# Single-port robotic transcervical long-segment thoracic tracheal reconstruction: Cadaveric proof-of-concept study

Check for updates

Natalie S. Lui, MD, MAS, FACS,[a] F. Christopher Holsinger, MD, FACS,[b] Michael R. Ma, MD,[a,c] Jeffrey R. Janus, MD,[d] and Karthik Balakrishnan, MD, MPH, FAAP, FACS[b,c]

## ABSTRACT

**Objective:** Slide tracheoplasty is the standard technique to repair congenital long-segment tracheal stenosis. This operation most commonly requires median sternotomy, which has drawbacks in young children. We hypothesized that a transcervical approach without sternotomy would be feasible if done with a single-port robotic system.

**Methods:** This proof-of concept study was performed in 2 small adult cadavers using a single-port robotic surgical system via a small neck incision. Relevant information, including operative time and details of operative technique, were recorded.

**Results:** Long-segment slide tracheoplasty was completed successfully in 2 cadavers using a small neck incision and a single-port robotic surgical system. Strengths and pitfalls of the technique were identified, including technical refinements from the first attempt to the second. Operative time for robotic mobilization, incision, and anastomosis of the trachea was comparable to standard open approaches.

**Conclusions:** Small-incision transcervical slide tracheoplasty, assisted by a single-port surgical robotic system, is feasible in a human cadaver. More work is needed to determine safety and applicability in live patients, particularly in children. (JTCVS Techniques 2022;16:231-6)
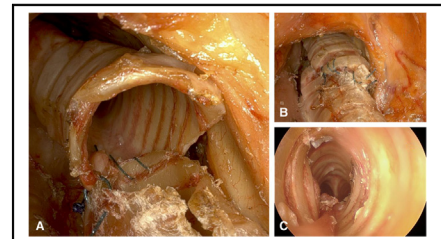
Robotic view of partial and completed slide anastomosis with endoluminal view.

**CENTRAL MESSAGE**

*A small-incision approach allows proof-of-concept single-port robot-assisted complex long-segment tracheal reconstruction without sternotomy or thoracotomy.*

---

**PERSPECTIVE**

Current approaches to long-segment tracheal reconstruction require sternotomy, or, less often, thoracotomy. These approaches have significant drawbacks. Newer technologies such as single-port robotic systems may facilitate less invasive approaches. We present cadaveric proof-of-concept data demonstrating that a small neck incision allows complex long-segment robot-assisted tracheal reconstruction.

---

▶ Video clip is available online.

Long-segment tracheal stenosis poses a unique surgical challenge, particularly in children with congenital stenosis, due to complete tracheal rings or sleeve/stovepipe trachea. These conditions involve a cartilaginous, often funnel-shaped, narrowing of the trachea that may cause severe respiratory distress and life-threatening airway compromise. In many cases, patients have long-segment narrowing of the trachea, defined variably as >50% of the tracheal

```
┌─────────────────────────────────────┐
│   Abbreviations and Acronyms        │
│      CPB = cardiopulmonary bypass   │
└─────────────────────────────────────┘
```

length[1] or simply as a segment too long to resect without a high-tension anastomosis.

In the absence of a viable option for simple resection-reanastomosis, the operative repair of long-segment congenital tracheal stenosis has demanded creative solutions. Over the past 2 decades, slide tracheoplasty has become the most common and successful strategy. This operation, first described in 1989[2] and subsequently popularized by groups in Cincinnati and London, rearranges the tracheal wall to increase diameter at the expense of tracheal length. Other authors have clearly described the details of the operation.[3] The slide technique offers the advantages of using native tracheal tissue without need for grafts and creating a long, ovoid anastomosis to reduce anastomotic tension and avoid circular restenosis. However, it is a technically demanding operation with complex geometry that requires a wide operative exposure through median sternotomy or, much less commonly, thoracotomy for access to the distal portions of the trachea. Furthermore, the need to transect and manipulate the trachea during repair generally requires either cardiopulmonary bypass (CPB) support or extracorporeal membrane oxygenation with central cannulation.

