amount of tear trough injections performed.

This study conducted additionally measurements during three facial expressions (repose, Duchenne-type smiling, maximal OOM contraction) and found that independent of facial expression the venous blood flow was in 100% of the cases oriented caudally, streaming away from the intra-orbital located superior ophthalmic vein. In repose, the diameter of the angular vein was on average 2.7 mm and the mean venous blood flow was 10.2 cm/sec. During Duchenne-type smiling = partial contraction of OOM and contraction of zygomaticus major muscle, the diameter of the vein increased statistically significantly to 3.0 mm whereas the venous blood flow stopped and was not detectable (0.0 cm/sec). This phenomenon was previously described by Cotofana et al. in an ultrasound-based study in which 15 healthy volunteers were asked to smile and the blood flow in the midfacial segment (lateral to the infraorbital foramen) stopped.[36] This effect was observed in the present study as well and can be used to underline the validity of the measurements performed herein. When the patients were asked to forcefully contract their OOM, the venous blood flow decreased from 10 cm/sec to 7.3 cm/sec providing evidence that the OOM can alter the venous blood within the tear trough. Interestingly however, the diameter of the angular vein increased statistically significantly ($p < 0.001$) from 2.7 mm to 2.8 mm. The increase in diameter during smiling and during maximal OOM contraction was observed in each of the measured locations indicating that it is not a local effect of one of the portions of the OOM but rather a cumulative effect influencing the entire tear trough. Clinically, the detected changes in venous blood flow and angular vein diameter during various facial movements are novel and meaningful. Asking patient to remain in repose during tear trough filler injections will prevent the change in diameter of the angular vein during facial expression and thus potentially reducing the risk of intravenous product application. Likewise, changes in the tension of the zygomaticus major muscle (which can compress the angular vein and obstruct venous outflow coming from the tear trough) as observed after face lift surgeries or following facial suspension threads treatment might alter the venous outflow. A subsequent increase in diameter of the angular vein in the tear trough could potentially result in an increased risk for intra-venous product application. However, it has to be differentiated whether patients are treated for their tear trough or their midface when utilizing soft tissue fillers. A recent report by Cotofana et al.[37] suggested dynamic filling for avoiding the facial overfilled syndrome when targeting the midface. Here, the cause is based on the mobile transverse facial septum which pushes the midfacial fat compartments cranially during smiling; this can be used to gauge the correct amount of product during midfacial filling. Too much injected product will result in “apple cheeks” and unnatural midfacial mobility which is not visible at rest. Asking the patient to smile allows to estimate the correct amount. On the contrary, asking patients to smile during tear trough filler treatment could increase the diameter of the angular vein and result in an increased risk for intra-venous product administration.

One can speculate that the intramuscular course of the angular vein in the tear trough and the compression of the angular vein deep to the zygomaticus major muscle has the physiologic function of a muscular pump which helps to propel the venous blood from the face caudally into the jugular veins. The muscles of facial expression hereby support the venous blood movement which can be analogous to the calf muscular pump. Aesthetic procedures influencing normal facial muscle function or affecting the physiologic pathway of the facial venous drainage system could potentially have additional effects which are not immediately visible or are beyond our current understanding.[38] However, it should be stated that almost no tissue-function relationships are by coincidence in the human body and that more consequences result from soft tissue augmentation than are potentially expected or currently known.[39–42]

Limitations of the present study are the small sample size with n = 40 investigated tear troughs and that the investigated population was of Caucasian origin only. Future studies may seek to address these shortcomings.

CONCLUSION

The results of this functional ultrasound-based investigation reveal that within the tear trough no major arterial vessel was found in the sample investigated with the methodology applied. The previously described course of the angular vein was confirmed, and it was identified that the angular vein does not travel deep to the OOM but inside the muscle. This finding is novel and is confirmed by the functional component of this investigation. Based on the results presented herein the deep injection approach to the tear trough is favored as a physiologic space between the vein, muscle and periosteum was identified. However, injectors should be mindful when targeting this unforgiving anatomical region due to its thin, soft tissue thickness and its connection to the periorbital anatomy.

