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Free functional platysma transfer for restoration of spontaneous eye closure in facial paralysis: an analysis of anatomy, imaging, and clinical outcomes

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Author Role/Participation

All authors (Jonathan I. Leckenby; Alap U. Patel; Swapnil Patel; Akm A. Rahman; Shameem Haque; AO Grobbelaar) contributed to this work in the following manner:

- Substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data
- Drafting the article or revising it critically for important intellectual content

- Final approval of the version to be published
- Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

The University of Rochester Institutional Review Board approved this research (Study #1877).

This research is not a clinical trial.

Short Running Head: Blink restoration using platysma transfer.

Abstract:

Background: Facial palsy patients suffer an array of problems ranging from functional to psychological issues. With regard to the eye, lacrimation, lagophthalmos and the inability to spontaneously blink are the main symptoms and if left untreated can compromise the cornea and vision. This paper reports the outcomes of 23 free functional vascularized platysma transfers used for reanimation of the eye in unilateral facial paralysis.

Methods: Data was collected prospectively for all patients undergoing reanimation of the paralyzed eye using free functional platysma transfer. The only exclusion criterium was that a minimum of a two-year follow up was required. Patients were assessed pre- and post-operatively and scored using the eFACE tool focusing on eye-symmetry with documentation of blink reflex.

Results: A total of 26 free functional platysma transfer were completed between 2011 and 2018; three patients were excluded due to inadequate follow up. The mean age was 9.1 years (SD 7.1) and a ratio of 12 males to 11 females. Pre-operatively no patients had evidence of a blink reflex in comparison to 22 patients at two-year follow up. There was a statistically significant improvement in palpebral fissure ($p < 0.001$) and full eye closure ($p < 0.001$) scores at two-year follow up however, there was no statistically significant difference in gentle eye closure ($p = 0.15$).

Conclusions: This is the first report of free functional platysma long-term outcomes in eye reanimation. The results demonstrate that successful restoration of the blink reflex can be achieved and full eye closure is obtainable following surgery.

In facial palsy, paralysis of the eye may result in the loss of the normal blink reflex. Furthermore, the inability to close, protect and remoisten the eye can result in corneal ulceration and eventual blindness[1-4]. The gold standard operative treatment to reanimate the face is utilize free functional muscle transfers (FFMT)[5-7]. FFMTs have largely been reserved for mid-face reanimation, with individual surgeon preference for single versus two-stage procedures[8,9], selection of donor nerves[10-12] and muscle chosen for transfer[13-16].

Current treatments for eye paralysis include non-operative and operative modalities. Upper-lid loading is the mainstay of treatment in adults[17,18]. Alternatives include lateral tarsorrhaphies or lower lid support with grafts and slings[19]; these are not without unwanted tradeoffs with reduced vision being reported particularly with laterally gaze[20]. Attempts have been made to restore dynamic closure of the eye. Gilles described temporalis transfers in two slips to the upper and lower eyelids[21] resulting in a slit-like appearance of the eye which is unappealing aesthetically due to bulkiness over the lateral orbital rim and additionally, is reliant on cortical plasticity[22,23]. The use of palpebral springs gained some popularity[24,25], however problems with implant fracture and extrusion have largely seen this abandoned[17].

Since Lee and Terzis[26] first proposed using the platysma to reanimate the eye sphincter there have been several different approaches to the surgical technique. Nassif[27,28] advocates a two-stage approach using two cross-facial nerve grafts (CFNG) powered by contra-lateral terminal branches of the zygomatic division of the facial nerve. At the second stage, two small rectangular sections of platysma are harvested and placed in each of the eyelids through blepharoplasty incisions. One CFNG is used to neurotize the upper lid and the other, the lower lid. This has been modified by Biglioli[29] who reports using single CFNG to neurotize a single platysma graft in the upper lid and balances the lower lid with a fascial sling. Terzis reports the use of vascularized platysma FFMTs in two pediatric[30] and four adult[31] cases however, the surgical technique is only briefly described. The most comprehensive report of 24 vascularized platysma FFMTs is from Guelinckx[32]. Other FFMTs such as gracilis, pectoralis minor and extensor pollicis brevis have been described[33,34]. The aim of this report is to complete an anatomical study of the platysma muscle and demonstrate the clinical outcomes using platysma as a vascularized FFMT for reanimation of the eye.

Methods

Anatomical Study:

The platysma muscle of 18 formaldehyde-embalmed cadavers (mean age of 76.2 years) were dissected and 36 platysma muscles were evaluated (Figure 1). The mean lengths and widths were 12.7 cm (SD 1.76 cm) and 4.67 cm (SD 0.53 cm) correspondingly. In all specimens, a branch from the mandibular nerve consistently entered the platysma muscle at the deep surface. In 8 samples a second nerve arising from the cervical branch was seen entering at the lateral border in close relation to the greater auricular nerve emergence. Whilst stimulation was not possible, the findings support dominant innervation is from the marginal mandibular branch of the facial nerve.

Three-hundred Computer Tomography angiograms (mean age of 61 years, SD 17 years, 57% male) were reviewed retrospectively to assess blood supply to the platysma muscle. The mean cranio-caudal length was 10.2 cm (SD 1.9 cm), with a mean thickness of 0.26 cm (SD 0.07 cm). The submental artery was the primary supplier in 92% (n=276) of cases, sublingual artery in 7% (n=23) with a single case being supplied by the inferior labial branch of facial artery (Figure 2). At the origin, the submental artery measured on average 2.0 mm in diameter, sublingual artery 2.3 mm, and inferior labial 2.0 mm. The first perforating branch to the platysma arose at a distance of approximately 24 mm on the right and 23 mm on the left from the origin of submental artery. The artery ran either deep (60%) or superficial (40%) to the digastric muscle. The primary venous drainage of the platysma was either the external jugular (n=174, 58%), submental (n=98, 33%), or anterior jugular (n=28, 9%). The platysma muscle is consistent with a Mathes & Nahai Type II muscle.