Median sternotomy, although a widely useful surgical approach, has some drawbacks in children. For example, sternal wound infection increases with younger age,[4] and slide tracheoplasty is most commonly performed in infants and young children. In addition, sternotomy generally requires several weeks (6 weeks at our institution) of postoperative positioning and lifting precautions as well.[5] Finally, median sternotomy scars may be problematic due to pruritus, undesirable cosmesis, or hypertrophic scarring.[6]

Robot-assisted approaches to the airway have been described, including robotic tracheal and carinal reconstruction.[7,8] Meanwhile, single-port flexible robot systems have been used to perform complex operations through very small access ports; for example, transoral resection of oropharyngeal neoplasms[9] and sublabial approaches for thyroidectomy.[10] However, robot-assisted treatment of long-segment stenosis, and execution of slide tracheoplasty, have not previously been described either through an open approach or through a small incision. We hypothesized that a single-incision transcervical approach, using a single-port flexible robotic surgery system (da Vinci SP, Intuitive Surgical), would permit adequate access and visualization to allow performance of a long-segment thoracic slide tracheoplasty without sternotomy. This article describes the technique and proof of concept in a cadaveric model. Note that the da Vinci SP robot is not approved for use by the US Food and Drug Administration in the thorax or in pediatric patients.

## METHODS AND RESULTS

This study is not considered human subjects research by the Stanford University Institutional Review Board because it was a cadaver study without identifiable patient information.

### Equipment and Robotic System

The da Vinci SP single-port robotic system was used for this study. This system was Food and Drug Administration-approved for genitourinary surgery in 2014[11] and provides a flexible camera with a 3-dimensional console view as well as up to 3 working instruments at a time. The system passes through either a 25-mm cannula or an inflatable access port that permits insufflation and allows articulation of the robotic instruments outside the wound; we used the inflatable port (SP Access Kit; Intuitive Surgical).

### Cadavers and Positioning

Two cadavers were used. The first was 1.68 m tall and 40.8 kg, with body mass index of 14.5. The second was 1.65 m tall and 54.5 kg, with body mass index of 20. The cadavers were positioned supine on the laboratory operating table with the base of the robot to the left of the table. The robotic arm was placed to aim directly in a craniocaudal direction.

### Incision and Docking

The cadaver was placed supine with the neck extended and head turned toward the right. Use of a shoulder roll did not alter access appreciably. In the first case, a 4-cm longitudinal incision was made anterior to the border of the left sternocleidomastoid muscle, starting 2-cm superior to the left clavicle (Figure 1, A). In the second case, a 4-cm transverse incision was made for better cosmesis (Figure 1, B). The subcutaneous fat and platysma were divided and the sternocleidomastoid muscle and carotid sheath were mobilized laterally. The omohyoid muscle was divided and the sternothyroid muscle dissected from the thyroid gland to create space for the wound protector ring. The trachea was identified inferior to the thyroid, which was not dissected to minimize risk to the recurrent laryngeal nerve.

The inflatable access port was placed in the incision, with the medial side fitting between the sternothyroid muscle and thyroid (Figure 1, C). The field was insufflated using air to 5 mm Hg. The 2.5-cm cannula was inserted, and the single-port robotic system was docked. The camera was inserted with 3 instruments: cadiere in Arm 1, monopolar scissors in Arm 2, and fenestrated grasper in Arm 3. A red rubber catheter was inserted into the wound protector to evacuate smoke during the case, with the tip external to the wound.

**Tracheal dissection.** Tracheal dissection was performed first on the left and anterior sides, with the cadiere in Arm 1 and monopolar scissors in Arm 2 active, and the fenestrated grasper in Arm 3 retracting toward the trachea toward the right (Figure 2, A). The lateral vascular supply to the trachea was divided, and the esophagus and left recurrent laryngeal nerve were visible and preserved. The posterior trachea was dissected in similar fashion. A small injury to the mid-trachea at the cartilaginous-membranous junction was repaired primarily with a single stitch. This was believed to be the result of using a relatively sharp instrument for dissection.

