Aesth Plast Surg
https://doi.org/10.1007/s00266-020-02066-6

Personal Strategy to Avoid Fat Embolism During Fat Grafting: Brisk Withdrawal of Cannula While Injection

Fahd Benslimane[1]

Received: 7 September 2020 / Accepted: 21 November 2020

Abstract

Introduction Complications of fat grafting by means of injection may lead to unwanted passage of substrate into vessel lumens resulting in catastrophic complications. Likewise, a similar trend of complications is observed with non-autologous fillers regardless of an almost generalized use of blunt cannulas, the latter being implicated in the majority of serious vascular complications of hyaluronic acid injection. This report is the product of investigation to review all cases that underwent an original technique of fat injection: "The smart fat injection" during the cannula's brisk withdrawal technique. The aim of this research was to document the safety of this technique by searching if fat embolism had occurred and if yes, its incidence in this group of fat injection surgeries.

Method This retrospective review included 3039 patients who underwent the smart fat injection at the facial or corporeal level between 2001 and 2019. The study focused on the search for complications linked to fat yet also cruorical embolism, as the latter may resemble the clinical symptoms of fat embolism.

Results The assessment of the 3039 patients who underwent the smart fat injection during cannula's brisk withdrawal, resulted in none presenting clinically detectable fat or a cruorical embolism.

Conclusion This report documents the safety of the smart fat injection developed over a period of 22 years. It further explains the rationale of the technique for avoiding fat embolism while simultaneously enhancing fat take. This technique should not be implemented without appropriate in vitro training.

Level of Evidence V This journal requires that authors assign a level of evidence to each article. For a full description of these Evidence-Based Medicine Ratings, please refer to Table of Contents or online Instructions to Authors www.springer.com/00266.

Keywords Fat embolism · Fat injection · BBL · Complication of fillers · Patient safety · Brisk withdrawal technique

Introduction

Fat grafting by means of injection for aesthetic facial and body contouring has gained popularity. Yet, when injections are performed at the facial level, secondary complications whereby the unwanted fat passage into vessel lumens may lead to permanent visual loss or brain infarction [1, 2]. This same situation may also occur with non-autologous fillers. Since 2015, there have been 70 newly reported cases of soft-tissue non-autologous filler blindness associated or not to brain infarction [3, 4]. The actual incidence of such catastrophic complications may be more common [5]. Until 2014, autologous fat appeared to be the most frequent filler that caused blindness [6]. This propensity, however, has changed in the last three-year period, as non-autologous fillers became popular [7]. Blunt cannulas were introduced to avoid such types of complications [8]. Regardless of its wide usage, the majority of severe hyaluronic acid–related intravascular events that were referred to the department of plastic surgery in

Supplementary information The online version contains supplementary material at (doi:https://doi.org/10.1007/s00266-020-02066-6).

✉ Fahd Benslimane
clinique.benslimane@gmail.com

[1] Plastic Surgeon, Clinique Benslimane, Casablanca, Morocco

Shanghai Jiao Tong University was performed with cannulas, not needles [4]. At the corporeal level, ASAPS members performed 24,099 fat grafting procedures in the buttock area in 2018 increasing its number by 19% in one year [9]. Fat injection for body contouring can cause fat embolism syndrome (FES) secondary to passage of fat into the bloodstream. The so-called Brazilian butt lift (BBL), which is not a Brazilian technique [10], experienced an increased death rate of 1 in 1030 reported in 2017, which made this surgery the deadliest procedure in cosmetic surgery in the same year [11–14]. Specifically in the area of South Florida, 11 deaths were registered in the preceding 3 years and 5 deaths during the year 2019 [15]. Safety concerns have led the ASERF task force to perform a vast work, which resulted in issuing recommendations to curtail complications linked to gluteal fat injections [16–18]. In a recent article, Lari et al. [19] proposed the use of extracorporeal membrane oxygenation (ECMO) and its potential application as a main modality of treatment for macroscopic fat embolism (MAFE). Other authors proposed strategies for safer fat injections. These include "smart sensing cannulas" [20] and "real-time ultrasound-assisted gluteal fat grafting" [21]. These are recent technologies solely devoted to the grafting of the buttock subcutaneous plane, excluding all other areas. The aim of this paper is to present the "smart fat injection" technique during the cannula's brisk withdrawal in association with well-accepted recommendations that have stood the proof of time in order to avoid fat embolism [22–24]. This technique may also be applied to the entire face and body and to non-autologous filler injections. Finally, an ex vivo experiment was conducted to observe substrate distribution with "smart fat injection" compared to more traditional injection techniques.

Method

A retrospective review was constructed between the years of May 2001 and December 2019 of patient files for whom I surgically performed 4195 microfat graft (MFG) procedures on for facial volume enhancement. The total number of files was 2696 consecutive patients, of which 2625 were female and 71 male. Patient ages ranged from 19 to 78 years old. The grafted areas were administered as follow: 1277 upper eyelids, 689 temples, 490 zygomatic areas, 411 parotid areas, 406 midfaces, 301 lower eyelids, 201 glabellas, 111 jawlines, 91 foreheads, 82 chins, 77 deep cheeks (buccal fat pad), 46 noses and 13 intra-orbital's MFG (Table 1). All 2696 patients were operated on under local anesthesia with implementation of the highest patient safety criteria in the OR under the supervision of a board-certified anesthesiologist for sedation and strict monitoring. All grafted areas were infiltrated with lidocaine and epinephrine to promote vasoconstriction. The harvesting cannula diameters ranged from 0.9 mm to 5 mm, their port sizes ranged from 0.3 to 0.9 mm and the number of ports ranged from 1 to 160. Aspirated substrate was double centrifuged, supranatant oil and infranatant liquid were eliminated [25]. MFG was performed in all patients with cannulas ranging from 21 to 25 gage. A total of 1346 patients were grafted with both blunt cannulas and sharp needles, the gauge of the latter ranged from 18 to 27 gage. Deposited quantities at each pass were limited to 0.030–0.050 in the face and 0.060–0.0010 for peri- and intra-orbital MFG. A total number of files that consists of 343 consecutive female patients on whom I performed fat grafting for body volume enhancement during the same period were also reviewed retrospectively (Table 2). Their age range was from 20 to 56 years old. These patients were distributed as follow: 131 cases of calves-ankles' MFG, 109 buttocks' millifat graft and 103 breasts' MFG. All 343 patients were operated on in the OR with implementation of the highest patient safety criteria under the supervision of a board-certified anesthesiologist for sedation and strict monitoring. All grafted areas were infiltrated with lidocaine and epinephrine to promote vasoconstriction. Aspirated substrate was centrifuged, supranatant oil and infranatant liquid were eliminated. From the 131 patients operated on for calf-ankle microfat grafting, 121 surgeries were performed under local anesthesia combined with sedation, and 10 surgeries were performed under epidural and sedation. MFG was performed with cannulas, with diameters ranging from 2 to 3.5 mm, their length ranged from 20 to 25 cm. Five out of the 131 patients were grafted with cannulas and sharp needles, the latter's diameter ranged from 18 to 21 gage. Sharp needle MFG was performed at the subcutaneous level in order to expand the skin and enhance its host properties because of apparent non-traumatic skin tightness. Out of the 109 buttocks that were fat-grafted, 98 were operated on under epidural and sedation, 11 were performed under local anesthesia combined with sedation. Millifat grafting was performed with cannulas, with diameters ranging from 2 to 3.5 mm, their length ranged from 20 to 25 cm. All 103 breast MFG was operated on under local anesthesia combined with sedation. MFG was performed in all 103 patients with 18 and 21 gage sharp needles along with blunt cannulas with the same gauge. Deposited quantities of substrate at each pass were limited to 0.05–0.20 ml in buttocks and legs. This quantity was deposited along a length of 20–25 cm, i.e., the length of cannulas' injection. The maximum 0.20 cc of substrate deposited along 20 cm length results roughly in 0.01 cc per cm. For breast fat grafting, deposited quantities of substrate at each pass were limited to 0.03–0.05 cc. There was minimal clinical follow-up for all 3039 patients