Surgical Approach:

Patient selection is the frequently the most important predictor of surgical success. From our experience, this operation would be recommended for patients who present with recurrent conjunctivitis, persistent epiphora, lack of Bell's phenomenon, or those with scleral show greater than 3 mm during forced eye closure.

The operation is completed in two stages. The first stage is typically combined with smile reanimation, and starts with the endoscopically-assisted harvest of bilateral sural nerve grafts. A facelift incision with short submandibular extension is made on the non-paralyzed side. A terminal branch of the zygomatic division is identified using a nerve stimulator. Both grafts are reversed and tunneled subcutaneously below the philtrum to the contralateral side. One CFNG is coapted to the zygomatic branch in an end-to-end fashion, with the distal end being banked in the pre-tragal region and marked with a 5-0 non-absorbable blue suture. A terminal branch of the buccal division is identified and the second CFNG is coapted to this, with the distal end being marked with a 5-0 non-absorbable black suture; this facilitates identifying the correct CFNG at the second stage.

A minimum of six months is permitted for axonal regeneration through the CFNGs. At the second stage procedure, the inferior portion of the previous facial incision is used to enter the non-paralyzed side to access the platysma (Figure 3d). Using a subcutaneous plane, the anterior surface of the platysma is exposed using the following landmarks: the inferior border arises at the clavicle, the superior border at the mandible, although the true termination is within the superficial muscular aponeurotic system further cranially, the posterior/lateral border at the anterior margin of the sternocleidomastoid (SCM) and anterior/medial border is at the midline of the neck. The nerve can be typically identified 1 cm below the mandible and 3 cm ventral to the anterior border of the SCM. The nerve is isolated and stimulated to confirm indirect contraction of the muscle. The medial border muscle is dissected free at the midline, elevated off the clavicle and retracted cranially, separating the muscle from the SCM laterally. The perforators enter the muscle from the deep surface and the small pedicle can be seen traversing the muscle when the flap is reflected cranially; we do not attempt to directly visualize the individual perforators directly through fear of causing inadvertent injury. The flap is based on the facial artery and vein in a retrograde fashion as the submental arises from the facial artery. Dissection of the facial vessels continues cranially to the level of the bifurcation of the labial arteries to provide greater pedicle length. The facial vessels are ligated proximal to the origin of the submental branch and distally at the level of the superior labial artery. The submental artery is divided distal to the perforating branches that enter the platysma (Figure 3).

A standard face-lift incision is made on the paralyzed side and the skin flap is raised paying close attention to the CFNGs in the subcutaneous tissue. The CFNG marked with a blue non-absorbable suture is identified to confirm the zygomatic CFNG in cases where two CFNGs have been placed. The superficial temporal arteries are prepared for microsurgical anastomosis. A curvilinear incision is made at the medial nasal wall over the medial canthal ligament. Two subcutaneous tunnels are created in the upper and lower eyelids; the lacrimal duct is cannulated to prevent iatrogenic injury during this process. The platysma muscle flap is split longitudinally for three quarters of the length in a caudo-cranial direction. The muscle slips are passed through the subcutaneous tunnels and secured to the medial canthal ligament using 4-0 Vicryl. The cranial end of the muscle is secured to the zygomatic arch with the vascular pedicle facing externally (Figure

4). The facial vessels are anastomosed to the superficial temporal vessels and the nerve to platysma is coapted to the CFNG. The face is closed over a non-suctioning drain on the FFMT side and a low-suction drain is placed in the donor side.

Clinical Outcome

All sequential patients who had platysma FFMTs between September 2011 and April 2018 were reviewed. If patients had a follow-up of less than two years they were excluded. All patients routinely had pre- and post-operative photography and video recordings according to our protocol[35]. A panel of four independent evaluators used the eFACE assessment tool to score the paralyzed eye in comparison to the normal eye[36-38]. In brief, resting palpebral fissure was graded with a score out of 200, where 0/200 represents the worst lagophthalmos and 200/200 the worst ptosis, so an optimum score would be 100/200. Eye closure was scored out of 100, where 0/100 represents no eye closure and 100/100 full symmetrical eye closure. Patients were assessed at each visit for the presence of a blink reflex using a cotton swab, and problematic eye-symptoms were documented.

Statistical analysis was completed using GraphPad Prism version 9.0.0 for macOS (GraphPad Software, San Diego, California USA, www.graphpad.com). Normality was tested using a Kolmorogov-Smirnov test where appropriate and pre-operative and post-operative changes were tested using paired Student's t-tests. Significance was attributed when $p < 0.05$.

Results

Between 2011 and 2018, 26 sequential patients underwent platysma FFMTs to reanimate their paralyzed eye, all being performed by the senior author (AOG). 22 cases were combined with FFMT for midface reanimation. Three patients were excluded due to a follow-up of less than two years. At the time of the second-stage surgery, mean patient age was 9.1 years (SD 7.1 years, 13 males and 10 females). The mean length and width of the muscle following disinsertion was 82 mm (SD 4.8 mm) and 37 mm (SD 3.1 mm) correspondingly. The mean total operative time from incision to closure was 8.6 hours (SD 2.4 hours) in combined cases and 5.2 hours (SD 1.8 hours) for eye reanimation alone procedures. There were no incidences of flap failures, no post-operative surgical site infections or hematomas, and no surgical revisions have thus far been required however, two patients developed hypertrophic scars that resolved with steroid injections.