The right main bronchus was dissected next, with the cadiere in Arm 1 retracting toward the trachea toward the left, and the monopolar scissors in Arm 2 and fenestrated grasper in Arm 3 active (Figure 2, B). The lateral vascular supply to the trachea was preserved on the right. The subcarinal lymph nodes were dissected from the carina to increase mobility. The right
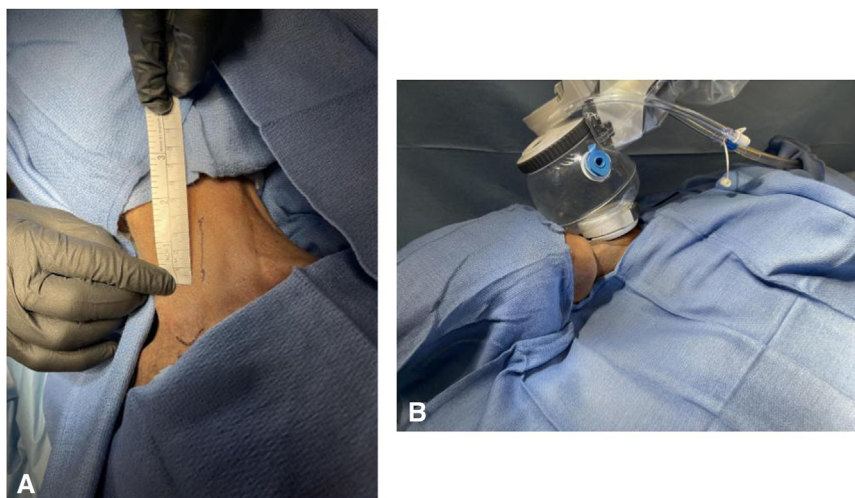
**FIGURE 1.** The incision was made in the *left* neck. Both longitudinal (A) and transverse incisions were effective, and the sealed wound protector was fit into the incision (B) before inserting the 2.5-cm SP cannula and docking the robot.

recurrent laryngeal nerve was not visualized. Good mobility of the trachea and proximal mainstem bronchi, comparable to that desired in open slide tracheoplasty, was achieved and demonstrated by traction on the upper and lower ends of the trachea.

## Slide Tracheoplasty

The trachea was transected at an angle from anterior midline superiorly to posterior midline inferiorly, over a length of 5 tracheal rings or about 3 cm (Figure 3, *A*). The monopolar scissors were used to make the initial incision into the trachea, and the scissors without cautery were used for the transection. The trachea was further opened with a 1-cm anterior midline incision in the proximal trachea and 1-cm posterior midline incision in the distal trachea (Figure 3, *B*). We considered rotating the incisions to allow the initial anastomotic sutures to be placed through cartilage rather than membranous trachea, but this is not expected to be a concern in patients with complete rings. Visualization of the entire planned anastomosis was excellent.

The anastomosis was performed with 2 V-loc 180 3-0 6-in dyed sutures with V-20 needle (Medtronic), both starting at the posterior midline and running in each direction (Figure 4, *A*). A smaller needle may be beneficial, particularly in patients with small body habitus. Differential suturing was used to ensure even approximation of the upper and lower halves of the slide. Needle drivers were used in Arms 1 and 2, and the fenestrated grasper remained in Arm 3. The posterior stitches were tightened only after the membranous wall was complete, to prevent tearing through of the sutures. The stitches were overlapped anteriorly and then cut (Figure 4, *B*).

Rigid bronchoscopy showed an intact, widely patent tracheal anastomosis (Figure 4, *C*). There was mild bunching of the posterior membranous portion, likely due to pulling tight of the barbed sutures but not significant enough to compromise the airway lumen. No significant figure-8 deformity was appreciated.

## Operative Time

The initial open cervical approach and dissection required approximately 5 minutes. Total time from docking the robotic system to completion of the tracheal anastomosis in the first cadaver specimen was 3 hours and 37 minutes.