Table 1 Distribution of the grafted areas with the smart fat injection during cannula's brisk withdrawal technique at the facial level

Facial grafted areas by means of fat injection'	Number	Fat or cruorical embolism	Percentage
Upper eyelid's MFG	1277	0	0%
Temples' MFG	689	0	0%
Zygoma MFG	490	0	0%
Midfaces' MFG	456	0	0%
Lower eyelids' MFG	401	0	0%
Parotid area MFG	261	0	0%
Glabellas' MFG	201	0	0%
Jawlines' MFG	111	0	0%
Foreheads' MFG	91	0	0%
Chins' MFG	82	0	0%
Deep cheeks' MFG (buccal fat pad)	77	0	0%
Noses' MFG	46	0	0%
Intra-orbital's MFG	13	0	0%
Total procedures	4195	0	0%

Table 2 Distribution of the grafted areas with the smart fat injection during cannula's brisk withdrawal technique at corporeal level

Corporeal grafted areas by means of fat injection	Number	Fat or cruorical embolism	Percentage fat embolism
Calves-ankles' fat graft	131	0	0%
Buttocks' fat graft	109	0	0%
Breasts' MFG	103	0	0%
Total	343	0	0%

within 54 days. Such a period was judged enough as symptoms of MAFE start almost immediately at the time of fat injection within minutes or maximum hours after fat injection [26]. Furthermore, all patients who underwent fat grafting with cannulas brisk withdrawal were distance-monitored for a period of three months or more by phone, text message or email. The study's focus was to find complications that may have occurred that were linked to fatty or cruorical embolism, since the latter may resemble clinical symptoms of fatty embolism [19]. The aim was to document the safety level of fat injection during the cannula's brisk withdrawal technique. Given the fact that I learned gluteal fat grafting with surgeons who were injecting inside the muscles "to enhance fat take", I did the same. However, from the beginning of my experience, I questioned myself about the possibility of perforating deep veins with the injection's cannulas and fat embolism. The close intimacy between the cannula's tip and vessels of the grafted areas was of great concern. The same concern was raised for periocular; glabella and nasal vessels where the incidence of filler embolism is described as high [7]. Fat injection was performed only during slow retrograde motion of the cannula as advocated by Coleman [23, 24]. To further enhance patient safety, I developed the "smart fat injection during cannula's brisk withdrawal technique" hereinafter-named 'smart fat injection' (SFI). This technique was first implemented in the legs [27]. The smart fat injection is subdivided into a sequence of four steps.

The first step begins with cautious, slow motion cannula advancement into the leg tissues including the calf muscles in order to trace multiple paths without injection. Initially, when opposition to the cannula's advancement due to muscle fascia resistance is felt, the 5 or 10 cc syringe is firmly grasped with the palm of the hand; several paths are traced through the muscles, in a pre-tunneling fashion, perforating fasciae at different spots, soft bony contact being searched at the end of each laid tunnel when bony structure is anatomically present in the axis of the tunnel. No injection is performed at this stage in order to avoid splitting my attention between 2 equally important gestures: 1. The initial tracing of tunnels within tissues, which have varied densities and resistances and require a different level of force and penetration. It is essential to focus the maximum attention on tracing these tunnels without injecting as to be able to foresee the smoothest possible contact between the cannula's tip and an eventual vessel in case the latter would be anatomically positioned in the axis of the tunnel. In turn, this will avoid deep vessel laceration. The same attention is necessary as to be able to foresee a smooth/soft bony contact in case a bony structure exists at

