Surgical Technique

Subretinal Pneumatic Displacement of Subretinal Hemorrhage

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Massive submacular hemorrhage (SMH) is a rare complication of choroidal neovascularization, which often portends a poor visual prognosis. In 1982, the Glatt and Machemer[1] work involving injection of autologous blood into the subretinal space of rabbits showed early photoreceptor edema within 24 hours, severe damage to the outer nuclear layer at 7 days, and photoreceptor and outer nuclear layer absence at 2 weeks. Shortly thereafter, Toth et al[2] showed the importance of photoreceptor toxicity from fibrin degradation products in a cat model and proposed the idea of using subretinal tissue plasminogen activator (rTPA) in facilitating clot removal.[3] These studies highlighted the toxic effects of SMH and provided the impetus for later therapeutic interventions aimed at removing or displacing the SMH.

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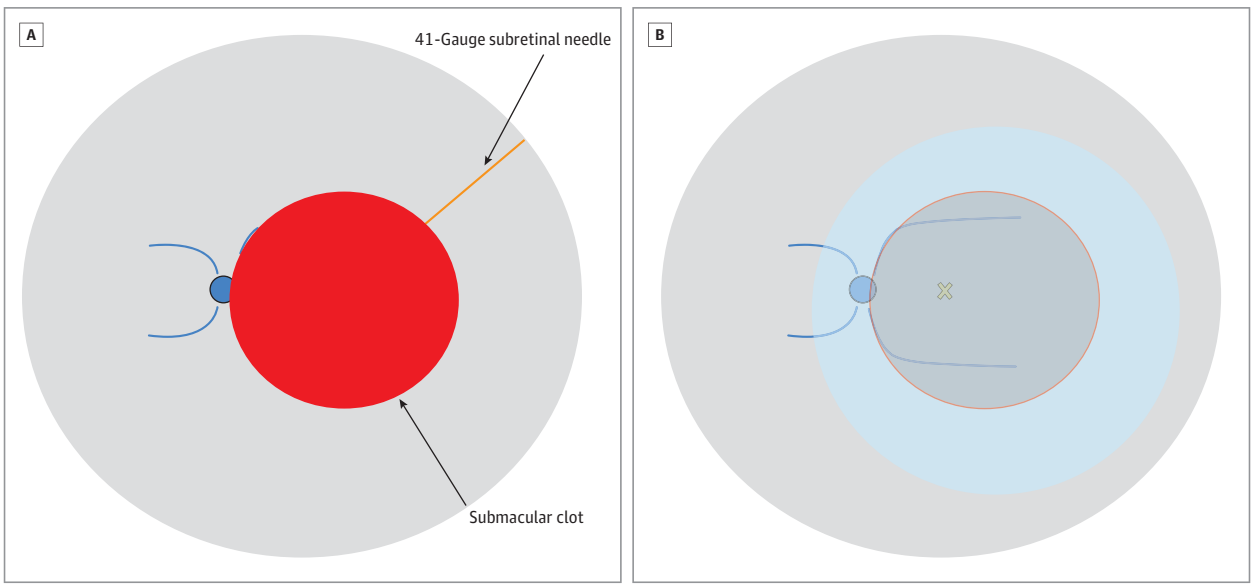
Initial interventions were aimed at SMH evacuation. In 1996, Kamei et al[4] proposed SMH removal with subretinal rTPA and using perfluorocarbon to express hemorrhage out of the subretinal space, and Claes and Zivojnovic[5] proposed rTPA injection with evacuation of SMH through a large retinotomy. Later, results of the Submacular Surgery Trials for the group B (blood) subgroup showed no apparent visual benefit from surgery compared with observation at 36 months' follow-up.[6] Since surgical SMH evacuation did not improve visual outcomes and may, in fact, contribute to photoreceptor and retinal pigment epithelium damage, efforts to displace rather than evacuate SMH gained popularity. In 1996, Heriot[7] first introduced a method using intravitreal gas and rTPA to displace the SMH away from the macula as an outpatient procedure. Later, other investigators reported some displacement success with vitrectomy, subretinal rTPA, and a vitreous cavity gas bubble.[8,9] Since the advent of anti–vascular endothelial growth factor agents, adjuvant pharmacotherapy with subretinal anti–vascular endothelial agents has been added to the management of SMH and shown to be compatible with subretinal rTPA.[10,11]

