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Current management of tracheostomy in intensive care: percutaneous dilatational techniques, clinical outcomes and future perspectives

Yoğun bakımda trakeostominin güncel yönetimi: perkütan dilatasyonel teknikler, klinik sonuçlar ve gelecek perspektifleri

Muammer Hayri BEKTAŞ* Kadir KABAHASANOĞLU

Bandırma Onyedi Eylül University, Faculty of Medicine, Department of Anesthesiology and Reanimation, Balıkesir, Türkiye
*Sorumlu Yazar / Corresponding Author, E-mail: mbektas@bandirma.edu.tr

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ABSTRACT

Objective: Tracheostomy is a widely utilized procedure in intensive care units (ICUs) to establish a secure long-term airway for patients requiring extended mechanical ventilation or those with upper airway obstruction. Historically, airway access was dominated by surgical tracheostomy techniques, but practice has shifted toward percutaneous dilatational tracheostomy (PDT) due to its minimally invasive approach, reduced complication rates, and the convenience of bedside performance.
Materials and Methods: This review covers tracheostomy terminology and historical evolution, and examines current literature on indications, contraindications, technical approaches, and complication management in the ICU setting.
Results: Performing a tracheostomy early (within 7–10 days of intubation) can significantly reduce ventilator-associated pneumonia (VAP) risk and shorten ICU length of stay. However, decisions must be individualized based on each patient's clinical circumstances. Adjunctive use of ultrasound and bronchoscopy improves the safety and precision of PDT, and diligent post-procedure care is essential to prevent complications such as tracheal stenosis, infection, and tracheoesophageal fistula.
Conclusions: The field of tracheostomy management is on the verge of transformation through emerging technologies. Innovations such as robotic-assisted techniques, high-resolution imaging guidance, custom-designed patient-specific 3D-printed tracheostomy tubes, and telemedicine follow-ups promise to enhance the safety, effectiveness, and accessibility of tracheostomy care, ultimately improving patient outcomes.
Keywords: Tracheotomy, tracheostomy, percutaneous dilatational tracheostomy, intensive care, mechanical ventilation

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ÖZET

Amaç: Trakeostomi, yoğun bakım ünitelerinde uzun süreli mekanik ventilasyon gereksinimi olan veya üst hava yolu obstrüksiyonu bulunan hastalarda kalıcı bir hava yolu sağlamak için sık uygulanan bir girişimdir. Geçmişte cerrahi trakeostomi daha yaygınken, perkütan dilatasyonel trakeostomi (PDT) minimal invaziv yapısı, daha düşük komplikasyon oranları ve yatak başında uygulanabilmesi nedeniyle giderek tercih edilmektedir. Bu derleme, kritik bakımda trakeostomi konusunda güncel ve kanıta dayalı bir kaynak sunmayı ve en iyi uygulamaların standardizasyonuna yönelik çabaları desteklemeyi amaçlamaktadır.
Materyal ve Metot: Bu derleme, trakeotomi/trakeostomi terminolojisi ile tarihsel evrimini özetlemekte; endikasyonlar, kontrendikasyonlar, teknik yaklaşımlar ve komplikasyon yönetimine ilişkin güncel literatürü irdelemektedir.
Bulgular: Kanıtlar, trakeostominin entübasyondan itibaren <7–10 gün içinde gerçekleştirilmesinin ventilatör ilişkili pnömoni (VİP) insidansını azaltabileceğini ve YBÜ kalış süresini kısaltabileceğini göstermektedir; ancak karar her hasta özelinde değerlendirilmelidir. Ultrasonografi ve bronkoskopi gibi yardımcı görüntüleme modalitelerinin kullanımı PDT'nin güvenliğini artırabilir; bununla birlikte, işlem sonrası titiz bakım, trakeal stenoz, enfeksiyon veya trakeoözofageal fistül gibi komplikasyonların önlenmesi için esastır.
Sonuç: Geleceğe bakıldığında robot-yardımlı teknikler, yüksek çözünürlüklü görüntü kılavuzluğu, hastaya özgü üç boyutlu (3B) baskılı trakeostomi tüpleri ve teletıp tabanlı takip gibi gelişen teknolojilerin trakeostomi yönetimine daha fazla entegre olması beklenmektedir.
Anahtar Kelimeler: Trakeotomi, trakeostomi, perkütan dilatasyonel trakeostomi, yoğun bakım, mekanik ventilasyon