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Figure Legend

Figure 1. Ultrasound examination of the facial vein in the tear trough region performed on a 43-year-old male study participant during repose, smiling and maximum orbicularis oculi muscle contraction. By using a thick layer of contact gel, direct skin contact of the ultrasound probe was avoided.

Figure 2. The four measurement locations during the ultrasound examination. P4 is defined as the mid-pupillary line, P3 as the medial limbus, P2 as the medial canthus and P1 as the most medial point at which the angular vein could be detected.

Figure 3. Ultrasound image of the tear trough region demonstrates the facial vein embedded in the orbicularis oculi muscle. The orbicularis oculi muscle is connected to the upper aspects of the maxilla and the zygomatic bone (ie, the inferior orbital rim) via the orbicularis retaining ligament.

Figure 4. Doppler-encoded ultrasound images showing the blood flow of the angular vein during repose, smiling and maximum orbicularis oculi muscle contraction. During smiling, no blood flow of the angular vein was detectable.

Figure 5. Bar graph showing the average venous blood flow (cm/sec) of the angular vein for all measurement locations (P1-P4) at repose, smiling and maximum orbicularis oculi muscle contraction. While subjects were smiling venous blood flow was not detected in any of the investigated cases. A statistically significant difference could be found between the values obtained during repose and smiling as well as for repose and maximum orbicularis oculi muscle contraction, with each $p < 0.001$.

Figure 6. Bar graph showing the average diameter (mm) of the angular vein for all measurement locations (P1-P4) at repose, smiling and maximum orbicularis oculi muscle contraction. A statistically significant difference could be found between the values obtained during repose and smiling as well

as for the values obtained during repose and maximum orbicularis oculi muscle contraction, with each $p < 0.001$.

Figure 7. Cadaveric dissection showing the anatomical relationship of the angular vein to the orbicularis oculi muscle. The facial vein emerges from the anterior border of the masseter muscle and courses superiorly beneath the zygomaticus major and minor muscles towards to the infraorbital region where it runs inside the orbicularis oculi muscle. The piercing of the orbicularis oculi muscle is shown schematically in the drawing on the right side.