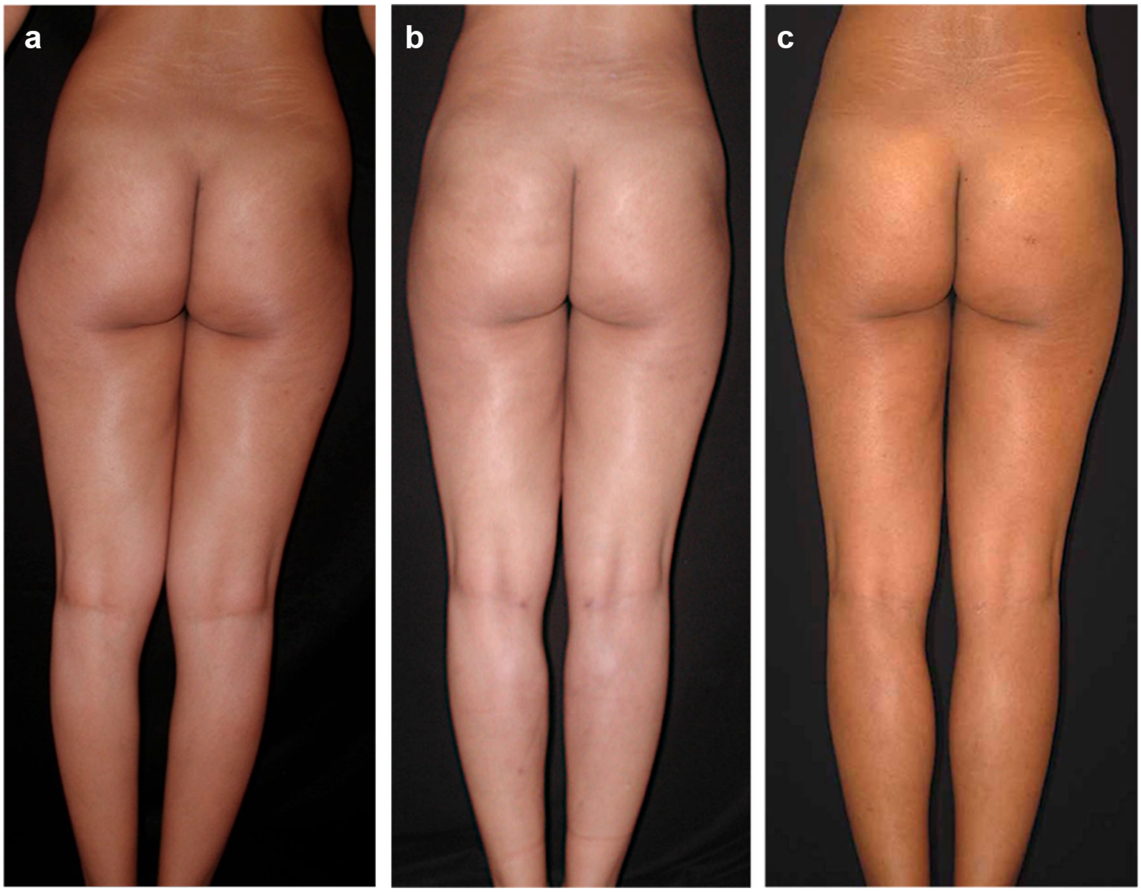

Fig. 1 **a** Pre-operative photograph of a patient whose leg column of each lower limb presents a deviation from the straight axis. Traditional lipo was performed to her lateral thighs, hips and lateral upper leg. Microfat graft was performed in the following quantities: 260 cc per calf and ankle, 142 cc of her left buttock, 150 cc of her right buttock **b** 45 days post-operative photograph of the same patient. Her lower limbs display straightness. **c** 48 months post-operatively the result is stable. Little changes have occurred as she maintained the straightness of her lower limbs, her legs and ankles are in continuity with the axis of her thighs which confers a perception of a long leg, starting very high in the pelvis and continuing straight down to the knee, leg ankle and foot

the distal extremity of the tunnel axis. 2. The limitation of minimal quantity of substrate injection during the cannula's brisk withdrawal. The latter is not initiated before my dominant hand is familiarized with the tissues' resistance at different depths nor before pre-tunneling.

The second step of the procedure consists of stopping the cannula's advancement when it reaches the distal extremity of each traced tunnel.

The third step of the procedure consists of substrate injection during the cannula's brisk withdrawal. The palm of the hand is moved away from the body of the syringe, the latter being held solely by the fingertips. From this step on, the force of the fingertips alone achieves all subsequent penetration of the cannula into the recipient's tissues. The needed force for the cannula's advancement is minimal as the tunnels were already traced. Fat is deposited only once a brisk withdrawal of the cannula is initiated: The thenar eminence exerts a gentle pressure on the plunger while the fingertips delicately pull the body of the syringe backward against the palm of the hand. For legs and buttocks, a maximum substrate fat of 0.2 cc is distributed along the 20 cm of the cannula's length, i.e., 0.01 cc per cm (Supplementery video 1–7).

The fourth step consists of the cannula's brisk stop when its tip is close to the entry orifice at the end of each sequence: This avoids the cannula's exit from the entry port at each brisk withdrawal. Smart fat injection was then implemented in other corporeal areas such as the buttocks (Supplementery video 3) (Fig. 1) and breast (Supplementery video 4). This technique was further applied for facial MFG: upper eyelid's (Supplementery video 5) (Fig. 2), intra-orbital (Fig. 2), temples, forehead, glabella (Supplementery video 6), lower eyelids, zygoma, parotid region, nose (Supplementery video 2), midface, cheek (buccal fat pad), chin and jawline MFG. Rigorous principles were implemented for the upper eyelid and intra-orbital MFG in particular as it demands permanent attention in order to advance the cannula in a slow-cautious manner

Fig. 2 **a** Pre-operative photograph of a patient who had a car accident with a fracture of the floor of her left orbit responsible for the lower position of her left eyeball in relation to the right. She also presents a ptosis, upper eyelid hollowness and skin retraction of her left UEL secondary to a scar. **b** Postoperative photographs at day one of the same patient after she underwent a bilateral canthoplasty, a z plasty of the left UEL, 1.6 cc intra-orbital MFG in her left orbit, 5.8 cc MFG of her left UEL, 4 cc MFG of her right UEL, 2 cc MFG of her left lower eyelid (LEL) and 1.6 cc MFG of her right LEL. Photographs **c** was taken at day 8 photograph **d** at 54 days, then photograph **e** at 5 years without any touch-up. Intra-orbital MFG on a seeing eye lifted her left eyeball to an equivalent position than the right eyeball. At five years, she displays a correction of her eyelid ptosis which favors the theory of the regenerative effect of fat grafted both at pre and retro septal space

Fig. 3 Photograph while the aspirating tube is perforated at its distal extremity with an 11 blade to create a port allowing the entry of cannulas of different gauges, from 2 mm to 4 mm. The aim was to simulate an accidental perforation-cannulation of a large vein

in the pre- or retro-septal space avoiding eyeball perforation and/or periocular and levator muscle laceration. Care is taken to avoid injecting neither when the cannula is advanced nor when it is in the stopping mode. The substrate is deposited during the sole "brisk withdrawal mode". I maintain the highest level of speculation that the cannula's tip is inside the lumen of a vessel or in the vicinity of a lacerated vein each time it is advanced: With such a questionable scenario in mind, my brain does not allow me to push the plunger unless I initiate the cannula's brisk withdrawal. This technique presents also the advantage of depositing dust like substrate [25] as the cannula's brisk withdrawal leaves a smaller quantity of substrate along its entire path when compared to a slower speed cannula withdrawal at equal pressure on the plunger.

Fig. 4 Photograph of the 5-cc syringe filled with fresh fat aspirated the same morning from a patient. The substrate was colored with methyl blue in a proportion of one cc of dye to 4 cc of fat in order to enhance its visibility in both the transparent tube and the aspirator collector

Finally, an ex vivo experiment was conducted to compare substrate distribution during the injection with 3 different techniques:

1. Injection during slow-gentle withdrawal of the cannula.
2. Injection during constant motion of the cannula as advocated by ASERF.
3. Injection during brisk withdrawal of the cannula.