INTRODUCTION

In critically ill patients, a tracheostomy provides a secure airway for prolonged mechanical ventilation and relieves upper airway obstruction when needed. Although the terms tracheotomy and tracheostomy carry distinct definitions, in practice, they are often used interchangeably. Tracheotomy technically refers to the surgical creation of an opening in the trachea, whereas tracheostomy refers to maintaining that opening (stoma) over time with a cannula in place. In modern ICU practice, "tracheostomy" is the prevalent term encompassing both the initial procedure and ongoing stoma management. Over the past few decades, percutaneous dilatational tracheostomy (PDT) techniques have increasingly supplanted open surgical tracheostomy for most ICU patients, given the advantages of performing the procedure at the bedside with less tissue disruption and lower complication rates.1,2 This review discusses the current indications, contraindications, and techniques for tracheostomy, compares surgical and percutaneous approaches, and highlights clinical outcomes and future developments relevant to intensive care.

MATERIALS AND METHODS

This narrative review was conducted by examining recent literature on tracheostomy management in intensive care. The scope of the review includes indications, contraindications, technical approaches (open surgical and percutaneous), optimal timing of tracheostomy, associated complications, decannulation and follow-up practices, and emerging innovations in tracheostomy care. Additionally, relevant data from the authors' ICU practice are included to illustrate current clinical outcomes.

RESULTS

Indications

Tracheostomy is indicated in a variety of clinical scenarios when a patient is expected to require an artificial airway for an extended period or when

• **Prolonged mechanical ventilation:** Conditions like severe traumatic injuries, major neurological insults (e.g., stroke, traumatic brain injury), neuromuscular disorders, or high cervical spinal cord injury often necessitate ventilation for weeks, making tracheostomy beneficial for long-term airway management.1,5

• **Upper airway obstruction:** Acute or chronic airway narrowing due to congenital anomalies, maxillofacial trauma, head and neck tumors, foreign bodies, or extensive airway edema can require a tracheostomy to bypass the obstruction.2,6

• **Facilitation of weaning:** Tracheostomy can aid in weaning from ventilation by reducing dead space, improving patient comfort compared to an endotracheal tube, lowering sedation needs, and facilitating pulmonary hygiene.5,7 Patients often tolerate breathing trials better with a tracheostomy, potentially expediting liberation from the ventilator.

• **Secretion management and airway protection:** In chronic lung diseases (such as COPD, bronchiectasis) or in patients with impaired neurologic status (e.g. prolonged coma, neurodegenerative diseases), a tracheostomy allows more effective suctioning of secretions and protects the airway by enabling a cuffed tube, thereby preventing aspiration.8

CONTRAINDICATIONS

There are no absolute contraindications to tracheostomy, but several relative contraindications warrant caution or a modified approach:

• **Severe coagulopathy:** Uncorrected bleeding diathesis increases the risk of hemorrhage during tracheostomy. It is advisable to stabilize coagulation parameters (e.g. with transfusions or factor replacements) before the procedure.5

• **Significant neck deformity or mass:** Distorted anatomy from large thyroid goiters, cervical tumors, prior neck surgery, or radiation can obscure landmarks and complicate both percutaneous and surgical tracheostomy. These situations may necessitate an open surgical approach with an experienced surgeon.

• **Local infection at the site:** Cellulitis or abscess in the anterior neck elevates the risk of infectious complications and poor wound healing. If feasible, the procedure may be deferred or an alternative approach chosen.

• **Lack of operator experience:** A percutaneous approach in an ICU setting should only be done by clinicians adequate training and experience, as inexperience is associated with higher complication rates.1,4

Pediatric patients and others with challenging anatomy (e.g. high tracheal stenosis or tracheomalacia) also pose increased risk; in such cases, involvement of a specialized team and careful selection of technique (often surgical) are recommended.3

SURGICAL TRACHEOSTOMY

Open surgical tracheostomy involves a horizontal incision at the lower neck and dissection to expose the trachea under controlled conditions (usually in the operating room). A tracheal window or flap is created (typically between the 2nd and 4th tracheal rings) and a tracheostomy tube is inserted directly under direct vision. Surgical tracheostomy is often preferred in cases of difficult anatomy or other contraindications to the percutaneous route – for example, patients with substantial obesity or short neck, extensive scarring from previous neck surgery, large cervical tumors or goiters, or uncorrectable coagulopathy. 2,9 In emergency scenarios where the airway must be accessed very rapidly (or when percutaneous equipment is unavailable), the surgical approach is the default. The primary disadvantages of surgical tracheostomy are the need to transport the patient to an operating theater (or have surgical capabilities at the bedside), greater tissue dissection (leading to more bleeding and local trauma), and a potentially higher risk of certain complications such as wound infection or tracheal ring fractures.