Figure 1

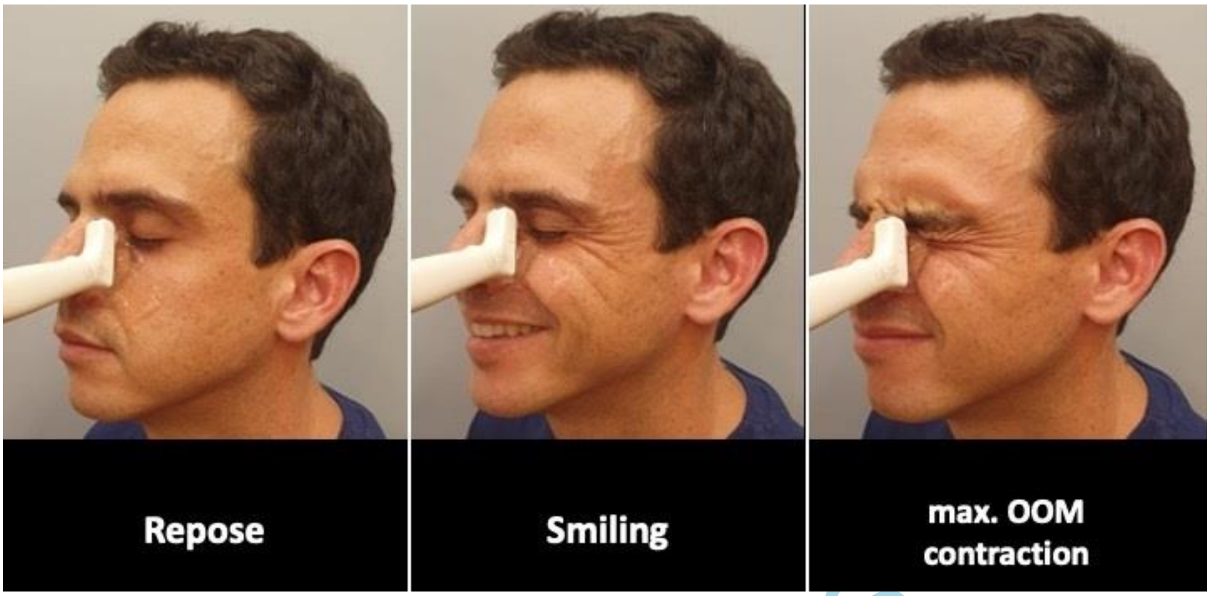


Figure 2

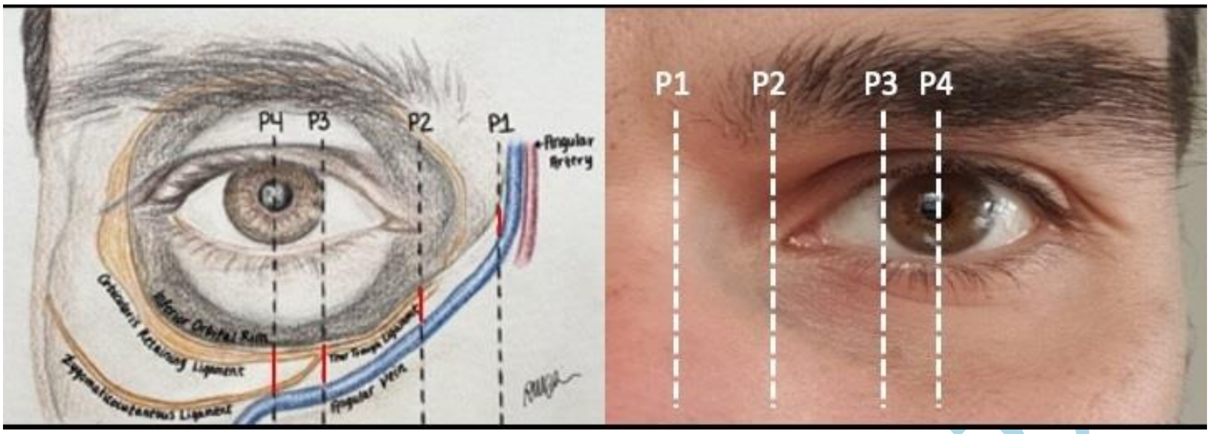

P4
P3
P2
P1
Angular Artery
Inferior Orbital Rim
Angular Vein
P1
P2
P3
P4