Pre-operatively, all patients had the presence of a blink reflex on their normal side however, no patient had evidence of a blink reflex on their paralyzed side. At two-year post-operative follow-up, 22 out of 23 patients had developed a blink reflex on the paralyzed side, this took on average 14.1 months (SD 2.3 months) to develop. Patients reported a statistically significant improvement of epiphora with 18 patients symptomatic pre-operatively and only three post-operatively ($p < 0.05$). 14 patients pre-operatively required daily usage of lubricating eye-drops; this was significantly reduced to three patients at two-year follow-up ($p<0.05$). For all other eye symptoms there was no significant difference pre- and post-operatively (Table 1).

Utilizing the eFACE scoring methodology, the pre-operative palpebral fissure had a mean score of 78/200 (SD 12) and post-operatively this was significantly increased to 108/200 (SD 8) ($p < 0.05$). The mean pre-operative score for gentle eye-closure was 34/100 (SD 7) and post-operatively was 37 (SD 8), however this was not statistically different ($p = 0.15$). The mean pre-operative score for full eyelid closure was 46/100 (SD 6) pre-operatively and 89/100 (SD 13) post-operatively ($p < 0.05$) at two-years. Figures 5 through 7 demonstrate pre-operative and post-operative results.

Discussion

The detailed anatomical study is the first of its kind to describe the platysma muscle. Whilst the clinical applications of using the muscle as a FFMT are limited, this study reconfirms that one application is to restore eye-closure. When considering eye-closure it is important to differentiate between involuntary closure, blinking, and voluntary closure. The corneal eye blink reflex neural circuit is initiated by corneal sensory receptors that are transmitted along the trigeminal primary afferent nerves to the spinal trigeminal tract. Here secondary trigeminal afferents synapse with reticular formation interneurons which send axons bilaterally to the facial motor neurons in the facial nucleus and the component innervating orbicularis oculi is stimulated to involuntarily close the eye. By utilizing a contralateral zygomatic branch, restoration of both types of closure is possible. Lee and Terzis first introduced the concept of using the muscle as a FFMT for eye closure[26] and Terzis has published the outcomes of six platysma FFMTs[30,31] the most comprehensive series was recently published by Guelinckx[32]; our study confirms the long-term reliability of the procedure.

The cadaveric study confirms the viability of the platysma muscle as a free flap and supports the Mathes and Nahai Type II classification of the muscle. The dominant artery was the submental artery, a direct branch of the facial artery in 92% of 300 CTAs studied; this is of clinical relevance as the pedicle can be reliably based on the facial vessels. This contradicts a recent cadaveric study[39] that reports a predominant arterial supply from the superior thyroid artery (57%), facial (29%) and lingual (7%). Our findings are supported by anatomical textbooks[40] and Lee & Terzis[26], as well as Guelinckx[32] and perhaps the blood supply is more dynamic than can be appreciated in cadaveric dissection. Our practice is to use the facial vessels in a retrograde fashion and the pedicle length and caliber is sufficient for anastomosis with the superficial temporal vessels.

The surgical technique described in this study differs from previous published reports. In contrast to harvesting platysma as a non-vascularized graft, our operative time is longer than 70 minutes[29]. Though harvesting a platysma graft is undoubtedly quicker, there are concerns regarding revascularization of the muscle. The average weight of the flap harvested in our series was 5.2 g (SD 2.6 g) which is much greater than the maximum recommended weight for which adequate revascularization can be expected[41,42]. Without successful revascularization, the graft will become ischaemic, potentially resulting in infection or scarring. Similar to published reports, no incidences of flap failure or infection were experienced in our series, suggesting the increased operative time may be beneficial in the long-term. In 85% of cases the procedure was combined with a second FFMT to reanimate the mid-face and therefore, the second sural nerve graft was reserved for this purpose. Biglioli's report only requires one CFNG for upper eye-lid reanimation as a static sling is used in the lower lid and does not fully recreate the orbicularis oculi muscle. Harvesting a second sural nerve graft added 48 min (SD 12 min) to the first-stage operative time. Combining the eye and facial reanimation took 8.6 hours (SD 2.4 hours). As expected, this improved over time with experience and, compared to operative time in patients undergoing facial reanimation alone, was approximately 3.2 hours longer. Our practice is to routinely perform two FFMTs at the same time for bilateral facial paralysis[43] and the additional time required to combine reanimation of the eye with the smile appears justified.

The second technical difference is the choice of how the platysma muscle is innervated. It is clear that direct neurotization can lead to de-novo formation of neuromuscular junctions however, studies have shown this to be inferior to reinnervation through neurorrhaphy[44], except in situations of prolonged denervation[41,42,45]. By introducing a vascularized muscle, the nerve to platysma can be raised with the flap and superior re-innervation of the muscle can be expected through a direct neurorrhaphy. Terzis describes basing the flap on a cervical branch[31]. Our cadaveric study and intraoperative findings demonstrate the constant nerve supply was from the marginal mandibular branch, agreeing with Guelinckx's series[32]. Clinically, a cervical branch was seen to enter the muscle in six cases, three of which resulted in partial contraction of the muscle when stimulated; in these cases, both branches were used with the marginal mandibular being the primary nerve and the cervical branch being coapted to the CFNG in an end-to-side fashion. There were no significant differences in the outcomes when comparing the groups of one versus two nerves raising questions regarding the ability of the cervical branch to reinnervate the muscle. In our limited experience, dissecting the flap in older patients was easier due to the increased caliber vessels and the larger muscle. In any age group, it is of particular importance to avoid dissection of the perforating branches to platysma; we find that leaving a small cuff off adipose tissue avoids risk of damaging this very small caliber vessels. Finally, our preference is to route the CFNG subcutaneously through the philtrum as this is the same tunnel used for the traditional mid-face reanimation. Our concern would be that the CFNG may be more apparent passing over the nasal bridge rather than being better disguised in the soft tissue of the cheek. We prefer a closed approach to tunneling the muscle through the eyelids rather than an open blepharoplasty incision however, either approach appears plausible. Guelinckx's series describes passing the CFNG supraorbitally and also uses an open blepharoplasty incision for flap insetting.