Institutional experience: At our center, PDT has largely replaced surgical tracheostomy for routine cases. Over the past year, for example, 40 tracheostomies were performed in the ICU, of which approximately 90% were percutaneous bedside procedures and 10% were open surgical tracheostomies. All percutaneous cases were completed successfully at the bedside, with only one requiring conversion to an open approach due to unforeseen anatomical difficulty (an extremely obese patient with obscured landmarks). Our overall procedural success rate exceeds 98%, and no procedure-related deaths have occurred. Minor bleeding (requiring transient uptitration of PEEP or topical hemostatics) occurred in about 5% of PDT cases, while no major hemorrhage was observed. There were no incidents of tracheoesophageal fistula or pneumothorax in our series. In our practice, surgical tracheostomy is reserved for select situations such as prior extensive neck surgery or irradiation, massive obesity, or when airway anatomy on imaging suggests high risk for percutaneous access. In these instances, we consult otolaryngology (ENT) and the tracheostomy is performed under general anesthesia in the operating room. By leveraging each technique's strengths in appropriate contexts, we have maintained a low complication profile. Notably, our ICU team does not routinely use bronchoscopic or ultrasound guidance during PDT; instead, we rely on careful anatomical landmark identification and a standardized stepwise dilation technique. This streamlined approach has proven safe in our experience, though we remain prepared to employ bronchoscopic guidance if difficulties arise (for example, in cases of unexpected difficult anatomy or to confirm tube placement if capnography is inconclusive).

PERCUTANEOUS DILATATIONAL TRACHEOSTOMY (PDT)

General Overview

Percutaneous dilatational tracheostomy is performed at the bedside in the ICU using a Seldinger guidewire technique to minimize surgical dissection. After appropriate neck positioning and local anesthesia/sedation, a needle is introduced into the trachea (usually between the second and third tracheal rings) and a guidewire is passed through the needle into the airway. The tract is then sequentially dilated to create a stoma, through which a tracheostomy tube is inserted. Several variations of the dilational method exist. The Ciaglia technique uses multiple incrementally larger dilators over the guidewire to gradually enlarge the opening. The Ciaglia Blue Rhino is a modification using a single tapered dilator (curved, "rhino horn" shaped) for one-step dilation. 1,2 The Griggs technique employs a specially designed guidewire dilating forceps to widen the tract by blunt dissection. Another approach uses a balloon catheter (as in angioplasty) to dilate the tracheal opening. All these methods share the advantages of being relatively quick and feasible at the bedside, obviating patient transport out of the ICU, and studies and meta-analyses have shown PDT to have complication rates comparable to or lower than surgical tracheostomy in appropriately selected patients.6,9

Pre-Procedural Preparation

Proper preparation is critical for a safe PDT:

- **Sedation and analgesia:** The patient should receive adequate sedation and pain control (and often short-acting paralytics) to prevent movement and coughing during the procedure, while carefully maintaining oxygenation and ventilation.

- **Imaging and anatomical assessment:** Bedside ultrasound can be used before or during the procedure to identify blood vessels in the planned trajectory and to find the midline and optimal tracheal level for puncture.7,8 In some cases, palpation alone is sufficient, but ultrasound is particularly helpful in obese patients or those with unusual anatomy. Bronchoscopic visualization through the endotracheal tube is another common adjunct to directly see the needle entry and guidewire position in the trachea.