## Adverse Events

As noted earlier, a small tear was created in the posterior mid-trachea during dissection. We expect that this can be avoided by using a more blunt instrument to dissect the posterior trachea free. Placement of an esophageal bougie (eg, a 24Fr Maloney dilator) is sometimes used to facilitate this dissection in open slide tracheoplasty and may be helpful in the robot-assisted procedure as well. It should be noted that evaluating the posterior trachea, repairing the tear, and checking for gaps in the posterior anastomosis was much easier with the robot than in conventional open
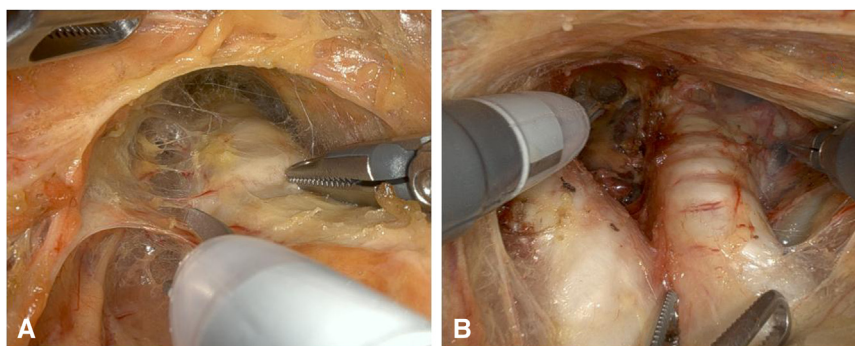


**FIGURE 2.** The trachea was dissected starting with the *left* and anterior sides (A) and then extending to the *right* main bronchus (B), using the cadiere and monopolar scissors and retracting with the fenestrated grasper.
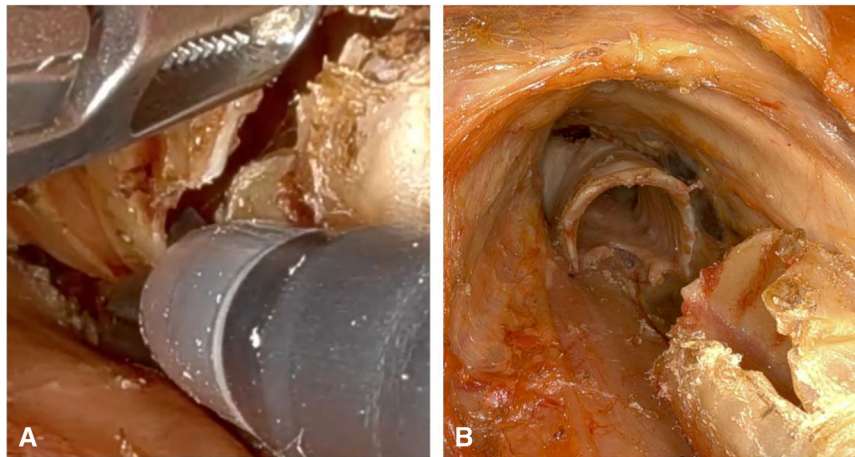
**FIGURE 3.** The trachea was transected at an angle from anterior midline superiorly to posterior midline inferiorly, over a length of 5 tracheal rings or about 3 cm (A) and then further opened with a 1 cm anterior midline incision in the proximal trachea and 1 cm posterior midline incision in the distal trachea (B).

reconstruction, where visualization of the posterior aspect of the anastomosis, and access for spot repairs, is challenging.

We also noted some subcutaneous emphysema in the cadavers at the end of each procedure. This is not surprising given that we were insufflating the neck and mediastinum throughout the procedure.

## DISCUSSION

This study demonstrates the feasibility of a robotic transcervical approach to complex thoracic tracheal reconstruction, using a single-port robotic system through a small neck incision. The technique is briefly demonstrated in the associated video (Video 1), narrated by the senior author (K.B.). This approach offers several advantages: excellent visualization of the entire trachea, carina, and proximal mainstem bronchi, avoidance of median sternotomy scar and postoperative sternotomy precautions, and a cosmetically

reasonable neck incision. In addition, the robotic system provides a unique 3-dimensional view of the anatomy from an angle not easily achieved with an open approach.