Our results demonstrate that 96% had an established blink reflex on the previously paralyzed side at two-year follow-up. This is higher than previous reports however, the literature is limited. In the largest published series, Guelinckx reported that 15 of 24 patients (62%) had established a blink reflex at 16 months follow-up. Terzis reported an 8% improvement in blink reflex in two pediatric cases[30] and, in a series of four adults, demonstrated an improvement in blink score from 1 to 3 out of 5[31]. We find that routine testing for the blink reflex at each patient visit is an important aspect of monitoring for early reinnervation; even a slight muscle movement can be detected more easily than when asking the patient to close their eyes. The superior results in our study are likely to be attributed to two factors: patient age and follow-up length. The mean age in our study was 10 years, in contrast to 30 years in Guelinckx's report and 46 years in Terzis' adult report. The literature supports that axonal regeneration is poorer with increasing age [44,46] and this is likely to be the principal cause for the difference. Currently, we choose to limit this procedure as a rule of thumb to patients under the age of thirty years. Contrary to this is the one case that failed to develop any movement, FFPT18. The patient was 6 years old at her second stage and no identifiable cause for this was discovered. However, it is well documented in the functional muscle outcome literature that between 10 - 20% of smile reanimation patients failure to gain movement of the FFMT [6,47], and continues to be the driving force behind basic science research into nerve regeneration. Finally, this study's follow up is longer than previous reports which may also support the notion that axonal regeneration may continue to become established up to two years following surgery.

This study reports statistically significant improvements in the symmetry of the eye, both whilst in repose and during forced closure. For this study we elected to use the most widely supported outcome measure for facial paralysis in an effort to standardize surgical outcomes moving forward[37]. All of the previous studies cited use different scoring systems to grade eye closure and therefore, direct comparisons with these is difficult. Consistently throughout the published reports eye closure improved. In our study, the palpebral fissure improved from 78 – 108 (out of 200) representing a change from mild-moderate lagophthalmos to very mild ptosis. There was no improvement in gentle eye-closure. There was a significant improvement in forced eye-closure from 46 – 89 (out of 100). Guelinckx reports similar findings with 88% of patients achieving good/excellent results, Biglioli reports a 2.6 mm improvement in eye closure at the cost of 1.5 mm ptosis and Terzis reports 1.5 times better outcomes for dynamic rather than for static procedures however, there was no statistical improvement in the four cases of platysma FFMT.

The goal of reanimating the eye is to replicate the ocular sphincter as best as possible. Whilst the platysma is phenotypically similar to orbicularis oculi in muscle fiber composition[33,48], the biomechanical properties differ greatly from the muscle fiber length to the organization of the motor end plates[49,50]. Coupling this with the variability associated with axonal regeneration across long nerve grafts it is perhaps even more surprising that our results, combined with those previously published, are as good as they are. However, due to the inconsistent implementation of methodology it is not possible to analyze this data further and it is paramount that within the facial palsy community the reporting of outcomes must be standardized[35].

Conclusion

The long-term outcomes of eye reanimation in facial paralysis using vascularized platysma FFMTs demonstrate that the technique is viable and the results are generally excellent. The surgical procedure is technically demanding but a logical approach is described here to facilitate the facial palsy community. The findings suggest that the time and effort invested in harvesting a vascularized flap is beneficial to patient outcomes however, a standardized reporting of outcomes needs to be adopted within the community to compare results directly.

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Figure Legends:

Figure 1 Cadaveric dissection demonstrating the platysma flap from the deep surface. The facial artery (**A**) and vein (**V**) are seen at the cranial aspect of the flap and the nerve supply (**N**), arising from the marginal mandibular branch of the facial nerve, is seen entering the flap at junction between the proximal and middle thirds. [Scale bar = 5 cm]

Figure 2 Confirmation of the blood supply to the platysma muscle was achieved through reviewing CT angiograms. Two variations were demonstrated: the dominant supply (71%, **A**) arose from the submental artery whilst the subsidiary supply arose from the sublingual artery (29%, **B**).

Figure 3 Intra-operative raising of the platysma flap. Following dissection of the superficial aspect of the muscle, a line it drawn along the inferior border of the mandible and the anterior border of sternocleidomastoid (SCM); the nerve to platysma is typically located 3 cm anterior to SCM and 1cm inferior to the mandible (**A**). The nerve is found deep to the muscle and correct identification is confirmed with stimulation (**B**). The flap is dis-inserted from the clavicle and reflected cranially to expose the vascular pedicle running along the deep surface of the muscle (**C**). Finally, the facial vessels are raised to supply the flap in a retrograde fashion (**D**).

Figure 4 Inset of the platysma flap. The flap is split parallel to the direction of muscle fibers and an overview of the inset is demonstrated in (**A**). After making curvilinear incision over the medial canthus, Carroll tendon forceps are used to create a subcutaneous tunnel to permit passage of the flap in the upper and lower eyelid (**B**). The flap is secured to the medial canthal ligament using absorbable sutures (**C**).

Finally, preparation for microsurgical anastomosis of the facial artery and vein to the superficial temporal artery and vein; neurorrhaphy to the CFNG is already complete (**D**).

Figure 5 Clinical outcomes of free platysma transfer for restoration of eye-closure. Pre-operative photographs at rest (5Ai) and with maximal effort eye-closure (5Aii). Two-year post-operative photographs at rest (5Bi) and with maximal effort eye-closure (5Bii).

Figure 6 Clinical outcomes of free platysma transfer for restoration of eye-closure. Pre-operative photographs at rest (6Ai) and with maximal effort eye-closure (6Aii). Two-year post-operative photographs at rest (6Bi) and with maximal effort eye-closure (6Bii).

Table Legend:

Table 1 Patient data from all 23 free functional platysma transfers. Post-operative analysis was completed at two-years following final surgery.