Figure 3

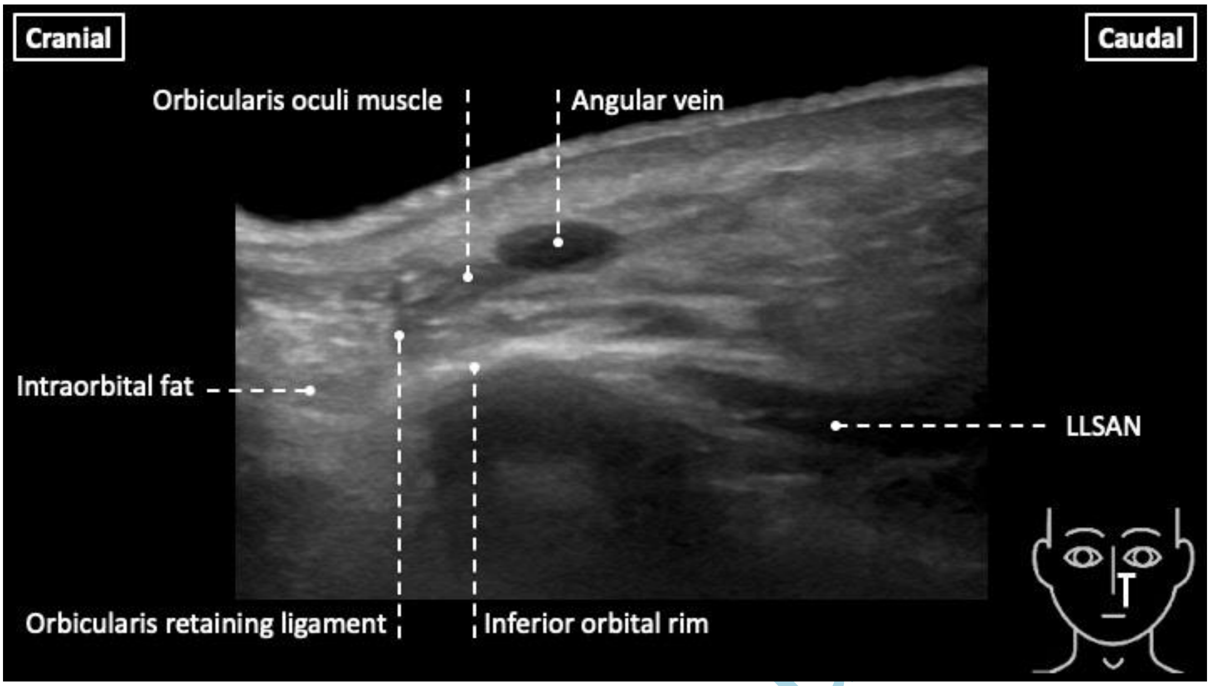

Cranial
Caudal
Orbicularis oculi muscle
Angular vein
Intraorbital fat
LLSAN
Orbicularis retaining ligament
Inferior orbital rim
T

