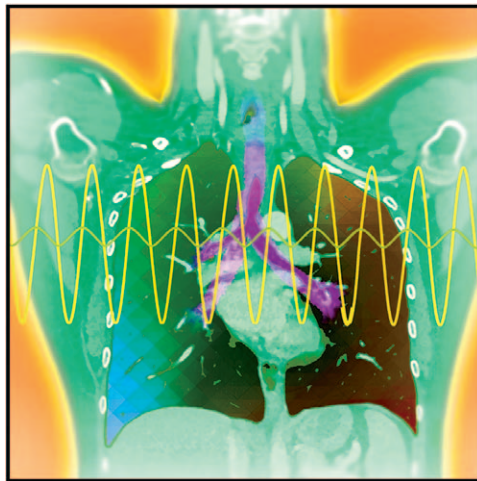


Efficacy of Superimposed High-frequency Jet Ventilation Applied to Variable Degrees of Tracheal Stenosis

One Step Forward to Optimized Patient Care

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THE number of procedures requiring high-frequency jet ventilation (HFJV) continually increases, and the advantages of HFJV are well recognized.^{1,2} The majority of procedures using HFJV are performed in patients with variable degrees of tracheal stenosis. However, a comprehensive study illustrating the efficacy and safety of HFJV for ventilation of patients with tracheal stenosis is not available. Clinicians face two major challenges when using HFJV for such procedures. One is assessment of the adequacy of ventilation and gas exchange because end-tidal carbon dioxide is often not reliable with HFJV. As a result, the adequacy of ventilation must be assessed by intermittent blood gas analysis. Another challenge is the assessment for the development of autopositive end-expiratory pressure (auto-PEEP). Because a large pressure gradient may exist across the obstructed segment of the trachea, it is impossible to monitor auto-PEEP distal to the obstructed segment unless an end-expiratory pause is applied or esophageal pressure is measured. High levels of auto-PEEP often go unnoticed by clinicians until critical complications develop: pneumothorax and circulatory collapse.³⁻⁵ Therefore, understanding the dynamic interaction between HFJV settings and the severity of the tracheal stenosis is important. In this issue of *ANESTHESIOLOGY*, Sütterlin *et al.*⁶ present a systematic evaluation of the interaction of HFJV and the severity of tracheal stenosis. They compared the efficacy of HFJV and superimposed HFJV (SHFJV; HFJV along with normal frequency jet ventilation)



“[Dr.] Sütterlin et al. provide clinicians with an insightful understanding of the advantages and limitations of high-frequency jet ventilation ... in the setting of tracheal stenosis.”

well understood but believed to be as a result of a combination of convection and diffusion.⁹ Unlike conventional mechanical ventilation, in which convection is the key component for gas exchange, gas exchange with HFJV is a result of gas diffusion and alveolar mixing generated by the small tidal volumes (often smaller than anatomic dead space) and high frequencies (>50 cycles per minute). Convection during HFJV particularly at high frequency (>300 cycles per minute) is reduced. HFJV alone can easily maintain adequate gas exchange in the absence of tracheal stenosis as demonstrated by Babinski *et al.*⁷ in patient and Sütterlin *et al.*¹⁰ in their animal model. The presence of a stenosis, however, alters gas flow dynamics and

and measured auto-PEEP distal to the stenosis in an adult human sized pig model. Their novel findings include (1) SHFJV produces more effective gas exchange than HFJV alone across a wide spectrum of frequencies; (2) at frequencies above 150 cycles per minute, the efficacy of HFJV alone is minimal; and (3) both HFJV and SHFJV generate high auto-PEEP distal to the obstructed segment particularly with severe tracheal stenosis. Their findings are important, clinically relevant, and greatly help clinicians to understand the dynamic interaction between ventilatory settings and the severity of tracheal stenosis.

Conventional HFJV is catheter based and the catheter is placed through glottis.⁷ However, catheter-free HFJV, as used in the study by Sütterlin *et al.*,⁶ is becoming more common. Instead of a small catheter, catheter-free jet ventilation is provided directly *via* a cuffed endotracheal tube.⁸ The mechanism of gas exchange with this technique is not

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renders HFJV alone less effective. SHFJV, defined as the application of HFJV in conjunction with conventional normal frequency jet ventilation, adds enhanced convection. Therefore, enhanced convection from normal frequency jet ventilation together with enhanced diffusion and alveolar mixing from HFJV enable SHFJV to produce more effective gas exchange than HFJV alone in the presence of a tracheal stenosis. Sütterlin *et al.*⁶ clearly demonstrated the superiority of SHFJV over HFJV alone at variable severity of tracheal stenosis across the large spectrum of frequencies they tested. Their data indicate that SHFJV should be used over HFJV alone regardless of the severity of tracheal stenosis.