Fig. 5 Photograph of two 5 cc syringes with connected in order to mix in a harmonious fashion the one cc dye with the four cc of fat

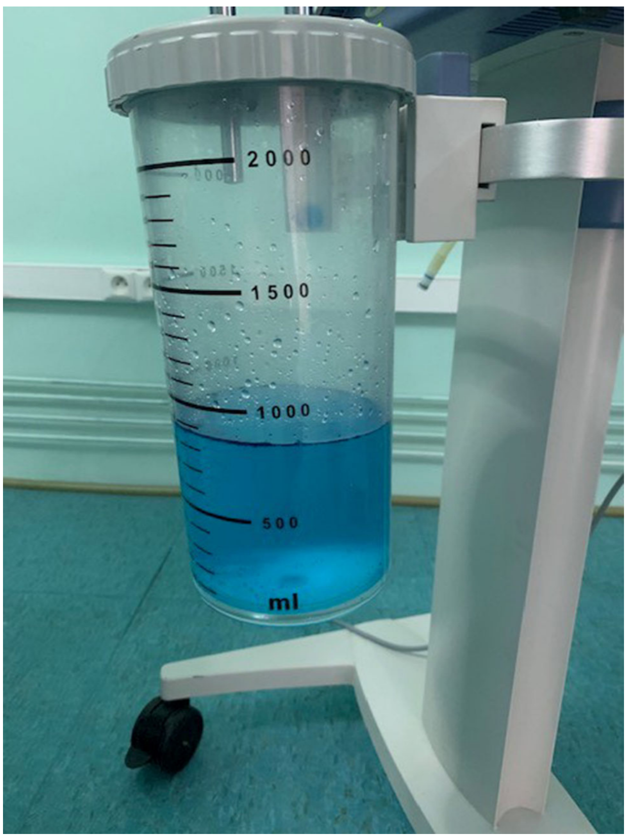

Fig. 6 Photograph of the aspirator's collector after injection of substrate during slow-gentle withdrawal of the cannula. The collector is clearly filled with part of the colored injected substrate

The aim was to simulate a vein with a transparent suction tube. The distal extremity of the latter was immersed in a container filled with water. Its proximal extremity was connected to a traditional lipo-aspirator. Aspiration was triggered to simulate blood flow with a negative pressure set as low as 200 mm Hg. Clear water was seen flowing

Fig. 7 Photograph of the aspirator's collector after injection of substrate during constant motion of the cannula. The collector is clearly filled with part of the colored injected substrate

from the distal container to the aspirator's collector. Aspiration was activated a couple of seconds before each of the 3 experiments in order to simulate what would happen if a cannula accidentally perforated and cannulated a vein in vivo, i.e., while blood was circulating. The tube was perforated at its distal extremity with an 11 blade (Fig. 3) to create a port allowing the entry of cannulas of different gauges from 2 mm to 4 mm. The aim was to simulate an accidental perforation-cannulation of a large vein.

A 5 cc syringe was connected to the cannula positioned inside the lumen of the aspirating tube. The syringe was filled with fresh fat aspirated the same morning from a patient. The substrate was colored with methyl blue in a proportion of one cc of dye to 4 cc of fat in order to enhance its visibility in both the transparent tube and the aspirator collector (Figs. 4, 5).

First Experiment

The first experiment consisted of injecting 0.2 cc of substrate during slow-gentle withdrawal of the cannula. It was noted that part of the colored injected substrate passed into

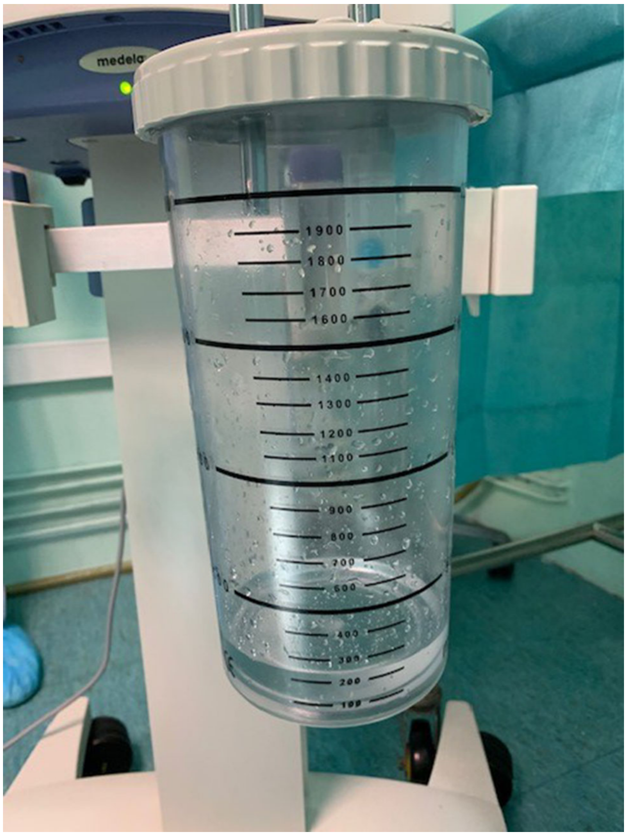

Fig. 8 Photograph of the aspirator's collector after injection of substrate during brisk withdrawal of the cannula. The color of the water in the aspirator's collector remained clear

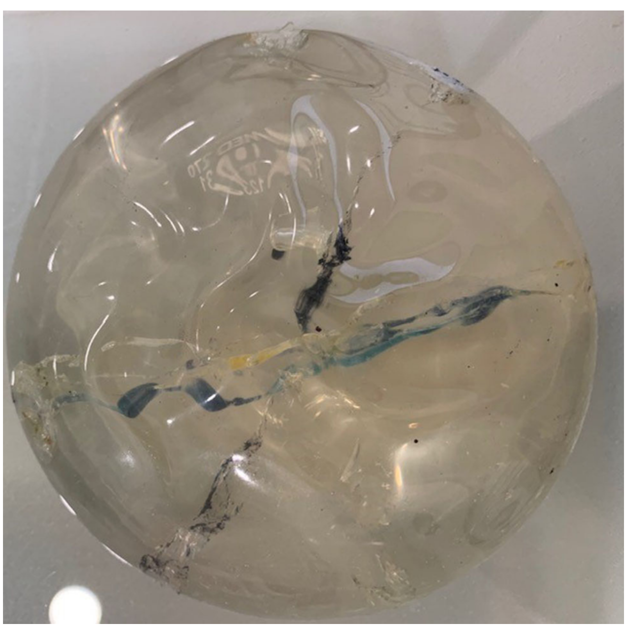

Fig. 9 Photograph of a smooth silicon breast implant that was skewered by the injecting cannula to observe the outline of the tinted substrate in the implant

the lumen of the tube, mixed with the aspirated water and ended up in the aspirator's collector (Supplamentery video 8), (Fig. 6).

Second Experiment

The second experiment consisted of injecting 0.2 cc of substrate during constant motion of the cannula. It was noted that part of the colored substrate passed into the lumen of the tube, mixed with the aspirated water and ended up in the aspirator's collector (Supplementery video 9) (Fig. 7).

Third Experiment

The third experiment consisted of injecting 0.2 cc of substrate during brisk withdrawal of the cannula. No colored substrate passed into the lumen of the tube. The color of the water in aspirator's collector remained clear (Supplementery video 10), (Fig. 8). In this third experiment, a tissue material was wrapped around the cannula to verify that the dye stained the material. Colored fat tinted the tissue material (Supplementery video 11).