Table 1

Patient ID	Gender	DOB	Diagnosis	First Stage	Second Stage	Eye Symptoms												eFACE Score					
						Blink		Dry Eyes		Infection		Epiphora		Pain in Bright Light		Blurred Vision		Palpebral Fissure		Gentle Closure		Full Closure	
						Pre-Op	Post-Op	Pre-Op	Post-Op	Pre-Op	Post-Op	Pre-Op	Post-Op	Pre-Op	Post-Op	Pre-Op	Post-Op	Pre-Op	Post-Op	Pre-Op	Post-Op	Pre-Op	Post-Op
FFPT01	M	03-10-06	Congenital	20-01-11	18-02-12	–	+	+	–	+	–	–	–	+	–	+	–	75	80	40	40	30	85
FFPT02	M	08-03-00	Mucoepidermoid cyst	04-04-11	18-04-12	–	+	–	–	–	–	+	–	–	–	–	–	60	95	35	35	45	80
FFPT03	M	05-09-04	Bell's palsy	18-07-11	30-07-12	–	+	+	+	–	–	+	–	–	–	–	–	60	85	35	35	40	75
FFPT04	F	20-10-95	Congenital	26-08-12	13-06-13	–	+	–	–	+	+	+	–	+	+	–	–	50	85	40	35	40	85
FFPT05	F	25-06-03	Skull base tumour	13-09-12	17-06-13	–	+	+	–	+	+	–	–	–	–	–	–	40	90	30	40	50	90
FFPT06	M	10-08-62	Cholesteatoma	25-10-12	04-04-13	–	+	+	+	–	–	+	–	–	–	–	–	60	70	55	45	45	75
FFPT07	F	17-11-07	Pilocytic astrocytoma	22-11-12	14-03-13	–	+	–	–	–	–	+	–	–	–	–	–	60	85	45	40	45	90
FFPT08	F	12-06-08	Congenital	06-12-12	02-09-13	–	+	–	–	–	–	–	–	+	+	–	–	40	80	30	25	40	100
FFPT09	F	29-05-08	Goldenhar Syndrome	31-01-13	03-11-14	–	+	+	–	+	–	+	–	–	–	–	–	35	85	25	30	45	95
FFPT10	M	21-12-08	Hemifacial microsomia	04-02-13	25-08-14	–	+	–	–	+	+	+	–	+	–	–	–	50	75	30	25	45	85
FFPT11	M	19-02-96	Acoustic Neuroma	04-03-13	17-02-14	–	–	+	+	–	–	+	+	+	+	–	–	40	70	25	25	40	90
FFPT12	M	15-03-09	Hemifacial microsomia	13-06-13	24-09-15	–	+	+	–	–	–	+	–	–	–	+	+	65	75	40	30	55	95
FFPT13	M	07-01-08	Congenital	15-06-13	04-12-14	–	+	+	–	–	–	+	–	–	–	–	–	75	85	45	45	45	80
FFPT14	F	18-02-10	Skull base tumour	09-06-14	19-01-15	–	+	–	–	+	–	+	–	–	–	–	–	60	85	30	30	30	95
FFPT15	F	28-12-09	Hemifacial microsomia	17-07-14	27-08-15	–	+	+	–	+	–	+	–	–	–	–	–	55	70	25	25	55	75
FFPT16	M	25-04-10	Congenital	21-07-14	19-10-15	–	+	+	–	–	–	+	–	–	–	–	–	60	95	30	45	40	80
FFPT17	M	24-08-67	Acoustic neuroma	11-08-14	16-09-15	–	+	–	–	–	–	–	–	–	–	–	–	55	80	40	50	55	95
FFPT18	F	17-12-09	Congenital	07-01-15	10-02-16	–	+	+	–	–	–	+	–	–	–	–	–	50	80	45	45	40	40
FFPT19	M	11-03-11	Goldenhar Syndrome	05-03-15	21-03-16	–	+	+	–	–	–	+	+	–	–	–	–	70	90	45	50	50	95
FFPT20	M	17-03-10	Congenital	09-03-15	21-12-15	–	+	+	–	+	+	+	–	+	–	–	–	30	80	25	30	45	100
FFPT21	M	04-08-11	Congenital	03-08-15	22-02-16	–	+	+	–	–	–	+	–	–	–	–	–	45	70	35	40	50	80
FFPT22	F	22-02-11	Congenital	10-08-15	10-03-16	–	+	–	–	–	–	–	–	–	–	–	–	60	85	30	30	35	80
FFPT23	F	28-08-10	CHARGE Syndrome	20-08-15	24-03-16	–	+	–	–	–	–	+	+	–	–	+	–	55	90	40	40	60	85