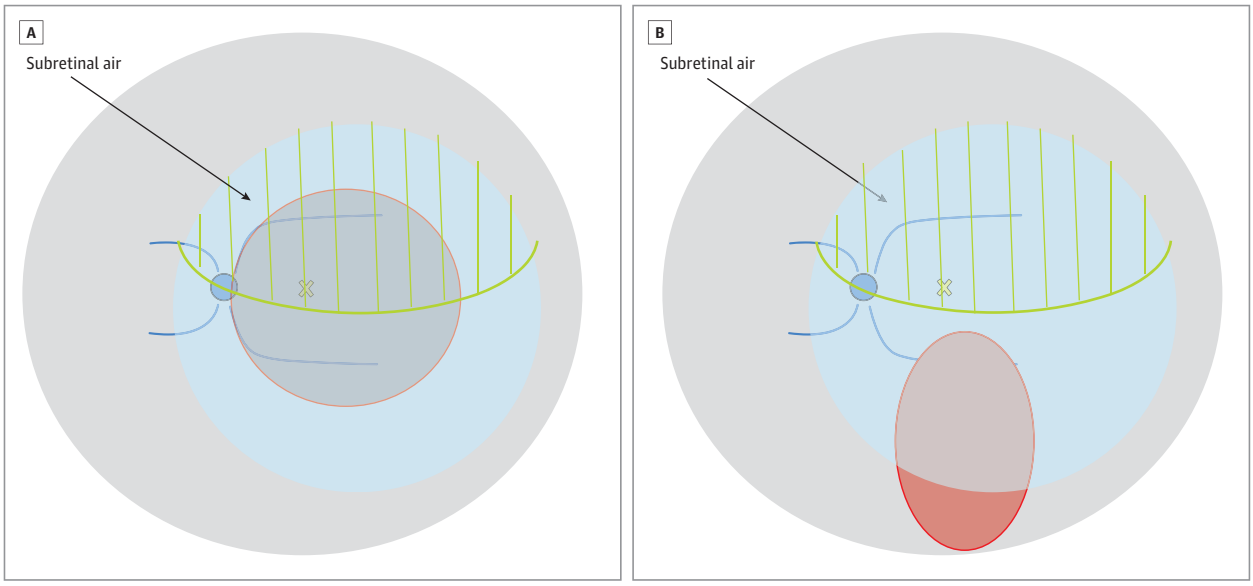
Since Heriot, numerous treatment strategies and a wide variation of displacement success have been reported; however, there is no consensus or treatment guidelines regarding optimal management. Nevertheless, advances in vitreoretinal surgery have continued to cultivate novel management strategies for SMH, and Lincoff's work[12] illustrating the forces influencing SMH mobility in the subretinal space has allowed a better understanding of the biophysical principals at play. With these principals in mind, we describe a simple technique for subretinal air delivery as well as the rationale for use of subretinal air as an adjuvant treatment to enhance and accelerate displacement of massive SMH justified by the physics principles governing SMH displacement.

Figure 1. Subretinal Therapeutic Cocktail Injection



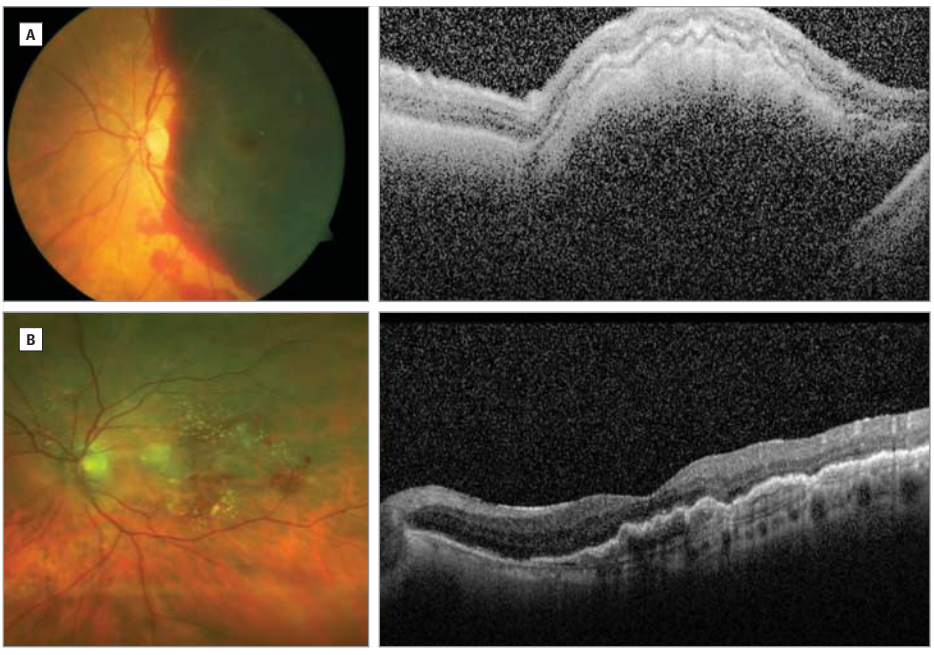
A 41-gauge needle is used to access the subretinal space within the clotted hemorrhagic retinal detachment (A). Subretinal tissue plasminogen activator and an anti–vascular endothelial growth factor agent are injected causing liquefaction of the submacular hemorrhage (inside red circle) and a subretinal fluid bleb (blue) with expansion of the retinal detachment borders (B).