The two first experiments were repeated three times each with a cannula of different diameter: 2, 3 and 4 mm. All experiments resulted in the same observations. The experiment with the cannula's brisk withdrawal technique was repeated five times. In the fourth and fifth repetition, a smooth silicon breast implant was skewered by the injecting cannula to observe the outline of the tinted substrate within the implant (Fig. 9).

Results

Out of the 3039 cases of smart fat injection (2696 at the facial level + 343 at the corporeal level), there was a zero patient ratio that presented clinically detectable of neither fat nor cruorical embolism as long as 54 days post-operative clinical examination. At 3 months + distant follow-up, there were no patients who reported symptoms of either fat nor cruorical embolism.

Discussion

Fat injection for volume enhancement at the facial level can cause catastrophic complications such as permanent vision loss and brain infarction [1–4]. Temourian in 1988 first reported a case of blindness with facial fat grafting [28]. Yang et al [1] reported the first case of sudden unilateral visual loss associated with brain infarction after autologous fat injection into the nasolabial groove.

Accidental blindness and/or brain infarction following facial injections is not specific to fat or filler injections for aesthetic purposes as these dreadful complications occurred with intra-lesional non-purified corticosteroid's injections [29–33]. This underscores the importance of three important commandments:

1. Slow non-forced injection is mandatory. It is well known that steroids were traditionally injected under high pressure to overcome pathologic tissue resistance. High pressure may lead to the rupture of vessel walls allowing passage of gross particles of corticosteroids or any other substrate inside the lumen of a vessel (Personal communication, Dr JW Little 2001, Washington DC). Filler injected in the peri-orbital area with more than the systolic blood pressure may force a column of filler "a retro" into the ophthalmic artery as far as the carotid artery leading to brain infarction. The same logic applies to blindness etiology: Fillers injected with more than the systolic blood pressure may force a column of filler back into the ophthalmic until the carotid artery. The systolic pressure in the carotid artery may push back the filler into the retinal artery leading to blindness [24].
2. Limited injection quantities of substrate at each pass, while the cannula moves in a retrograde manner is, in my view, the golden rule in order to avoid embolism. It allows minimal quantity deposit bolus at each pass [23, 24]. It logically can avoid large substrate injection inside the lumen of a vessel in case the latter was punctured and cannulated. The brisk withdrawal mode insures one more component for safety: it pulls the cannula's tip away from a given vessel at a high speed, hence distributing the tiny delivered quantity of substrate outside a breached vessel. Central retinal artery occlusion secondary to corticosteroid intra-lesional injections may have been the consequence of a high quantity of steroid delivered per cubic millimeter [29–33].
3. Anatomical knowledge is of paramount importance. Spatial location of important structures such as eyeballs, their musculature and surrounding vessels should be in front of the mind at all times during fat injection. Moreover, the possibility of arterial or venous malformations around critical areas such as the periorbit should always be considered: Intra-orbital filler injection for positive vector condition should not be undertaken before CT scan of the orbital area to rule out any vascular malformation inside the orbit; deep arterial or venous angioma, for example, would offer an easily cannulated vascular host or a possible starting point for an expansive hematoma. The same applies to the gluteal region: spatial location of the deep vessels, mostly gluteal veins should be in front of the mind at all times and the possibility of vessel malformations such as varicose veins in multiparous cases should be considered [34], although all nine women in the Rapkewicz et al. series did have previous pregnancies without identification of gluteal varicosities at autopsy [26]. Deep vascular malformations at the subcutaneous level may exist such as a large vessel communicating between the fat compartments and intramuscular vessels. This may give a false sense of safety to subcutaneous injections and CT scan may become mandatory to rule out such vascular anomalies. Blunt cannulas were introduced to avoid puncture of vessel walls and intra lumen injections [8]. However, cannulas use gave a false sense of safety [35]. Regardless of their prominent usage, the majority cases of severe intravascular embolism secondary to hyaluronic acid injections referred to the sole department of plastic surgery in Shanghai Jiao Tong University were performed with cannulas, not needles [4]. It has also been reported that the aspiration test to rule out that the tip of a needle or a cannula is inside the lumen of a vessel is ineffective [36–38]. Products with higher viscidity and larger particle size, such as fat and hyaluronic acid, require larger bore cannula/needle and a longer aspiration time to achieve successful aspiration [38]. Finally, it has been reported in a retrospective cohort study that hyaluronic acid injection induced bone resorption in the mentum documented with both 3D CT scan and intraoperative findings [39]. The severity of bone loss was positively correlated with the injection volume per time. Therefore, physicians may need to consider the possibility of bone resorption before engaging in large bolus deposit of hyaluronic acid against the bony skull; cannula use in a fanning mode to avoid high pressure per cubic millimeter might be safer. This paper presents my experience of 2696 consecutive patients on whom I performed 4195 procedures of SFI at the facial level. No major complication such as eyeball perforation, visual loss, brain infarction, permanent eyelid ptosis, permanent diplopia or infection secondary to buccal mucosa perforation occurred. This highlights the importance of injected bolus limited to 1/30–1/100 cc at each pass. It also underscores the importance of the SFI technique. The latter combines slow-cautious cannula advancement into facial tissues followed by brisk withdrawal, while the palm of the operator's hand gently pushes the plunger. Slow cannula advancement ensures that neither brutal penetration nor laceration of important structures will occur, hence avoiding permanent eyelid ptosis occurrence and eyeball or buccal's mucosa perforation. Injection during the sole cannula's brisk

withdrawal mode ensures that injection starts outside a vessel in case of accidental puncture of its wall. The cannula's brisk withdrawal should stop suddenly when the tip of the cannula is close to the entry orifice and this avoids the exit of the cannula at the end of each sequence. It may look as a difficult task, especially when the cannula is short such as the 35 mm-long cannulas for upper eyelid MFG or fillers injection. However, the process of repetition training such as injecting inside a sponge or a fruit allows proper execution of the gesture and leads to potentially mastering the brisk withdrawal.

Smart fat injection lends the opportunity for the surgeon to have a greater recipient volume to host the substrate as recipient tissue includes all available planes from dermis to bone contrary to what has been suggested by Song et al. [38]. It also allows regular use of sharp needles in order to expand tight tissues such as the dorsum of the nose, especially when fibrosis secondary to acne scars or other trauma compromises fat take. Multiple rigotomies allow tissue expansion and fibrotomies, while SFI with a sharp needle allows fat deposit in each cubic millimeter of the patient tissues from dermis to bone. Another advantage is when cannula clogging happens because of a thick parcel of fat that leads to substrate flow blockage the surgeon should resist the overwhelming temptation to exert a stronger pressure on the plunger as it may lead to a sudden eruption of a significant amount of fat under high pressure. This may result in turn to vessel wall rupture and passage of fatty embolus inside the vessel lumen (Personal communication, Dr JW Little 2001, Washington DC). This particular situation may be avoided with the cannula's brisk withdrawal as, even if a sudden irruption of a significant amount of fat under high pressure occurs, it will be delivered along the entire route traveled by the cannula in a retrograde-brisk manner. Regular epinephrine use is mandatory to promote capillary and small vessel vasoconstriction, hence their cannulation [23, 24]. However, epinephrine presents limitations since it cannot promote vasoconstriction of larger diameter vessels, especially when malformations such as large lakes hemangiomas are present.