Figure 1

Figure 2a

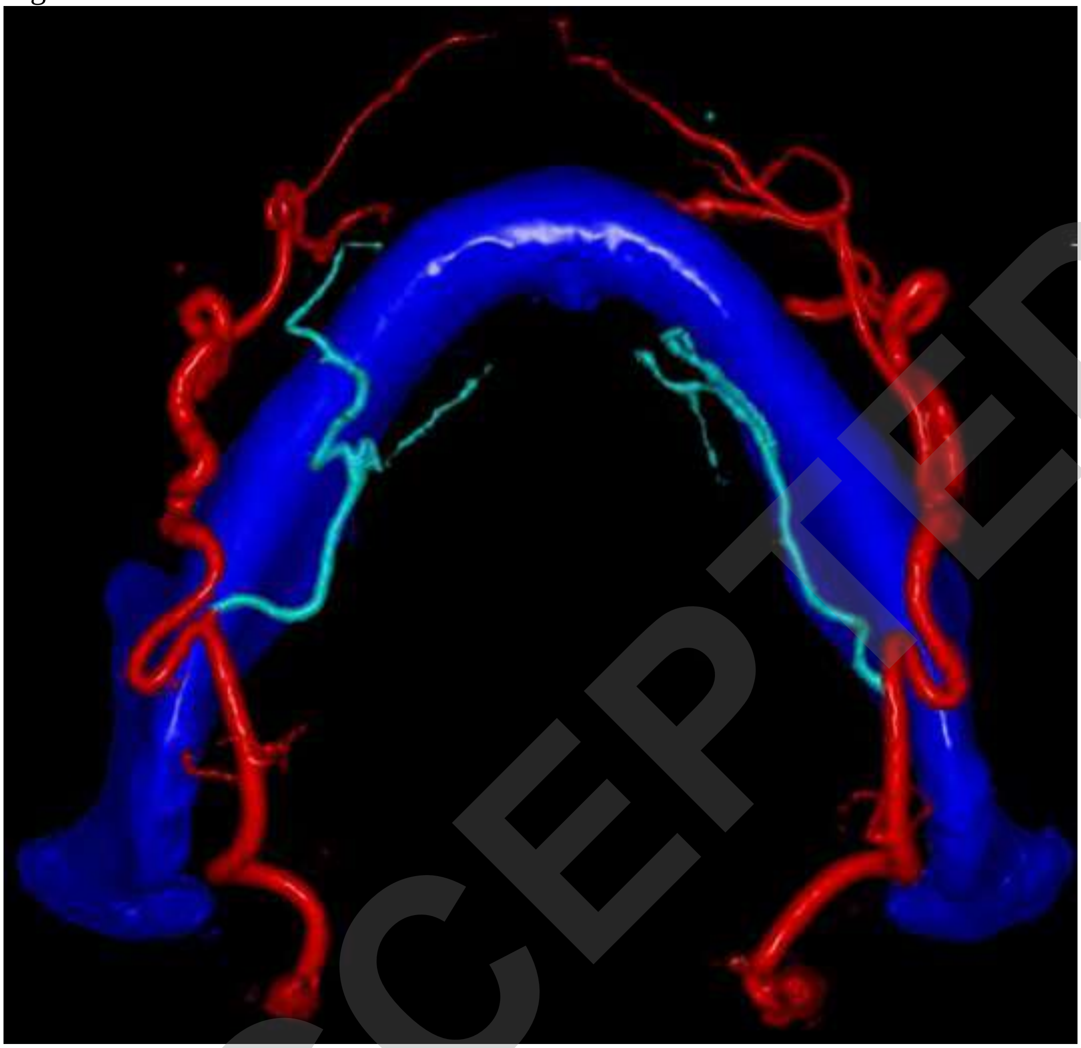


Figure 2b

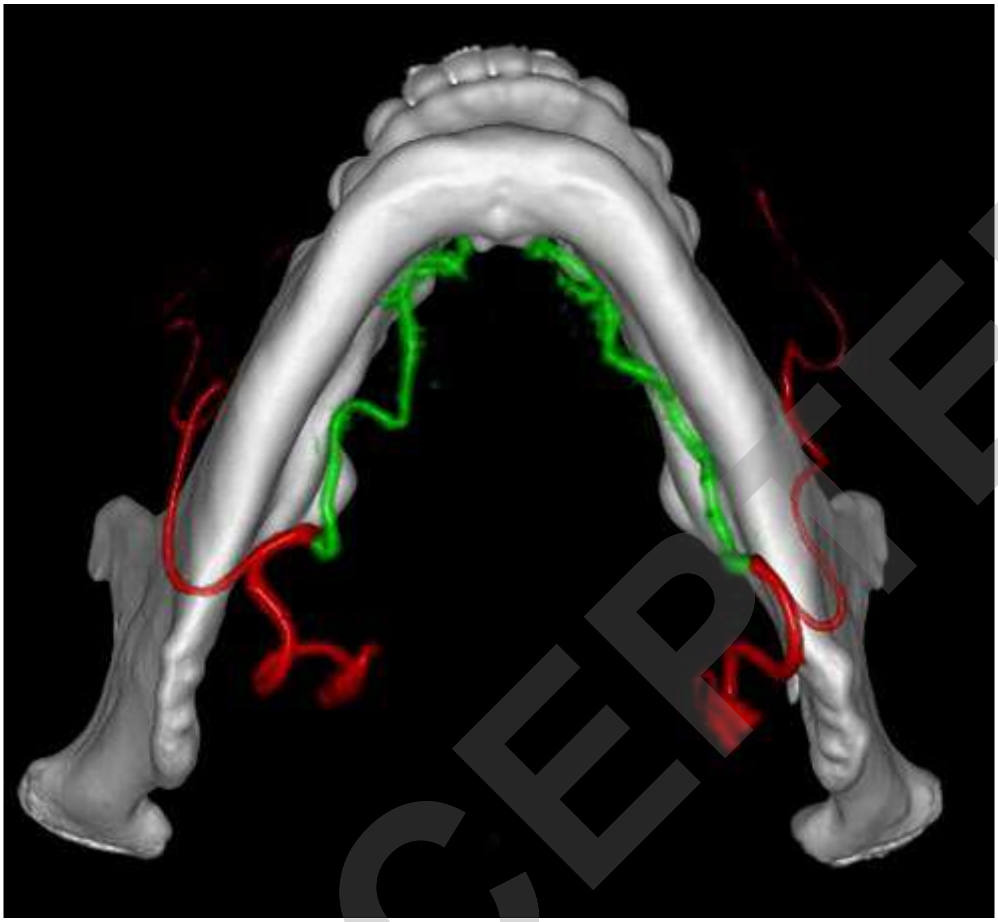