- **Sterility:** Full sterile technique is mandatory. The neck and chest are sterilely prepped and draped, and the operators wear sterile gowns, gloves, and face/eye protection. Meticulous attention to sterility reduces the risk of stoma infection and other infectious complications.11

Technical Procedure

After identifying the appropriate tracheal level (often between the 2nd and 3rd tracheal rings, below the cricoid cartilage), a needle is inserted into the tracheal lumen, usually midline or slightly left of midline (to avoid the innominate artery which lies on the right in the lower trachea). Free aspiration of air confirms entry into the airway, and the needle angle is adjusted to center it in the tracheal lumen. A guidewire is then threaded through the needle into the trachea and the needle is removed. Following this, a series of progressively larger dilators (or a single conical dilator in the one-step technique) is advanced over the guidewire to widen the stoma. In the forceps dilational technique, a special forceps is passed over the wire and used to stretch the tracheal opening. Once adequate dilation is achieved, the tracheostomy tube (loaded onto an introducer or guided by a tube exchanger) is inserted over the wire into the trachea. Correct placement is confirmed by end-tidal CO_2 detection, bilateral breath sounds, and chest rise. If bronchoscopy is being used, the bronchoscope (inserted via the orotracheal tube) can directly visualize the guidewire entering the trachea and subsequently ensure the tracheostomy tube is correctly positioned between the tracheal rings.

The cuff is then inflated, the ventilator circuit attached to the new tracheostomy tube, and the endotracheal tube is withdrawn. A chest X-ray is typically obtained afterward to check for complications like pneumothorax or malposition.

Ultrasound and Bronchoscopic Guidance

The use of real-time ultrasound and/or bronchoscopy during PDT can further improve safety:

• Ultrasound guidance: A high-frequency linear ultrasound probe can be used to mark tracheal rings and identify any overlying blood vessels (such as an aberrant thyroid artery or enlarged thyroid isthmus) Prior to puncture. Ultrasound thus helps avoid vascular injury and can delineate anatomical landmarks even when they are not palpable.9,10 Studies indicate that a preprocedure ultrasound scan may reduce periprocedural bleeding by identifying and allowing one to avoid aberrant vessels.12 Real-time ultrasound can also confirm needle entry into the trachea by showing the needle path and lung sliding or comet-tail artifacts when air enters tissue.

• Bronchoscopic guidance: Fiberoptic bronchoscopy through the existing airway (endotracheal tube) provides an internal view during PDT. The bronchoscope's light can often be seen through the tracheal wall, aiding proper puncture site selection. Visualization of the needle entering the lumen ensures midline placement and helps prevent posterior tracheal wall puncture. Keeping the bronchoscope at the carina can also prevent the guidewire or dilators from advancing too distally. Bronchoscopic technique is associated with a significantly lower risk of posterior wall injury and can help manage any immediate issues (e.g. identifying a false passage or suctioning blood).7,8 The drawbacks to bronchoscopy are added cost, the need for an additional skilled operator, and reduction of tidal volumes during the procedure (because the bronchoscope in the tube causes an air leak). In our unit's practice, bronchoscopy is reserved for difficult cases rather than routine use, but it remains an invaluable safety tool when anatomy or other factors are uncertain.

DISCUSSION

Timing of Tracheostomy: Early vs Late

The optimal timing for tracheostomy in ICU patients on prolonged ventilation has been debated. Early tracheostomy is often defined as within 7–10 days of endotracheal intubation, whereas late tracheostomy is performed beyond 10 days (and sometimes only after several weeks of unsuccessful weaning). Early tracheostomy has theoretical benefits: it may reduce the duration of sedation needed for an endotracheally intubated patient, facilitate earlier mobilization and oral care, and perhaps lower the incidence of ventilator-associated pneumonia by shortening the period of orotracheal intubation. Some studies and meta-analyses have suggested lower VAP rates and shorter ICU stays with tracheostomies done in the first week of ICU admission. 13 For example, one randomized trial reported a reduction in VAP and earlier weaning when tracheostomy was done at day 7 vs. day 14.5,14

However, large randomized studies such as the UK TracMan trial (which compared tracheostomy at ~day 4 vs. after day 10) did not show a significant difference in 30-day mortality between early and late groups.13,15 Many patients in the "late" arm ultimately never required tracheostomy at all, as they were extubated or died before reaching the time threshold, highlighting a key point: performing an unnecessary tracheostomy in someone who may be extubated in a few days confers risk with no benefit. Current evidence-based guidelines thus stop short of endorsing early tracheostomy for all, instead recommending that the decision be individualized. Important factors include the patient's neurological prognosis, pulmonary status, overall medical condition, and the likelihood of rapid recovery. In practice, a multidisciplinary discussion (intensivists, surgeons, respiratory therapists, etc.) should weigh the potential benefits of early tracheostomy against the risks, considering whether the patient is expected to require prolonged ventilation. If a patient is deteriorating or has little chance of extubation in the near term, an early tracheostomy can be beneficial. On the other hand, if there is reason to believe the patient might wean from the ventilator in under two weeks, it can be prudent to defer tracheostomy. In summary, timing should be tailored to the individual, and ongoing research (including meta-analyses of newer trials) will hopefully further clarify which subpopulations benefit most from early tracheostomy.

