Technical Note

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Carbon Dioxide Flushing Technique to Prevent Cerebral Arterial Air Embolism and Stroke During TEVAR

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Abstract

Purpose: To describe the technique of carbon dioxide (CO_2) flushing of thoracic stent-grafts to reduce the risk of cerebral air embolism. **Technique:** To remove room air, thoracic stent-grafts were preoperatively flushed 2 minutes with carbon dioxide from a cylinder connected to the flushing chamber of the captor valves of Zenith custom-made endografts; this was followed by the standard saline flush. Thirty-six patients undergoing thoracic endovascular aortic repairs (TEVAR) involving the ascending aorta and the aortic arch received CO_2-flushed Zenith endografts. One patient with a highly calcified arch experienced a minor stroke. **Conclusion:** Arterial air embolism is a potentially underappreciated problem of aortic endografting, especially in the proximal segments of the aorta. CO_2 flushing may have the potential to reduce air embolization during TEVAR.

Keywords

air embolism, aortic dissection, carbon dioxide, endovascular repair, stent-graft, stroke, thoracic aorta, thoracic aortic aneurysm, thoracic endovascular aortic repair

Introduction

After more than 20 years, thoracic endovascular aortic repair (TEVAR) is now the treatment of choice for thoracic aortic aneurysm and dissection, offering a clear benefit, with lower mortality and morbidity compared with open surgical repair.[1–3] TEVAR involves implanting tubular stent-grafts that are produced, constrained, and packed in gas-permeable packaging under room air conditions, so air-filled spaces exist within the constraining sleeve, delivery sheath, and the introducing catheter assembly. The assemblies are sterilized using an ethylene oxide gas mixture[4] that is removed by repeated vacuum and room air ventilation. As a result, the sterilized devices are delivered filled with room air.

Room air is typically removed from stent-grafts and their introducing catheter assemblies prior to introduction into the vasculature according to the instructions for use (IFU) by flushing the sheath in which the assembly is loaded with an isotonic solution, such as a 0.9% saline solution. The degree to which the air is removed by this saline flushing technique and the volume of air released into the vasculature are not known yet.

It is well recognized that TEVAR involves a significant risk for stroke, which has been reported to be 2% to 6%[5] and up to 10% in some studies.[6] Stroke is the major drawback of this technique. In more complex endovascular procedures of aortic arch pathologies, stroke rates have been reported to be up to 16%.[7] The pathomechanism of stroke during TEVAR is not sufficiently recognized. Generally, it is thought to be embolization of thrombotic and atherosclerotic material from the vessel wall caused by wire manipulation and "violent" apposition of the stent-graft on the aortic wall during deployment or repositioning.[8] This hypothesis has, however, never been supported by studies.

Another potential source of stroke is air embolism following release of trapped air from the stent-graft during deployment. Air embolism into the cerebral vasculature has been identified as the source of neurological deficits during coronary artery bypass grafting, endoscopy, and interventional procedures.[9–11] The hypothesis that air embolism

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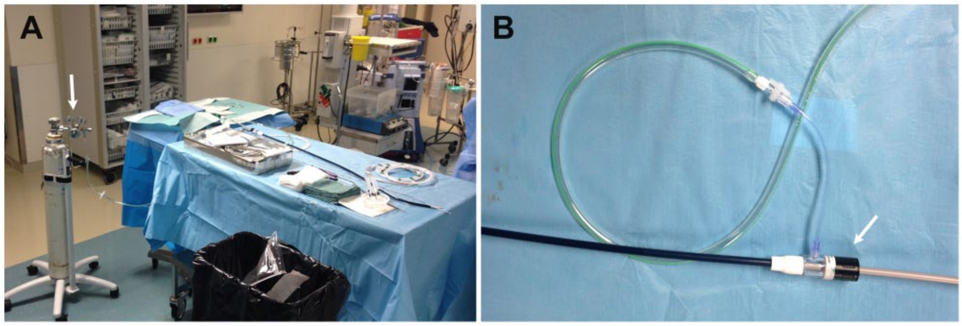

Figure 1. Carbon dioxide flushing technique. (A) The endovascular graft is connected to a carbon dioxide gas cylinder with a reduction valve (arrow). (B) The captor valve (arrow) is closed, and the tubing is connected to the sidearm of the flushing chamber.

plays a major role in the development of stroke during TEVAR has so far been neither established nor disproven.

Using carbon dioxide (CO_2) for high-pressure flushing of stent-grafts and their delivery systems can replace the ambient air in the stent-graft and its introducing assembly. CO_2 can then be removed from the stent-grafts and their delivery system prior to introduction into the body by flushing with saline or other solutions typically used for flushing. CO_2 has a much higher solubility in blood compared with room air.[12,13] It is preferred as a "trapped gas" compared with room air when introduced and potentially released into the vasculature because it resolves faster in blood than the nitrogen-rich room air, thus potentially causing less harm. We hypothesized that reducing the amount of room air present in the thoracic stent-graft during deployment can reduce the incidence of stroke during TEVAR. We present a technique for CO_2 flushing prior to the standard flushing technique.