Another interesting finding from the study by Sütterlin *et al.*⁶ is the importance of convection in SHFJV or HFJV. During all forms of high-frequency ventilation as ventilation frequency decreases, tidal volume increases. Extrapolation of the partial pressure of arterial blood carbon dioxide (P_{aCO_2}) curve obtained with HFJV alone to a frequency of 16 cycles per minute (normal frequency) indicates that normal frequency jet ventilation alone plays a major role in gas exchange. In other words, it is mainly convection that generates gas exchange. This is also well demonstrated in their SHFJV data where a reduction in frequency of the high-frequency component of SHFJV at any level of stenosis leads to a decrease in (closer to normal) P_{aCO_2} . Enhanced convection is more likely with catheter-based jet ventilation than with catheter-free jet ventilation. Catheter-based jet ventilation results in coaxial ventilation; inspiration is *via* the catheter, whereas exhalation occurs around the catheter. As a result, coaxial ventilation significantly reduces dead space and shortens the distance for diffusion and alveolar mixing generated by HFJV or SHFJV and subsequently increases the efficacy of ventilation and gas exchange. Future research in this area can be expected to refine our techniques and increase the safety of ventilation for the patients with tracheal stenosis.

The study by Sütterlin *et al.*⁶ also demonstrated that auto-PEEP is a major safety issue during jet ventilation.^{11–13} The highest auto-PEEP values occurred as expected in the presence of the severest tracheal stenosis.⁶ In the presence of a 94% obstruction, the median auto-PEEP was 10.3 cm H_2O and thus the maximum value of auto-PEEP must be much greater than 10.3 cm H_2O . At such a high level of auto-PEEP, barotrauma is a major concern. Actually, 1 of the 10 animals died of bilateral pneumothorax likely due to high auto-PEEP and high peak airway pressures. It is not clear how quickly such high auto-PEEP levels develop. Because each ventilatory setting lasted only 5 min, the high auto-PEEP level must have been rapidly created. Clinicians must be cautious because high levels of auto-PEEP can develop in minutes, if not seconds, with HFJV or SHFJV, particularly in the presence of moderate-to-severe tracheal stenosis. Therefore, we suggest careful monitoring for auto-PEEP and keeping it less than 10 cm H_2O . If an end-expiratory pause cannot be used to measure auto-PEEP, an esophageal catheter needs to be placed.

Superimposed HFJV can potentially be used in a variety of age groups during thoracic or pharyngeal surgery, in critically ill patients with severe airway obstruction while preparing

for a surgical airway or extracorporeal membrane oxygenation (ECMO), and in patients who need pulmonary vein isolation. Although SHFJV produces more effective gas exchange than HFJV alone, P_{aCO_2} is still a problem; P_{aCO_2} increased by 65% with moderate stenosis and 122% with severe stenosis.⁶ We suggest that SHFJV can be used in moderate stenosis but with great caution and should not be used with severe stenosis based on its efficacy. We also suggest careful monitoring of auto-PEEP by end-expiratory pause or esophageal manometry if the stenosis is at or above moderate. If there are any concerns that the obstruction could progress to complete, a surgical airway or ECMO team should be on standby. However, because it is difficult to monitor lung volumes and pressure with this technique, SHFJV should be applied for the shortest period possible and always with appropriately trained staff at the bedside who can respond to any disaster.

This model of trachea stenosis is well designed and well serves the purpose of this study. However, it does have limitations. As pointed out by the authors, the stenosis in this model was completely fixed at each level of severity. This may not represent the true interaction between the frequency of ventilation and the severity of tracheal stenosis, particularly at high levels of tracheal stenosis. To a certain degree, the stenosis in patients is distensible, and the auto-PEEP created may decrease the resistance at the site of stenosis. In other words, the efficacy of ventilation presented in this study may be underestimated. However, repetitive high-speed airflow at the site of stenosis may produce shear and stress and cause tissue edema, worsening the stenosis. In this case, the efficacy of SHFJV may be overestimated in this model compared with actual patients. To be safe, clinicians must realize that SHFJV may not solve all the issues associated with severe tracheal stenosis and should consider carefully the implications of this study and be aware that the severity of tracheal stenosis may worsen during SHFJV. If any concern exists that tracheal stenosis is so severe and might progress to complete obstruction, surgical airway or ECMO teams should be immediately available.