COMPLICATIONS

Tracheostomy is generally a safe procedure in experienced hands, but both early (procedure-related) and late (long-term) complications can occur. Vigilance and proper technique are required to minimize these risks.

Early Complications

• **Bleeding:** Some bleeding at the tracheostomy site is common, but significant hemorrhage is uncommon if coagulopathy is corrected and major vessels are avoided. Arterial bleeding can occur if the thyroid ima artery or jugular venous plexus is injured, or from a longitudinal tear in an anterior jugular vein. Bleeding risk is higher in coagulopathic patients and those with enlarged thyroid vessels. Prompt control with direct pressure, tightening of the tracheostomy ties (to tamponade), or occasionally surgical exploration may be required in case of severe hemorrhage.

• **Pneumothorax and subcutaneous emphysema:** Introduction of false passage or excessive force during dilation can lead to air dissecting into tissue planes. Misplacement of the needle laterally can puncture the pleura, causing a pneumothorax, or allow air to leak into subcutaneous tissue (subcutaneous emphysema) or mediastinum (pneumomediastinum). Proper midline technique and avoiding over-dilation of the tract help prevent this. If pneumothorax is suspected (e.g. sudden oxygen desaturation, unilateral breath sounds), a confirmatory chest X-ray or ultrasound should be obtained and a chest tube placed if needed.

• **Posterior tracheal wall injury:** Puncturing through the back wall of the trachea can cause a tracheoesophageal injury or create a false passage. This risk is significantly reduced by bronchoscopic guidance during percutaneous procedures.11 If the guidewire is seen endoscopically to tent the posterior wall or pass through it, the procedure should be aborted and repositioned. Careful needle control and stopping advancement as soon as the trachea is entered can prevent this complication.

Late Complications

• **Tracheal stenosis:** Over time, scarring can cause narrowing of the trachea at the stoma or where the tube's cuff presses on the tracheal rings. Prolonged intubation prior to tracheostomy or an oversized or overinflated tracheostomy cuff can contribute to cartilage damage and subsequent stenosis. The incidence of clinically significant tracheal stenosis after tracheostomy is low but not negligible, and patients who have been decannulated may present weeks to months later with stridor if a significant stenosis has developed.5,9 Ensuring the smallest effective cuff volume and periodic cuff pressure checks can mitigate this risk.

• **Tracheoesophageal fistula (TEF):** This is a rare complication where an abnormal connection forms between the trachea and esophagus. It can result from long-term pressure necrosis, typically if the tracheostomy tube erodes the posterior wall or if a rigid nasogastric tube and the tracheostomy tube lie adjacent, causing pressure necrosis of the tissue between them.2 Signs of TEF include aspiration of gastric contents or recurrent pneumonia in a patient with a tracheostomy, especially if mechanical ventilation is prolonged. Prevention focuses on avoiding excessive cuff pressures and, if possible, removing any nasogastric tubes early or alternating their side periodically.

• **Infection and granuloma formation:** The stoma and airway can be colonized by bacteria, and without good care the site may develop cellulitis or even wound abscess. Granulation tissue commonly forms at the tracheostomy site or on the tracheal mucosa near the tube tip, due to chronic irritation. Such granulomas can cause bleeding or difficulty with tube changes. Strict stoma care protocols, regular cleaning, and periodic tracheostomy tube changes under clean conditions help prevent infection. Use of a well-fitting, stabilized tube avoids excess movement and irritation that contribute to granulomas.11 If problematic granulomas occur (e.g. causing bleeding or airway obstruction), they can be treated with cautery or laser via bronchoscopy once the tracheostomy is removed.