Figure 3a

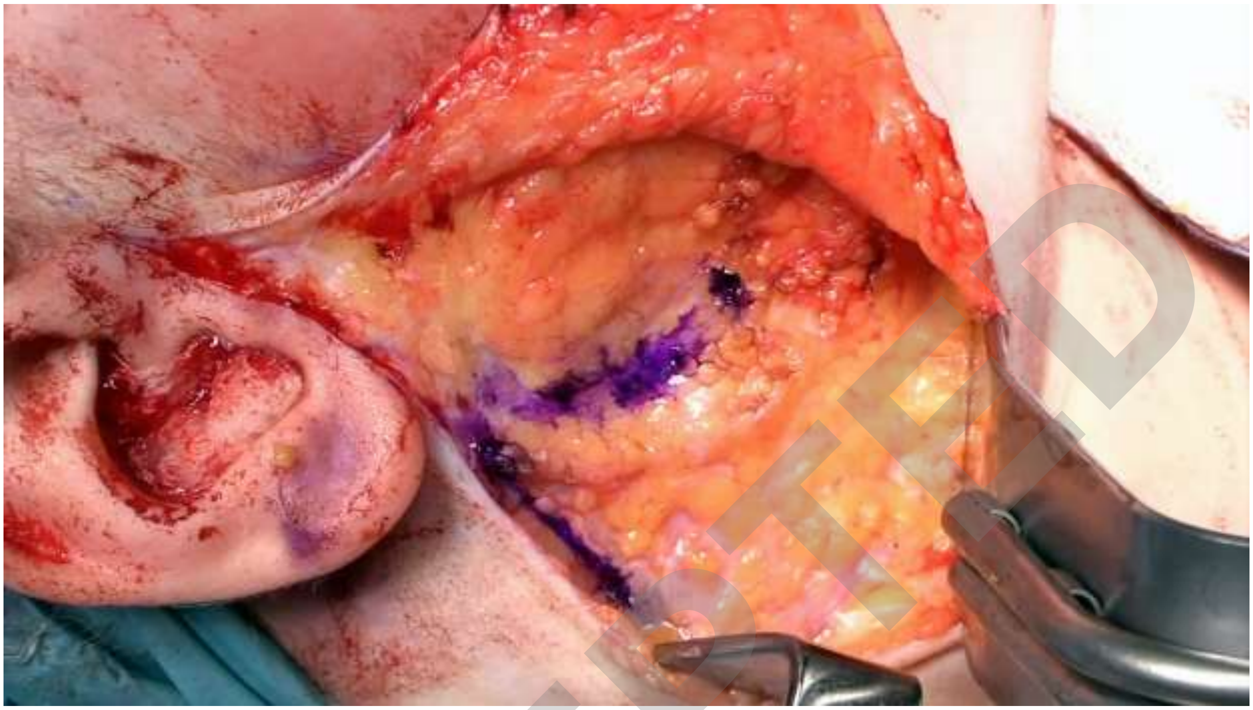
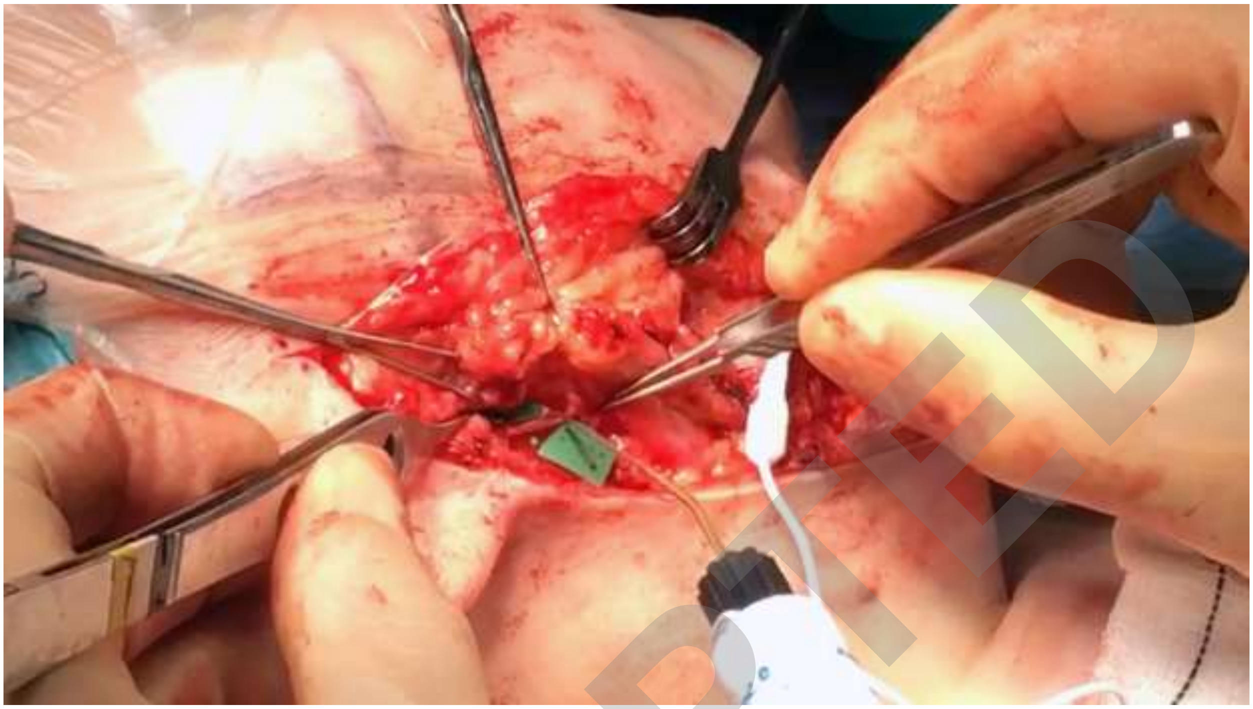