The transcervical approach using the inflatable access port allowed low-pressure insufflation to create adequate working space in the mediastinum. This space, combined with the narrow profile of the robotic instruments, allowed the flexible robotic camera to assume an optimal cobra position, providing a clear view of the working instruments and anastomotic line. Rotation of the anastomosis, often used in open repair for patients with a tracheal bronchus, in this case provided access to start the anastomosis at a more favorable location while using the robot. Use of a barbed suture, meanwhile, reduced the time required to create the anastomosis but eliminated the need for knot-tying within the mediastinum.
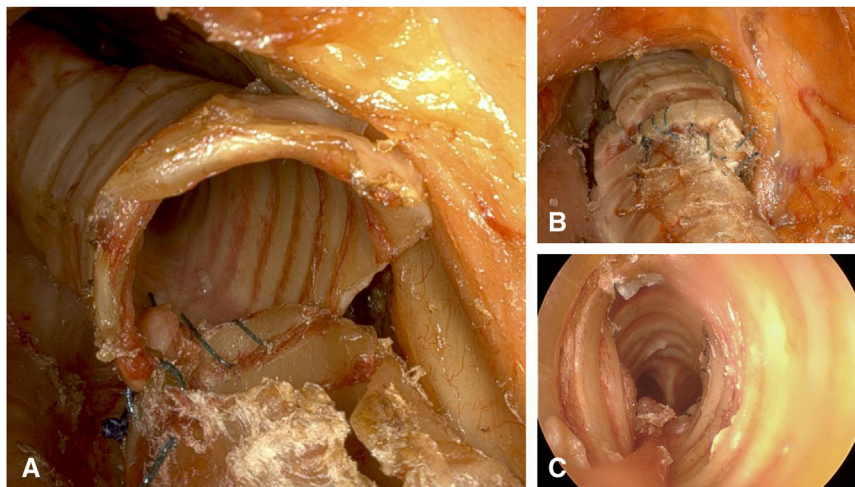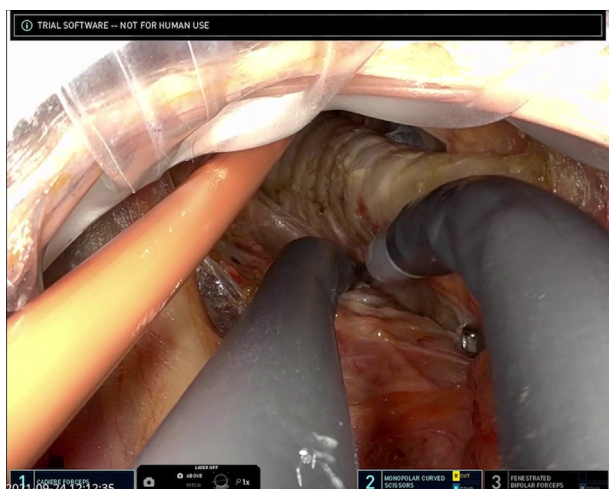


**FIGURE 4.** The anastomosis was performed with 2 V-loc sutures (Medtronic), starting in the posterior midline (A) and running anterosuperiorly on each side to meet anteriorly (B). Rigid bronchoscopy showed an intact, widely patent tracheal anastomosis (C).

**VIDEO 1.** This brief video demonstrates and describes the key portions of the operation. Until 1:14, the technique shown is similar to an open cervical slide tracheoplasty. Beginning at 1:14, the advantages of the robot-assisted technique become apparent in the excellent visualization, precise dissection, and precise suturing achieved even in this early proof-of-concept study. Video available at: https://www.jtcvs.org/article/S2666-2507(22)00470-9/fulltext.

Published studies have not generally reported operative time. However, 1 study led by an experienced slide tracheoplasty team reported a mean CPB time of 123 minutes,[3] and our center's experience has been similar for patients undergoing isolated tracheal repair, with bypass times ranging 45 minutes to 2 hours. Robotic operative time in the current study was about 3.5 hours, with 1 member of the surgical team having minimal previous experience with robotic surgery and with the frequent pauses and adjustments needed to work through this novel technique. We expect that this time will decrease with further practice.

Challenges encountered during this proof-of-concept study were minor. We encountered some difficulty dissecting the posterior membranous trachea from the esophagus, creating a small rent in the membranous portion adjacent to the posterior end of the tracheal cartilage rings. This was believed to be related to the use of the Maryland dissector, with its relatively sharp tips. The tear was repaired primarily and the anastomosis completed.

Of note, in the first case, we mobilized the entire left side of the trachea. Some surgeons believe that this is safe in children, whereas others prefer to preserve more vascular supply. The authors fall into the latter group. Accordingly, for the second case, a shorter segment of trachea was mobilized circumferentially. This did not impair the ability to mobilize and repair the trachea.