DECANNULATION and FOLLOW-UP

Removing a tracheostomy tube (decannulation) should be considered once the patient no longer requires mechanical ventilation and can maintain their airway independently. A careful assessment precedes decannulation, including evaluation of the patient's level of consciousness, cough strength, ability to manage secretions, and airway patency above the stoma. If the patient can tolerate having the tracheostomy tube corked (capped) for 24 hours while breathing comfortably around it and handling secretions, they are generally a good decannulation candidate. Prior to removal, downsizing the tracheostomy tube or using a fenestrated tube can help assess the patient's breathing through the natural upper airway. Once the tube is removed, the stoma is covered with a sterile dressing and usually closes on its own within 1–2 weeks. During this period, careful monitoring is necessary to ensure there is no respiratory distress, subcutaneous emphysema, or persistent air leak through the stoma. If the stoma fails to close spontaneously (which is uncommon), surgical closure may be performed. Long-term follow-up after decannulation might involve bronchoscopy to check for any significant tracheal stenosis at the site, especially in patients who had prolonged tracheostomy placement. Multidisciplinary followup (with pulmonology, ENT, speech therapy, etc.) can address any residual swallowing or voice issues and ensure return to baseline function.

FUTURE PERSPECTIVES

Advancements in technology and technique are poised to further improve tracheostomy care. Several promising developments are on the horizon, aiming to make the procedure safer, more personalized, and better integrated into overall patient management:

• **Robotic surgery and navigation systems:** Experimental robotic-assisted tracheostomy techniques are being developed to enhance precision. For instance, a pilot study by Xiao and colleagues demonstrated the feasibility of a flexible transoral mini-robotic device to perform an "inside-out" needle tracheostomy puncture with high accuracy.16 Such a system could allow delicate dissection and avoid critical structures in patients with complex anatomy. While robotic airway management (e.g. automated intubation devices) has already shown improved success rates in intubation, the application of robotics specifically to tracheostomy remains in early stages.16 Future platforms may incorporate image-guided robotic arms to consistently identify the optimal entry site and angle, potentially reducing complications. As these technologies mature, they could assist less-experienced operators or enable remote-controlled tracheostomies in resource-limited settings, though significant research and validation are still needed.

• **Advanced imaging and augmented reality guidance:** High-resolution imaging modalities are increasingly aiding tracheostomy planning and execution. Modern portable ultrasound devices offer enhanced visualization of neck anatomy, helping clinicians avoid aberrant vessels and localize the trachea even in challenging patients. 12,17 Looking ahead, augmented reality (AR) is being explored to overlay virtual guidance on a patient's anatomy during procedures. Preliminary studies have used AR headsets to project internal tracheal landmarks and optimal incision sites onto the patient, which enabled successful completion of percutaneous tracheostomies in simulated scenarios.12 With AR, anatomic information from CT or ultrasound could be integrated in real time, potentially improving accuracy for trainees and in difficult cases. Although these technologies are not yet standard, they represent a step toward imageenhanced tracheostomy, where clinicians have a richer visual map of patient-specific anatomy during the procedure.

• **3D printing and patient-specific cannulas:** Three-dimensional printing is opening the door to customized airway devices. Standard tracheostomy tubes come in fixed shapes and sizes, which may not fit optimally in patients with unique tracheal anatomies. In 2024, University Hospitals Cleveland reported the first-ever placement of a patient-specific 3D-printed tracheal T-tube under compassionate use.18 The custom-designed silicone tube was modeled from the patient's CT scan to match his tracheal dimensions and contour, and it led to the resolution of persistent complications that had occurred with stock tubes. Similarly, the Mayo Clinic has developed personalized 3D-printed tracheostomy tubes for complex pediatric cases of tracheal erosion.19 Such tailored cannulas can minimize chronic complications by providing a better fit, reducing pressure points that cause ulcers or granulation. In the future, an ICU physician might order a 3D-printed tracheostomy tube for a patient with unusual anatomy (for example, severe tracheomalacia or stenosis) to ensure optimal airway support. Regulatory and manufacturing challenges remain, but progress in biocompatible materials and printing speed suggests that patient-specific airway implants could become more widely available, transforming tracheostomy care for outlier cases.