Figure 4

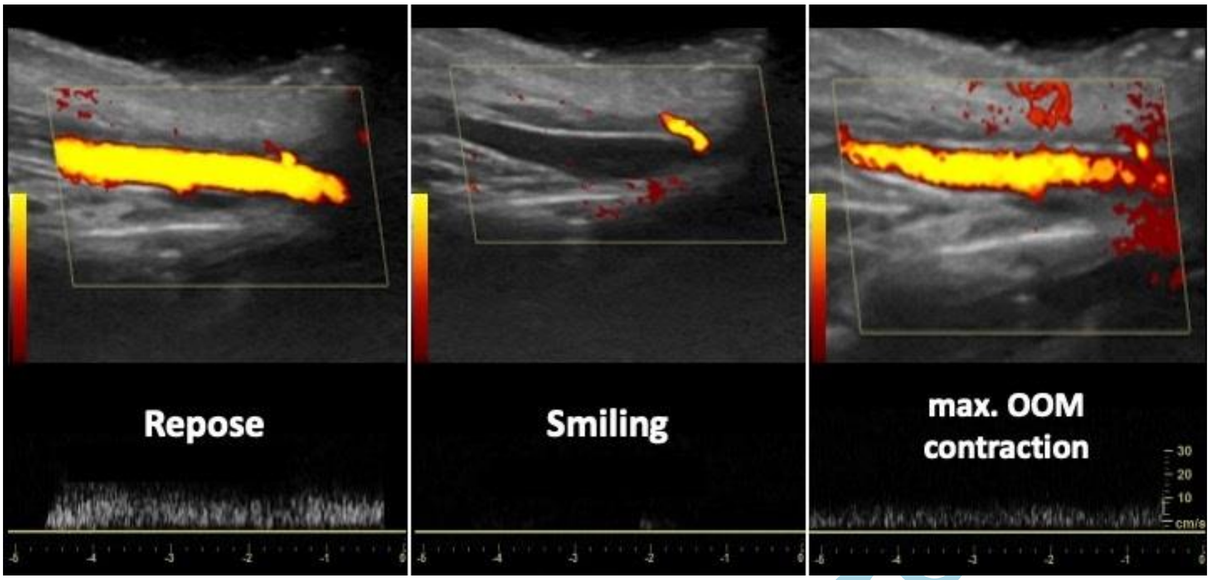


Figure 5

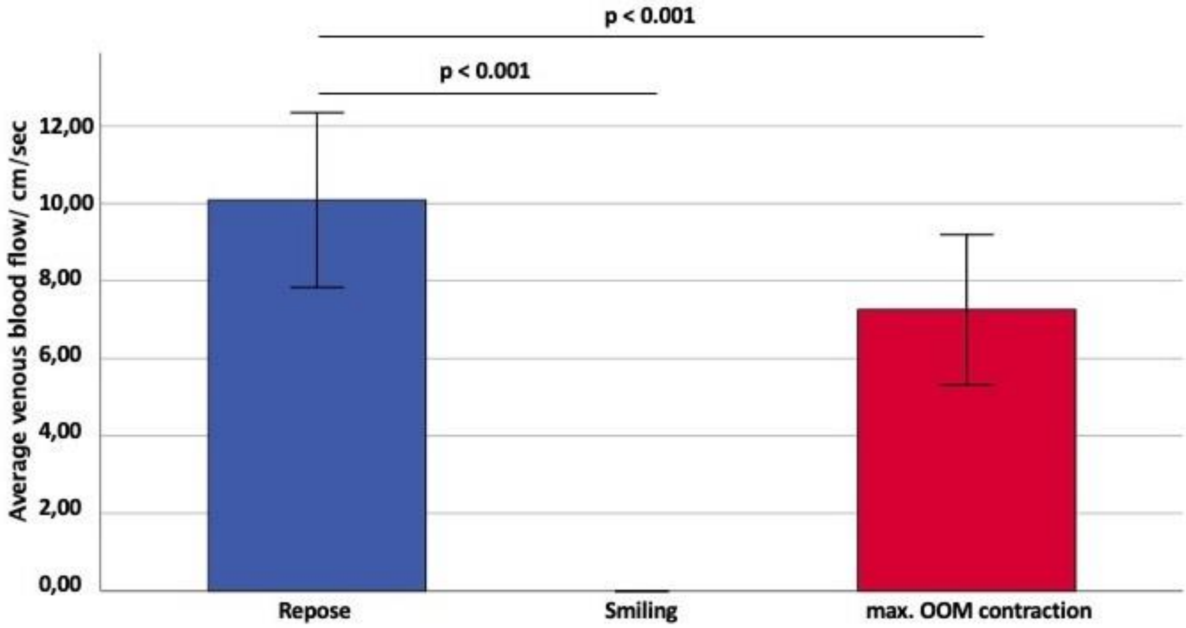

p < 0.001
p < 0.001
Average venous blood flow/ cm/sec
12,00
10,00
8,00
6,00
4,00
2,00
0,00
Repose
Smiling
max. OOM contraction