Figure 2. Subretinal Pneumatic Injection



Subretinal air (green) is placed to minimize the buoyancy of the liquefied submacular hemorrhage (A), facilitating inferior displacement of the submacular hemorrhage (B).

Figure 3. Fundus Photography and Horizontal Line Scan Spectral-Domain Optical Coherence Tomography (SD-OCT)

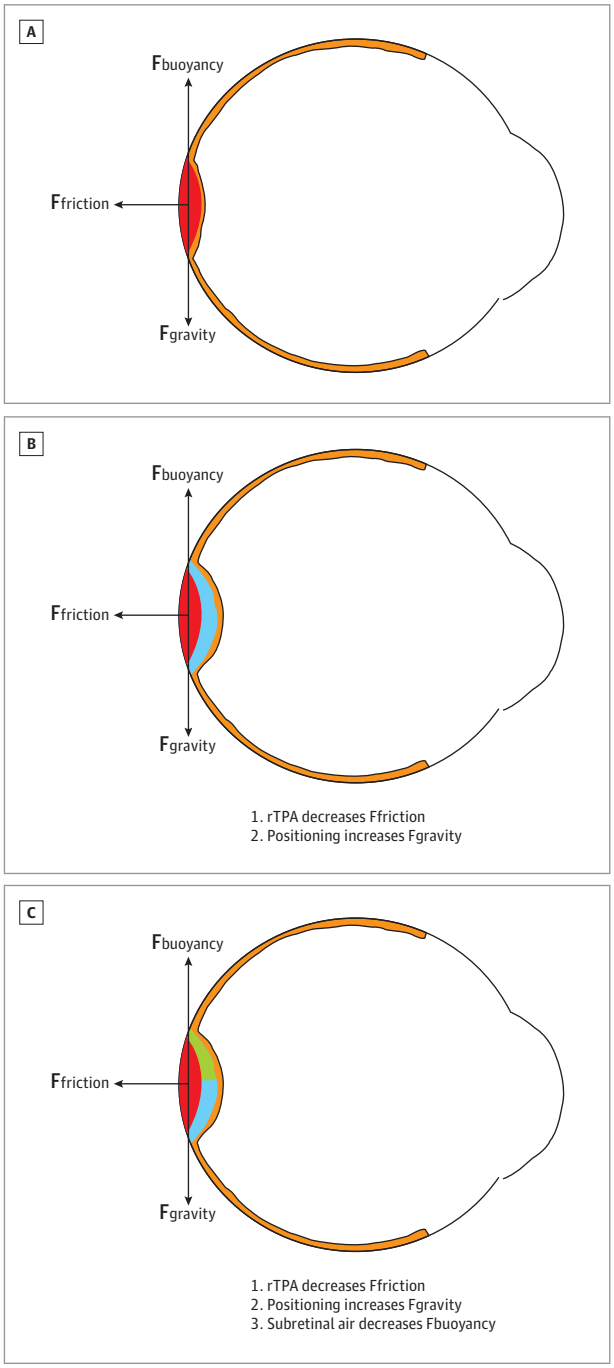


A, Preoperative fundus photograph and horizontal line scan SD-OCT demonstrating massive submacular hemorrhage with a hemorrhagic retinal detachment. B, One-month postoperative fundus photograph and horizontal line scan SD-OCT demonstrate marked interval improvement in the submacular hemorrhage and retinal architecture with residual small hyperreflective pigment epithelial detachments.