Technique

Patient preparation, anesthesia, vascular access, and the deployment technique were according to institutional standards, including cardiac output reduction using inflow occlusion with a compliant balloon in the inferior vena cava. The custom-made fenestrated/branched thoracic endovascular graft was unpacked and prepared in the usual manner except from the flushing steps. Specifically, before flushing the graft with saline solution, the flushing chamber of the captor valve was connected to a CO_2 gas cylinder with a reduction valve providing a pressure of 1.2 bar. After closing the captor valve, the endovascular graft was flushed for 2 minutes, followed by flushing with saline according to the IFU (Figure 1). Drips of saline on the top of the sheath and dilator tip confirmed the flushing of CO_2.

From January 1, 2014, to December 31, 2015, 36 patients (69±8 years; 23 men) underwent technically successful treatment of aortic lesions involving the ascending aorta and the aortic arch with custom-made devices fenestrated and branched stent-grafts (Cook Medical, Bloomington, IN, USA) or with the Cook Zenith Ascend device, a dedicated stent-graft for the ascending aorta. There were no major strokes, although a nondisabling minor stroke was diagnosed in 1 patient. This 81-year-old female smoker with a medical history of chronic obstructive pulmonary disease and hypertension had a severely calcified aortic arch. She suffered a left frontal lobe infarction and small bilateral posterior circulation strokes in the cerebellum with an initial National Institutes of Health Stroke Scale score of 3. Thirty-day survival was 97%; a multimorbid patient died postoperatively of multiorgan failure despite a successful branched TEVAR procedure.

Discussion

Mechanical saline flushing of stent-grafts is not as effective as in the case of uncovered stents because the fabric of the stent-graft significantly hampers the ability to completely "push out" room air from the introducing assembly. Factors such as degree of compression or the presence of side branches and other advanced tools of modern grafts may influence the amount of this "trapped air"; pockets of trapped air may not be flushed out.

Trapped air released during intravascular deployment of stent-grafts remains mostly unrecognized since it is not visible under fluoroscopy. If released in the abdominal aorta close to an abdominal aortic aneurysm, the air may become visible on postoperative computed tomography scans within days after the procedure (Figure 2). This fact has been widely ignored so far because this air does not seem to cause much harm and is resorbed within weeks. However, side effects of endovascular aneurysm repair include a postoperative decline in renal function. While this is currently mostly attributed to the use of ionized contrast media, one cannot exclude the potential negative effect of arterial air embolism in the kidneys.

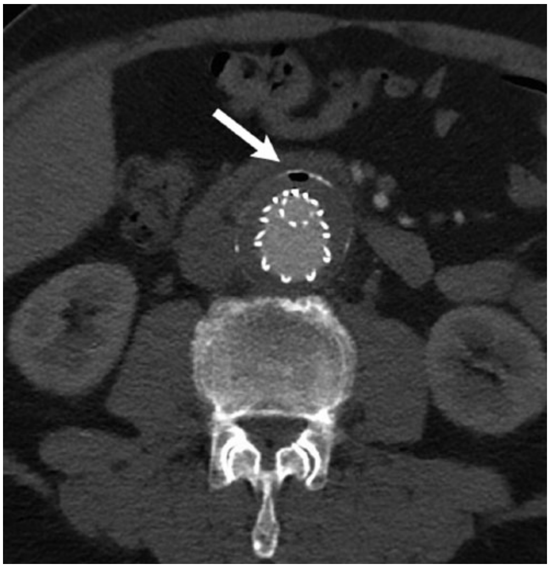

Figure 2. Computed tomography angiography 5 days after endovascular aneurysm repair showing an air bubble (arrow) of ~0.5 mL in the ventral aneurysm sac.

Moving proximal with stent-grafting in the aortic arch and ascending aorta necessitates revisiting this potential side effect of aortic endografting with increasing awareness. When stent-grafts are deployed in these aortic segments, the trapped air is released close to the supra-aortic vessels with a risk of air embolization into the brain. Bismuth et al[8] used transcranial Doppler to study 20 patients treated using TEVAR and found a maximum number of microembolic signals for patients treated in zones 0 to 2 during the deployment of the endograft. Melissano et al[14] noted a higher stroke rate in zone 0 deployments (9.4%) vs zones 1 (0%) or 2 (1.3%) in their study of 143 cases involving the aortic arch. These findings appear consistent with the hypothesis of air embolism. The same could happen if stent-grafts are released close to the coronary ostia, which could allow air embolization into the coronary arteries with a risk for myocardial infarction.

Conclusion

Trapped air in stent-grafts may play a crucial role in the stroke rate during TEVAR, although there are no studies that investigate air embolism as a source of this complication. Nonetheless, the release of trapped air needs to be controlled, especially when deploying stent-grafts close to coronary and supra-aortic arteries. CO_2 flushing of stent-grafts offers a feasible and low-cost method to reduce the amount of room air prior to deployment.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Tilo Kölbel is a consultant and lecturer for William Cook Europe and has patents licensed to William Cook Inc.

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