Potential hazards in considering this procedure in live patients include the ability to scale down to small children. Our cadavers were both small adults, approximating an adolescent or young adult. The majority of patients with congenital tracheal stenosis in our practice undergo repair in infancy or childhood. Current work in our group focuses on this challenge and on the problem of how to optimize cardiovascular support in this operation. During open reconstruction, patients are most often supported with CPB and less often with extracorporeal membrane oxygenation. It remains unclear how best to support patients undergoing transcervical thoracic repair with the robot. In larger children, the right neck may still be accessible, but in small children and infants, access may be a challenge.

Other potential failure points include significant bleeding; for example, from the innominate vessels. These were easily dissected from the trachea in the cadaver and are easily dissected from the trachea in live children during open repair, but contingency plans are essential. We tested the usability of rolled gauze and found that it could be inserted quickly to place pressure on vessels. The gauze did occupy a significant amount of space in the operative field. Similarly, we did not identify difficulty in avoiding the pleura, but rescue plans are necessary in the case of significant injury. In open thoracic slide tracheoplasty, patients generally have both lateral and mediastinal chest tubes in place for a few days after surgery. It bears considering how these might be placed in the case of a neck approach with the robot. Finally, we noted that the tissues became quite dry, likely due to the insufflation used. We are working to find ways to humidify the insufflated gas to avoid this problem; this improvement may also reduce associated fire risk when working with cautery near the airway in case of inadvertent airway entry with high inspired oxygen fraction.

## CONCLUSIONS

A final consideration is how to measure outcomes in patients undergoing this novel operation. We have previously described standard outcomes for thoracic tracheal reconstruction.[12] It remains to be seen if the same measures are appropriate for this less-invasive but technically challenging robotic procedure.

### Conflict of Interest Statement

### References
1. Speggiorin S, Torre M, Roebuck DJ, McLaren CA, Elliott MJ. A new morphologic classification of congenital tracheobronchial stenosis. *Ann Thorac Surg*. 2012;93:958-61.

2. Tsang V, Murday A, Gillbe C, Goldstraw P. Slide tracheoplasty for congenital funnel-shaped tracheal stenosis. *Ann Thorac Surg*. 1989;48:632-5.

3. Manning PB. Slide tracheoplasty for congenital tracheal stenosis. *Op Tech Thorac Cardiovasc Surg*. 2007;12:P184-93.

4. Ben-Ami E, Levy I, Katz J, Dagan O, Shalit I. Risk factors for sternal wound infection in children undergoing cardiac surgery: a case-control study. *J Hosp Infect*. 2008;70:335-40.

5. Clifton A, Cruz G, Patel Y, Cahalin LP, Moore JG. Sternal precautions and prone positioning of infants following median sternotomy: a nationwide survey. *Pediatr Phys Ther*. 2020;32:339-45.

6. Jina H, Simcock J. Median sternotomy scar assessment. *N Z Med J*. 2011;124:57-62.

7. Hu D, Wang Z, Tantai J, Yao F. Robotic-assisted thoracoscopic resection and reconstruction of the carina. *Interact Cardiovasc Thorac Surg*. 2020;31:912-4.

8. Li S, Qing A, Liang H, Liu H, Yang C, Deng H, et al. Nonintubated robotic-assisted thoracic surgery for tracheal/airway resection and reconstruction: technique description and preliminary results. *Ann Surg*. 2022;275:e534-6.

9. Holsinger FC, Magnuson JS, Weinstein GS, Chan JYK, Starmer HM, Tsang RKY, et al. A next-generation single-port robotic surgical system for transoral robotic surgery: results from prospective nonrandomized clinical trials. *JAMA Otolaryngol Head Neck Surg*. 2019;145:1027-34.

10. Chan JYK, Koh YW, Richmon J, Kim J, Holsinger FC, Orloff L, et al. Transoral thyroidectomy with a next generation flexible robotic system: a feasibility study in a cadaveric model. *Gland Surg*. 2019;8:644-7.

11. Chen MM, Orosco RK, Lim GC, Holsinger FC. Improved transoral dissection of the tongue base with a next-generation robotic surgical system. *Laryngoscope*. 2018;128:78-83.

12. Balakrishnan K, Sidell DR, Bauman NM, Bellia-Munzon GF, Boesch RP, Bromwich M, et al. Outcome measures for pediatric laryngotracheal reconstruction: international consensus statement. *Laryngoscope*. 2019;129:244-55.