Methods

The delivery of a subretinal therapeutic cocktail follows pars plana vitrectomy. A 41-gauge extendable subretinal cannula (23 gauge; DORC) connected to a syringe is inserted at the superior margin of the SMH and injected in the subretinal space. The injection consists of a combination of 0.4 mL of rTPA at a concentration of 12.5 µg/0.1 mL (total, 50 µg), 0.1 mL of bevacizumab (2.5 mg), and filtered air. Liquefaction of the clot by rTPA enhances its mobility within the subretinal space, while the 0.5-mL fluid volume injected within the subretinal space helps create space for movement of the clot inferiorly (**Figure 1**). A lower-volume subretinal injection may be sufficient for relatively smaller SMH. The SMH is immersed in subretinal air to greatly reduce hemorrhage buoyancy within the subretinal space, and the amount of subretinal air injected (typically 0.2 mL) should be sufficient to allow adequate sequestration of air in the central macular region, the area most critical to displace (**Figure 2**).

Figure 4. Principal Force Vectors (Not Drawn to Scale) Governing Movement of Red Blood Cells Within the Submacular Space



A, Frictional and buoyancy forces counteract the gravitational force limiting movement of clotted submacular hemorrhage. B, The clot is immersed in subretinal tissue plasminogen activator (rTPA) (blue), decreasing the frictional force while appropriate positioning maximizes the gravitational force. C, Subretinal air (green) greatly decreases the buoyancy of the liquefied clot.

A partial fluid-air exchange followed by nonexpansile sulfur hexafluoride (SF6 20%) gas injection of about 50% of the vitreous cavity keeps the subretinal air within the macula and prevents it from tracking superiorly within the subretinal space outside the area of desired displacement (**Video**). Postoperatively, the patient is positioned upright. Patients without foveal-involving SMH or relatively small SMH (not extending beyond one or both arcades) may be more appropriate for less invasive treatments as there is risk of inadvertent displacement of SMH into the fovea or iatrogenic macular hole.

In one example using this technique, an 88-year-old woman receiving monthly ranibizumab injections for neovascular macular degeneration presented 5 days after an acute decrease in visual acuity to count fingers from a previous baseline of 20/80 and a large SMH (**Figure 3**A). After undergoing the earlier-described surgery, she had profound displacement of SMH in less than 24 hours. After 1 month postoperatively, her visual acuity improved to 20/100 with relatively limited disruption of the retinal microstructure (Figure 3B).

Discussion

The key to successful SMH displacement fundamentally lies in understanding the interplay of various forces that facilitate movement in the subretinal space and manipulating these forces appropriately. Buoyancy, gravity, and frictional forces are the primary forces influencing SMH displacement[12] (**Figure 4**A).

Friction may be reduced when a thrombolytic agent enzymatically liquefies the hemorrhage reducing the friction between neighboring red blood cells (RBCs) as well as the friction between RBCs and the adjacent retinal pigment epithelium and neurosensory retina. An increased volume of injected fluid in the subretinal space also helps reduce that mechanical friction. This is achieved by increasing the volume of injected rTPA to 0.4 mL while reducing the concentration to 12.5 µg/0.1 mL to keep a maximum injected dose of 50 µg, below the toxicity dose. Bevacizumab is also added to increase volume and help reduce activity of the choroidal neovascularization during the postoperative course. Upright positioning maximizes the gravitational force for inferior SMH displacement by positioning the gravitational force vector parallel to the submacular space (Figure 4B).

Last, but perhaps most importantly, decreasing SMH buoyancy to the lowest possible degree should result in the most rapid and effective displacement. According to the Archimedes principle, when a body is immersed in a fluid or gas, it exerts a buoyancy (upthrust force) equal to the weight of the fluid or gas it displaces. Injection of a subretinal air bubble directly in the subretinal space greatly decreases the buoyancy of RBCs (Figure 4C). Since the weight of the gas displaced by the SMH is about 830 times less than fluid, SMH immersed in gas within the subretinal space has a buoyancy force 830 times less than immersion in fluid.[12] In this scenario, the much higher gravitational force relative to buoyancy force facilitates downward displacement of SMH. Indeed, subretinal air lowers the buoyancy of RBCs more profoundly compared with the scenario of RBCs immersed in fluid within the subretinal space with gas in the vitreous cavity. This ensures more effective inferior displacement of the SMH and prevents inadvertently displacing hemorrhage into the fovea. Consequently, subretinal pneumatic displacement may be an important adjuvant in a surgeon's armamentarium for accelerated and efficient displacement of massive SMH.

ARTICLE INFORMATION

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