Figure 3b



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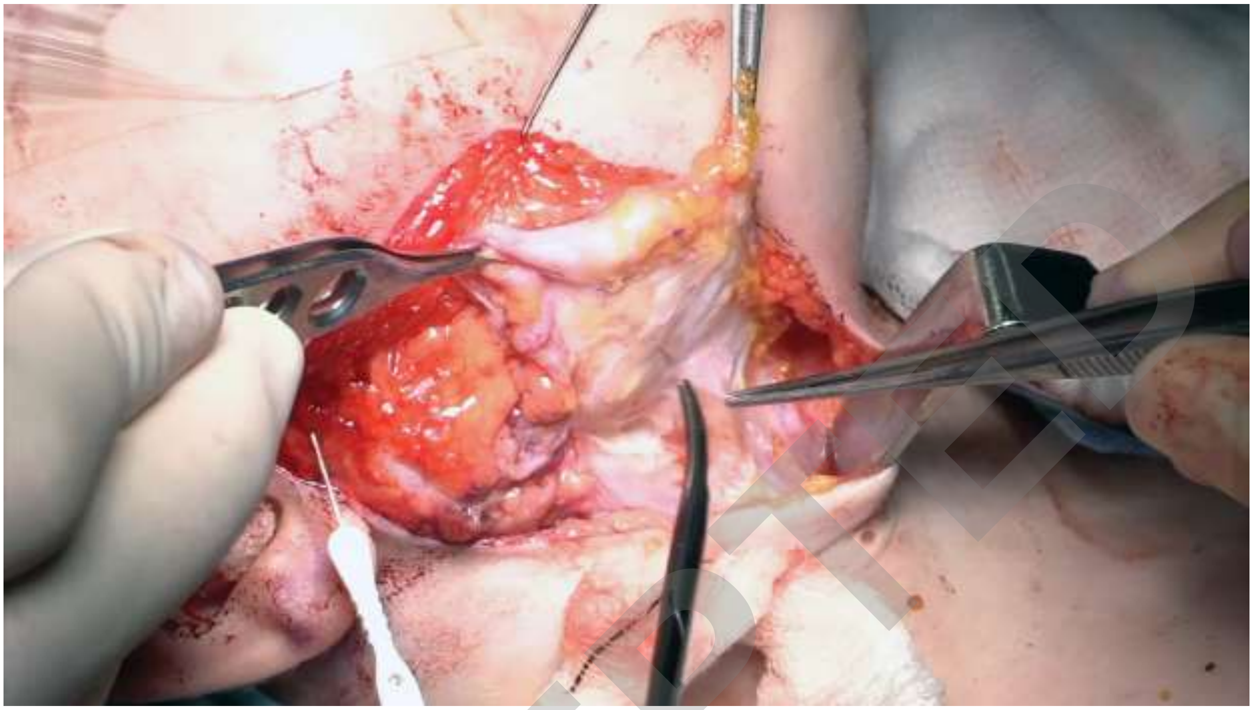

Figure 4a

Figure 4b

Figure 4c

Figure 4d

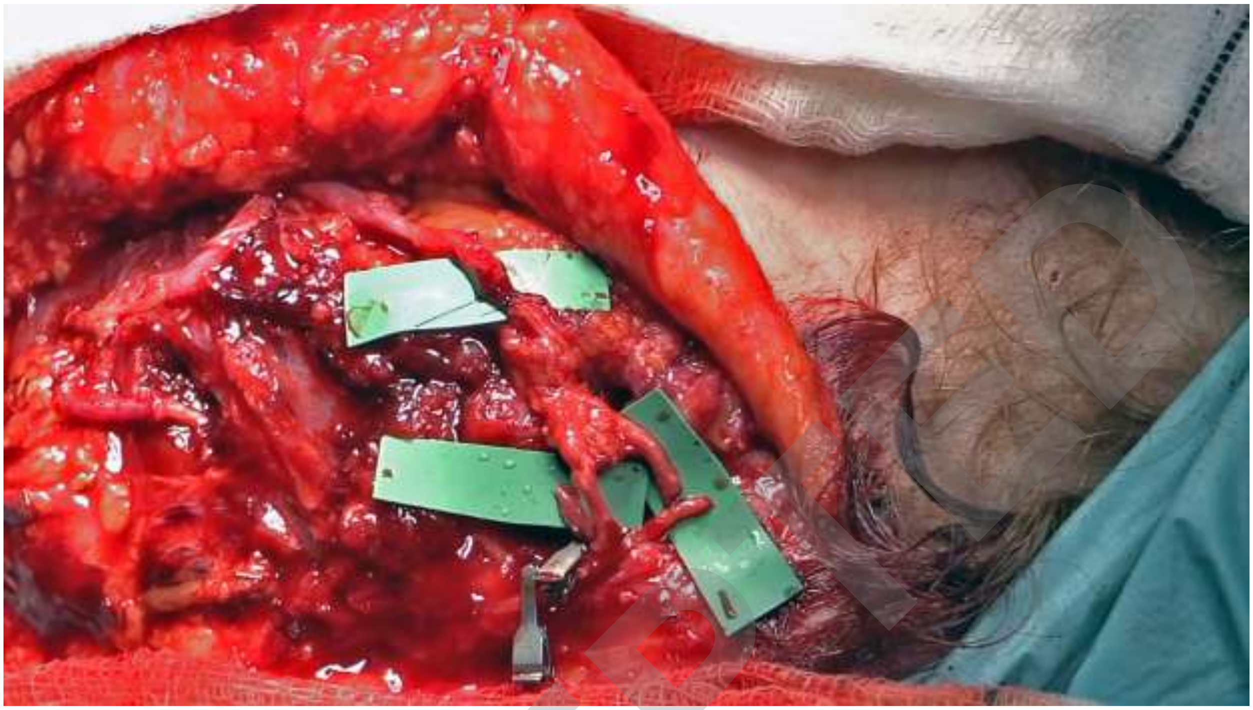

Figure 5ai

Figure 5aii

Figure 5bi

Figure 5bii

Figure 6ai

Figure 6aii

Figure 6bi

Figure 6bii