Figure 6

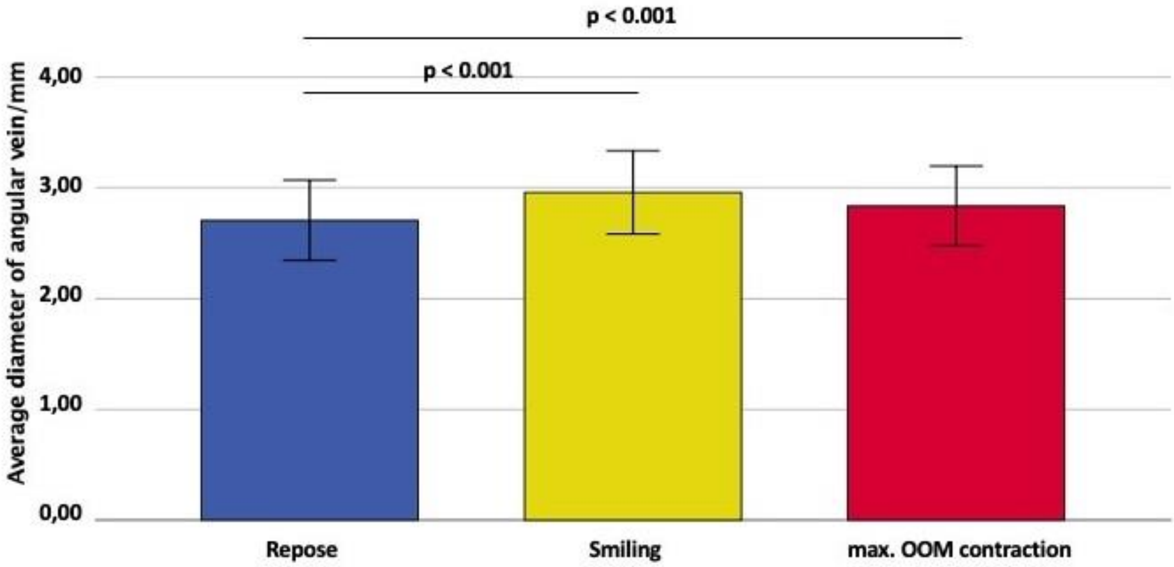
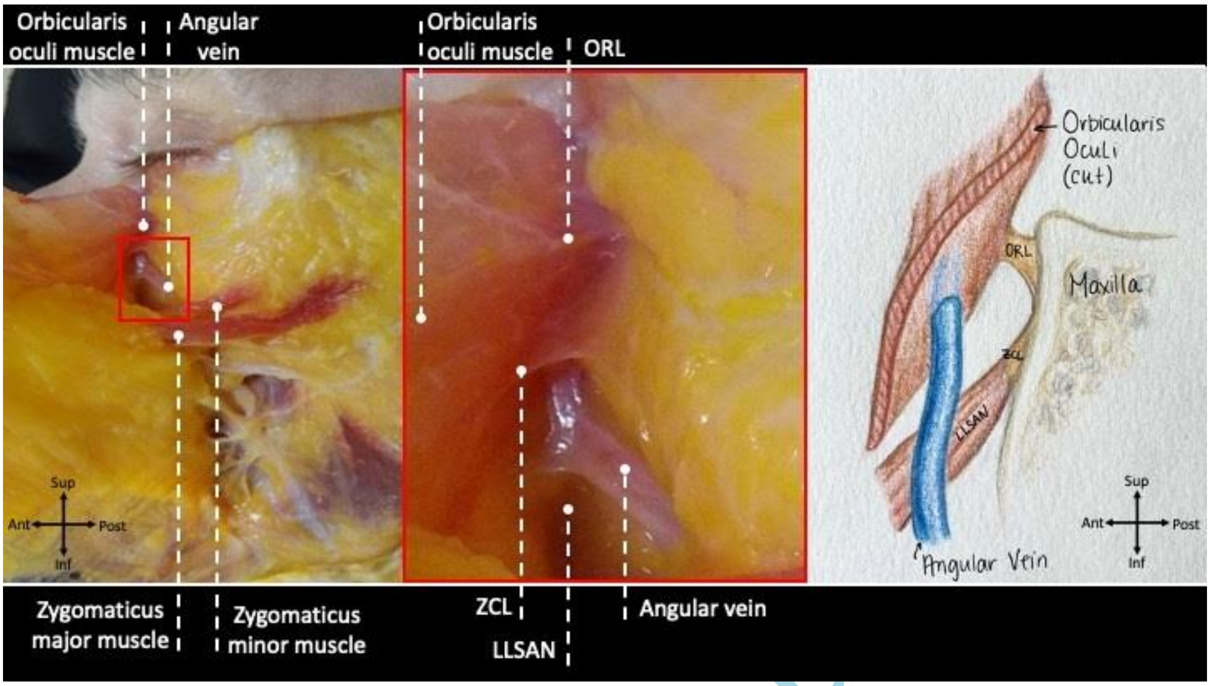

p < 0.001
p < 0.001
4,00
3,00
2,00
1,00
0,00
Average diameter of angular vein/mm
Repose
Smiling
max. OOM contraction

Figure 7


Orbicularis oculi muscle
Angular vein
Orbicularis oculi muscle
ORL
Sup
Ant
Post
Inf
Orbicularis Oculi (cut)
ORL
Maxilla
ZCL
LLSAN
Angular Vein
Sup
Ant
Post
Inf
Zygomaticus major muscle
Zygomaticus minor muscle
ZCL
LLSAN
Angular vein