Pulmonary fat embolism (PFE) secondary to body volume enhancement with fat grafting has been on the rise these last 5 years. PFE is triggered by the entry of fat into the bloodstream, which can occur in 2 different ways: microscopically (MIFE) producing FES or macroscopically (MAFE) producing direct occlusion of blood vessels [40–42]. In a broad review of the medical literature to identify reports describing MIFE and MAFE, Cardenas-Macarena et al. [43] determined the difference between the two terminologies (MIFE or MAFE) according to the clinical evolution that is reported in each publication. They considered MAFE if the symptoms began during surgery or during the first 24 h, and MIFE if symptoms began 24 h after surgery. This definition based on the chronology of onset of the first clinical signs of pulmonary embolism has been the argument in my paper to determine that patients who did not present any clinical sign of fat embolism within 54 days from the operation did not present this complication.

Cardenas-Camarena et al. [43] postulated that the answer to preventing MIFE could lie in the surnatant oil resulting from adipolysis as it is the most irritating part of liposuction substrate and is the most harmful if it enters the bloodstream. Therefore, elimination of oil by means of centrifugation may appear one more important recommendation to minimize MIFE compared to simple decantation or washing, the latter two are not as efficient for this task as centrifugation. Glover and Worthley demonstrated that fat particles that block pulmonary capillaries are as small as 10 to 40 microns [44]. These tiny particles can be hydrolysed resulting in free fatty acids that are toxic to endothelial and alveolar cells, resulting in hemorrhaging and alveolar oedema. The symptomatology presented by patients in these cases manifested between 48 and 72 h postoperatively.

On the other hand, MAFE is similar to pulmonary thromboembolism (PTE) [41]. It presents as an acute cardiorespiratory failure [11] and is totally due to a mechanical blockage of large blood vessels with a usually fatal outcome [41]. Clots of fat 10–80 mm in diameter have been detected in transesophageal echocardiograms [45]. This raises the question of the quantity of injected fat that would be necessary and sufficient of causing death of an adult patient: it has been estimated between 15 ml and 50 ml in adults [44, 46]. On another note, the gluteal venous system maintains a constant negative pressure. Vein wall puncture and injection of the fat inside its lumen are not necessary for MAFE to occur. A simple laceration of gluteal veins allows fat to be absorbed into the bloodstream [41]. For all the reasons cited above, limited injection quantity of substrate at each pass during the cannula's brisk withdrawal is, in my view, the golden rule in order to avoid embolism. The smart fat injection brings 2 new steps out of four that have not been described before:

The first step starts with slow-cautious cannula advancement into tissues to be grafted. This maneuver is repeated in a three-dimensional fashion throughout the entire area to be grafted without fat injection. It allows to trace all tunnels and to get familiar with tissue resistance specific to each patient. It allows avoiding attention dissociation between cannula motion and limited fat injection.

It is essential to focus the maximum attention on tracing these tunnels without injecting as to be able to foresee the smoothest possible contact between the cannula's tip and a deep vessel in case the latter would be anatomically positioned in the axis of the tunnel. In turn, this will avoid brutal impact of deep veins.

The second step of the procedure consists of stopping the cannula advancement when it reaches the distal extremity of the traced tunnel.

The third step of the procedure consists of substrate injection during the cannula's brisk withdrawal. The palm of the hand is moved away from the body of the syringe, the latter being held solely by the fingertips; the needed force for cannula advancement is minimal as tunnels have already been traced. Fat is deposited only once a brisk withdrawal of the cannula is initiated (Supplementary video 1–7). During this step, I maintain the highest level of speculation that the cannula's tip is inside the lumen of a vessel. With such a questionable scenario, my brain does not allow me to push the plunger unless I initiate the cannula's brisk withdrawal. This technique presents also the advantage of depositing dust like substrate as cannula's brisk withdrawal combined with gentle plunger pressure on a 5 or 10 cc syringe leaves a smaller quantity of substrate along its entire path when compared to a slower speed cannula's withdrawal at equal pressure on the plunger.

The fourth step consists of the cannula's brisk stop when its tip is close to the entry orifice at the end of each sequence. In my view, total control of fat delivery at each step of cannula motion, i.e., advancing mode, stopping mode, retrograde mode and stopping mode might be pivotal for safe fat grafting. Recent use of closed systems for automated fat injection does not offer such a control. Although some systems are equipped with flow control by means of a pedal, the activation of the latter may be tempting without cognitive control, specially for beginners, which may lead to saturate vena cava, lung parenchyma and heart cavities with injected fat as this has been already demonstrated in autopsies [15]. The immense performance of ASERF task force provided recommendations to curtail complications linked to gluteal fat injections. However, it cannot be claimed with certainty that fatal complications linked to MAFE or MIFE will be completely eliminated [47–50]. Human error is part of any human activity; the medical field is no exception. Recently, some authors proposed strategies for safer fat injections with smart cannulas or using real-time ultrasound-assisted gluteal fat grafting [20, 21]. These technologies are recent and do not stand up to the proof of time quite yet. Moreover, these technologies were developed in order to maintain cannula's tip away from muscular zone following ASERF task force recommendations. Subcutaneous areas may present vascular malformation with direct link to deep intramuscular veins. Moreover, the consequence of grafting the sole gluteal fat compartments would decrease the total amount of fat to be injected, the recipient therein, being amputated of its third if we consider that muscles of the gluteal region represent roughly 30% of buttock volume.