The findings by Sütterlin *et al.* provide clinicians with an insightful understanding of the advantages and limitations of HFJV and SHFJV in the setting of tracheal stenosis. We congratulate and thank Sütterlin *et al.* for their extraordinary work, and we are sure that clinicians will benefit from their findings.

Competing Interests

The authors are not supported by, nor maintain any financial interest in, any commercial activity that may be associated with the topic of this article.

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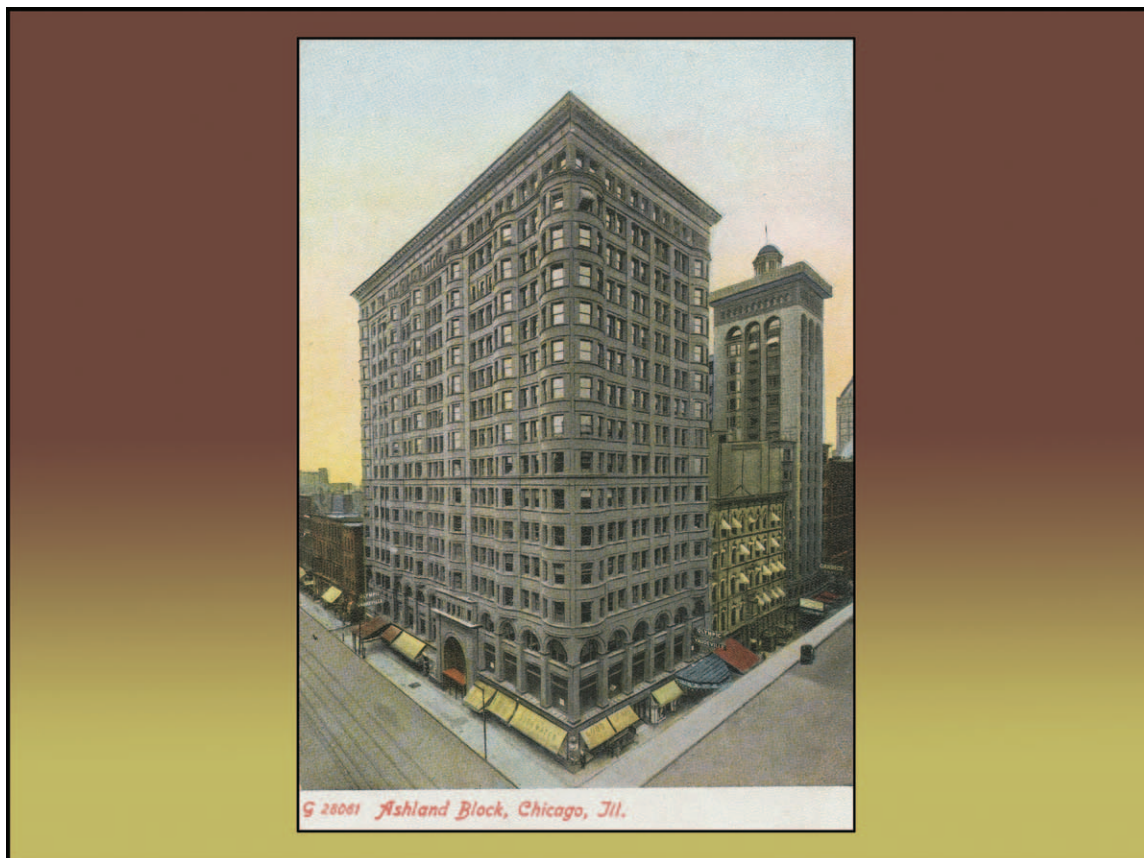
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Ashland Block, the Schiller Building, and Chicago's Post-Graduate School of Anaesthesia



Built on the northeast corner of Chicago's North Clark and West Randolph Streets, the 16-story Ashland Block (centered above) was designed by architect D. H. Burnham. Towering in the right background is the 17-story Schiller Building, the tallest skyscraper designed by Adler & Sullivan. After principal architect Louis Sullivan fired his lead draftsman, Frank Lloyd Wright, the latter set up office on the Schiller's 15th floor. Just two floors below Wright's office, Chicago's Post-Graduate School of Anaesthesia was founded in 1893 and would become the first institution to award the MSA—the Master of Science of Anaesthesia degree. (Copyright © the American Society of Anesthesiologists, Inc.)

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