• **Telemedicine and remote management:** Leveraging telemedicine for tracheostomy care can extend specialized expertise to patients and providers outside major centers. Telemedicine is already used for virtual ICU support and has been applied to tracheostomy follow-up in home or subacute settings. Recent studies in pediatric tracheostomy patients have shown that structured telehealth programs can significantly improve outcomes. In one program, providing respiratory care training and weekly telehealth check-ins for families of children with new tracheostomies reduced 30-day readmission rates and total hospital days compared to standard follow-up.16 Another study found that a nurse practitioner-led telehealth follow-up improved caregiver knowledge and self-efficacy in managing tracheostomy without increasing complications.16 Telemedicine allows experts (such as an academic airway team) to remotely assess stoma wounds, evaluate tracheostomy positioning via video, guide tube changes, or troubleshoot ventilator issues in real time. Especially for patients in rural areas or those who cannot easily travel, telemedicine can bridge gaps in care and ensure early intervention if problems arise. Going forward, integration of remote monitoring devices (for instance, sensors that detect airway pressures, ventilation patterns, or signs of tube occlusion) with telemedicine platforms could enable even more proactive management of tracheostomy patients at home.16 Widespread adoption of tele-tracheostomy programs, however, will require addressing barriers like internet access, device availability, and training for caregivers and staff to effectively utilize these tools.

• **Standardization and research initiatives:** As practices evolve, there is an ongoing push toward standardized protocols and multicenter research to optimize tracheostomy care. Professional societies and collaborative networks (e.g. the Global Tracheostomy Collaborative) are developing guidelines on many aspects of tracheostomy, from timing and technique selection to care bundles for stoma maintenance and swallowing assessment. Future large-scale trials may better define the long-term outcomes of surgical vs. percutaneous tracheostomy in specific patient populations, or quantify the benefits of routine adjuncts (like bronchoscopy or ultrasound) in varying settings. Standardization efforts also extend to emergency management of tracheostomy (ensuring all staff are trained in handling decannulation or obstruction events) and decannulation criteria. The goal of these initiatives is to reduce practice variability and improve safety across the board. Moreover, as novel technologies like those discussed above become available, formal studies will be needed to validate their efficacy and cost-effectiveness. For example, the cost-benefit of a 3D-printed tube or the impact of a robotic technique on complication rates should be rigorously evaluated. In the coming years, one can expect updated consensus guidelines that incorporate high-level evidence and expert input on how to best integrate these innovations into routine tracheostomy practice.

CONCLUSION

Tracheostomy remains a cornerstone of managing patients who require prolonged ventilatory support or protection of the airway in the ICU. The advent of percutaneous dilatational tracheostomy has revolutionized bedside airway management, offering a safe and efficient alternative to the traditional surgical tracheostomy in the majority of cases. PDT's minimally invasive, bedside approach has been associated with high success rates and a low incidence of serious complications in experienced hands, making it the preferred technique in many ICUs. Nonetheless, open surgical tracheostomy continues to play a vital role in certain contexts, particularly for patients with abnormal neck anatomy or other contraindications to the percutaneous method. Optimal patient care involves choosing the appropriate technique on a case-by-case basis, guided by multidisciplinary expertise.

Evidence is steadily accumulating to guide best practices – for example, early tracheostomy may confer benefits in select patients, but patient selection and timing must be individualized rather than protocolized. Likewise, adjuncts such as bronchoscopic or ultrasound guidance can enhance safety, though they may be reserved for anticipated difficult cases depending on institutional protocol and resources. Meticulous post-procedure care, including adherence to cleaning and humidification protocols and monitoring for complications, is essential to achieving favorable outcomes. As highlighted, emerging innovations promise to further refine tracheostomy management. Techniques involving robotics, enhanced imaging, and personalized devices are on the horizon and have shown encouraging preliminary results in improving precision and patient outcomes.16,18 Telemedicine is expanding access to specialized tracheostomy follow-up, potentially reducing complications and readmissions through earlier intervention.16 In the near future, we anticipate that these advancements – coupled with ongoing research and quality improvement initiatives – will lead to more standardized, safer, and patient-centered tracheostomy practices.

In summary, the field of tracheostomy in critical care is one of continual improvement. By synthesizing current evidence and embracing useful innovations, clinicians can ensure that each tracheostomy procedure is performed with the utmost care and that each patient benefits from strategies tailored to their needs. The ongoing evolution of techniques and technology holds great promise for enhancing the care of ICU patients with tracheostomies, from insertion to decannulation and beyond, ultimately improving both clinical outcomes and quality of life for these vulnerable patients.

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