This may lead surgeons to excessively fill the sole subcutaneous zone with the same amount used to inject both fatty and muscular compartments, hence compromising fat take and resulting in confluent pools of oily cysts, inflammation and pain (Fig. 10). Since the first publication by Carpaneda and Ribeiro in 1993 [51], it is well accepted that maximum diameter of deposited parcels of substrate should not be over 3.2 mm. Kato et al. [52] and Khouri et al. [53] confirmed these findings. However, 3.2 mm is the maximum size that may survive [51, 52], necrosis of parcels with a diameter of 1.6–2 mm was observed, the range of fat take was 1.6 and 3.2 mm in diameter [51] and 1.5–3 mm [52]. Hence, substrate deposit of parcels with diameters over 1.5 mm may result in fat necrosis, the buttocks' volume being mostly maintained by oily cysts (Fig. 10). A recent article described a curious intraoperative finding where several large viable adipose tissue nodules, up to 2 cm in diameter, were present [54]. The authors raised the clinical possibility "that larger aliquots of transferred fat can be viable than previously perceived". From a purist point of view, the formal question raised should offer the following options to the patient: would she prefer to undergo microfat grafted in dust like parcels resulting in a harmonious increase in breast or buttock volume without palpable nodules or would the same patient prefer to undergo fat grafting in large aliquots with the possibility of survival in the form of several large noticeable nodules approximately the size of a golf ball along with the possibility of multiple lakes of oily cysts? Moreover, a viable adipose tissue nodule the size of a golf ball may be formed either by depositing a single over-sized large bolus of fat or by depositing multiple small amounts

Fig. 10 CT scan oil cysts. CT scan of the buttock area of a patient operated on elsewhere. She consulted us because of persistent pain and feeling of heat and of fluctuant liquid mostly in her right buttock. Radiologic images show that one third to one half of her right buttock volume is maintained by large subcutaneous pools of oily cysts

of fat in the same spot. In both scenarios, such a bolus deposited in close intimacy to a lacerated gluteal vein may allow fat to be absorbed into the bloodstream because of the constant negative pressure that reigns in the gluteal venous system [41].

This paper presents my experience of smart fat injection at the corporeal level on 343 consecutive patients. Areas most at risk of fat embolism such as intramuscular injections in calves and buttock were injected for 18 consecutive years. Tunnels were traced in a three-dimensional fashion prior to any substrate injection. Fat was deposited only once a brisk withdrawal of the cannula was initiated. The injected quantities were limited to 0.05–0.2 cc along the 20 cm path created by the cannula in a retrograde fashion. With the smart fat injection technique, there was a zero patient ratio of clinically detectable of neither fat nor cruorical embolism as long as 54 days post-operative clinical examination. This demonstrates that meticulous fat injection in legs and buttocks with proper technique and focused attention may be safe even when intramuscular injections are performed. This report is not an invitation to intramuscular injection. ASERF recommendations should be followed and even enhanced with more strict recommendations for the sake of patient safety.

Conclusion

Further studies need to be performed on both experimental and clinical levels to further evaluate the safety of the smart fat injection. This technique is time consuming and tedious. It may not be intended for surgeons who wish to perform two, three or more procedures per day. On a purist level, the following question needs to be raised: is our vocation to operate on as many patients as possible, using devices that inject fat at high flows with less than optimal control of cannula movements at each step just for the sake of operating on a maximum of patients?

Leo Tolstoy claimed, “The 2 most powerful warriors are patience and time”. Within the art of cosmetic surgery, time is the master of all things as it influences the quality of our achievements. I believe in taking as much time as necessary to harvest micro-parcels of fat, i.e., less than 1 mm diameter and to graft those during the cannula’s brisk withdrawal. That will achieve a dust like fat deposit, which ultimately will result in non-perceptible grafted fat because of its perfect integration. The next direction would be the development of an automated device. A device that could combine the delicate balance of a controlled brisk cannula withdrawal and simultaneous gentle fat injection hence replicating “the prodigious hand of the artist, equal and rival to his thought process, as one cannot exist without the other.“ – Paul Valéry. This quotation by the renowned French philosopher highlights among other things the “rivalry” between the artist’s hand and thought. *“… La main prodigieuse de l’artiste, égale et rivale a sa pensée, l’une n’est rien sans l’autre.”*

Compliance with Ethical Standards

Conflict of interest The author has no conflicts of interest to disclose.

Human or Animal Rights This article does not contain any studies with human participants or animals performed by any of the authors.

Informed Consent For this type of study informed consent is not required.

References

1. Yang LDH, Kim HN, Shyn JC, Hwan H (1996) Sudden unilateral visual loss and brain infarction after autologous fat injection into the nasolabial groove. Br J Ophthalmol 80:1026
2. Snozzi P, van Loghem JAJ (2018) Complication management following rejuvenation procedures with hyaluronic acid fillers: an algorithm-based approach. Plast Reconstr Surg Glob Open 6:e2061
3. Sorensen EP, Council ML (2019) Update in soft-tissue filler–associated blindness. Dermatol Surg 00:1–7
4. Zhou S-B, Chiang C-A, Liu K (2020) False sense of safety: blunt cannulas cause the majority of severe vascular complications in hyaluronic acid injection. Plast Reconstr Surg 146(2):240e–241e
5. Sito G, Manzoni M, Sommariva R (2019) Vascular complications after facial filler injection: a literature review and meta-analysis. J Clin Aesthet Dermatol 12(6):E65–E72
6. Carruthers JDA, Fagien S, Rohrich RJ, Weinkle S, Carruthers A (2014) Blindness caused by cosmetic filler injection: a review of cause and therapy Plast. Reconstr Surg 134(6):1197–1201
7. Beleznay K, Carruthers JDA, Humphrey S et al (2019) Up-date on avoiding and treating blindness from fillers: a recent review of the world literature. Aesthet Surg J 39(6):662–674
8. de Maio M, DeBoulle K, Braz A, Rohrich RJ (2017) Alliance for the future of aesthetics consensus committee facial assessment and injection guide for botulinum toxin and injectable hyaluronic acid fillers focus on the midface. Plast Reconstr Surg 140:540e–550e
9. https://www.plasticsurgery.org/documents/News/Statistics/2018/plastic-surgery-statistics-full-report-2018.pdf
10. Del Vecchio D, Rohrich RJ (2020) A changing paradigm: the Brazilian butt lift is neither Brazilian nor a lift-why it needs to be called safe subcutaneous buttock augmentation. Plast Reconstr Surg 145(1):281–283
11. Mofid MM, Teitelbaum S, Suissa D et al (2017) Report on mortality from gluteal fat grafting: recommendations from the ASERF task force. Aesthet Surg J 37(7):796–806
12. Mills D, Rubin JP, Saltz R (2018) Multi-society gluteal fat grafting task force issues safety advisory urging practitioners to reevaluate technique. Available at: https://www.surgery. org/sites/default/files/Gluteal-Fat-Grafting-02-06-18_0.pdf. Accessed 19 Nov 2018
13. American Society for Aesthetic Plastic Surgery (2015) Cosmetic surgery national data bank statistics. Aesthet Surg J 35(Suppl 2):1–24

14. Rios LJ, Gupta V (2020) Improvement in Brazilian butt lift (BBL) safety with the current recommendations from ASERF, ASAPS and ISAPS. Aesth Surg J 40(8):864–870
15. Pazmino P mia.one/(2020) Gluteal fat grafting safety Webinar
16. https://www.aserf.org/calls-for-research-applications/aserf-outlines-recommendations-to-increase-safety-of-gluteal-fat-grafting-procedures
17. https://www.surgery.org/sites/default/files/Gluteal-Fat-Grafting-02-06-18_0.pdf
18. Whitfield RM, Rios LM, DiBernardo BE (2017) Making fat transfer to buttocks safer. Aesth Surg J 37(10):1199–1200
19. Lari A, Abdulshakoor A, Zogheib E, Assaf N, Mojallal A, Lari AR, Bauer C, Sinna S (2019) How to save a life from macroscopic fat embolism: a narrative review of treatment options. Aesthet Surg J 40(10):1098–1107
20. Cansancao AL, Condé-Green A, Vidigal RA, Rodriguez RL, D'Amico RA (2018) Real-time ultrasound- assisted gluteal fat grafting. Plast Reconstr Surg 142(2):372–376
21. Turer DM, Qaium EB, Lawrence AM, Clark WW, Rubin JP (2019) A smart sensing cannula for fat grafting. Plast Reconstr Surg 144:385
22. Coleman SR (1995) long-term survival of fat transplants: controlled demonstrations. Aesth Plast Surg 19:421–425
23. Coleman SR (2002) Avoidance of arterial occlusion from injection of soft tissue fillers. Aesth Surg J 22:555–557
24. Coleman SR (ed) (2004) Structural fat grafting. QMP, St Louis
25. Benslimane F, Cintra HPL (2020) 15 years of upper eyelid: the good, the bad and the ugly. Aesth Plast Surg. https://doi.org/10.1007/s00266-020-01946
26. Rapkiewicz AV, Kenerson K, Hutchins KD, Garavan F, Lew EO, Shuman MJ (2018) Fatal complications of aesthetic techniques: the gluteal region. J Forensic Sci. 63(5):1406–1412
27. Benslimane F (2012) The Benslimane's artistic model for leg beauty. Aesth Plast Surg 36(4):803–812
28. Teimourian B (1988) Blindness following fat injection. Plast Reconstr Surg 82:361
29. Von Bahr G (1963) Multiple embolisms in the fundus of the eye after an injection in the scalp. Acta Opthalmol (Copenh.) 41:85–91
30. Ellis PP (1978) Occlusion of the central retinal artery after retrobulbar corticosteroid injection. Am J Ophthalmol 85(3):352–356
31. Byers B (1979) Blindness secondary to steroid injections into the nasal turbinates. Arch Ophthalmol 97(1):79–80
32. Thomas EL, Laborde RP (1986) Retinal and choroidal vascular occlusion following intralesional corticosteroid injection of a chalazion. Ophthalmol 93(3):405–407
33. Shorr N, Seiff SR (1986) Central retinal artery occlusion associated with periocular corticosteroid injection for juvenile hemangioma. Ophthalmic Surg 17(4):229–231
34. Astarita DC, Scheinin LA, Sathyavagiswaran L (2015) Fat transfer and fatal macroembolization. J Forensic Sci 60(2):509–510
35. Yeh LC, Fabi SG, Welsh K (2017) Arterial penetration with blunt tipped cannulas using injectables: a false sense of safety? Dermatol Surg 43:464–467
36. Casabona G (2015) Blood aspiration test for cosmetic fillers to prevent accidental intravascular injection in the face. Dermatol Surg. 41:841–847
37. Carey W, Weinkle S (2015) Retraction of the plunger on a syringe of hyaluronic acid before injection: are we safe? Dermatol Surg. 41(1):S340–S346
38. Song P, Xu X, Chen M, Pu LLQ (2020) Prevention and management of serious complications after facial fat grafting. Clin Plast Surg 47:165–171
39. Guo X, Zhao J, Song G, Zong X, Zhang D, Lai C, Jin X (2020) Unexpected bone resorption in mentum induced by the soft-tissue filler hyaluronic acid: a preliminary retrospective cohort study of Asian patients. Plast Reconstr Surg 146:147e
40. George J, George R, Dixit R, Gupta RC, Gupta N (2013) Fat embolism syndrome. Lung India 30(1):47–53
41. Cardenas-Camarena L, Bayter JE, Aguirre-Serrano H, Cuenca-Pardo J (2015) Deaths caused by gluteal lipoinjection: what are we doing wrong? Plast Reconstr Surg 136(1):58–66
42. Costa AN, Mendes DM, Toufen C, Arrunátegui G, Caruso P, Roberto C, Carvalho R. De (2007) Case report. J Bras Pneumol 34:622–625
43. Cárdenas-Camarena L, Durán H, Robles-Cervantes JA, Bayter-Marin JE (2018) Critical differences between microscopic (MIFE) and macroscopic (MAFE) fat embolism during liposuction and gluteal lipoinjection. Plast Reconstr Surg 141(4):880–890
44. Glover P, Worthley LIG (1999) Fat embolism. Critical Care Resusc 1:276–284
45. Mellor A, Soni N (2001) Fat embolism. Anaesth 56(2):145–154. https://doi.org/10.1046/j.1365-2044.2001.01724.x
46. Wang A-Z, Zhou M, Jiang W, Zhang W-X (2008) The differences between venous air embolism and fat embolism in routine intraoperative monitoring methods, transesophageal echocardiography, and fatal volume in pigs. J Trauma 65(2):416–423
47. Cárdenas-Camarena L, Andrés Gerardo LP, Durán H, Bayter-Marin JE (2017) Strategies for reducing fatal complications in liposuction. Plast Reconstr Surg Glob Open 5(10):e1539
48. Bayter-Marin JE, Cárdenas-Camarena L, Aguirre-Serrano H, Durán H, Ramos-Gallardo G, Robles-Cervantes JA (2018) Understanding fatal fat embolism in gluteal lipoinjection: a review of the medical records and autopsy reports of 16 patients. Plast Reconstr Surg 142(5):1198–1208
49. Kalaaji A, Dreyer S, Vadseth L, Maric I, Jönsson V, Haukebøe TH (2019) Gluteal augmentation with fat: retrospective safety study and literature review. Aesthet Surg J 39(3):292–305
50. Ramos-Gallardo G, Orozco-Rentería D, Medina-Zamora P et al (2018) Prevention of fat embolism in fat injection for gluteal augmentation, anatomic study in fresh cadavers. J Invest Surg 31(4):292–297
51. Carpaneda CA, Ribeiro MT (1993) Study of the histologic alterations and viability of the adipose graft in humans. Aesth Plast Surg 17:43–47
52. Kato H, Mineda K, Eto H, Doi K, Kuno S, Kinoshita K, Yoshimura K (2014) Degeneration, regeneration, and cicatrization after fat grafting: dynamic total tissue remodeling during the first 3 months. Plast Reconstr Surg 133:303e
53. Khouri RK Jr, Khouri RER, Hernandez JRL, Khouri KR, Lancerotto L, Orgill DP (2014) Diffusion and perfusion: the keys to fat grafting. Plast Reconstr Surg 2:220e
54. Hagarty SE, Santos EF, Luo J (2020) Large viable fat nodules, months post-transfer, inside radiated breast implant pocket: a case report. Plast Reconstr Surg Glob Open 8:e2722