Robot-assisted, volumetric tongue base reduction and pharyngeal surgery for obstructive sleep apnea

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A structured approach to Surgery for OSA has been clearly defined and accepted by the American Academy of Sleep Medicine. The aim of surgery is to address the collapsibility of structures of the upper airway.

The da Vinci Robot (Intuitive Surgical, Sunnyvale, California, USA) has been validated and now approved by the Food and Drug Administration as an adjunct to transoral surgery. The robot has proved useful in transoral resection of oropharyngeal malignancy and has also been used in parapharyngeal space surgery and resection of recurrent nasopharyngeal carcinomas.

The robot provides excellent visual access by means of an optical system comprising 2 rod lens telescopes from which images are fused to create a three-dimensional (3D) display at the operating console. The robotic arms provide the opportunity to introduce 2 surgical instruments into the oral cavity, which are wristed to provide a further 4 degrees of movement without tremor. In addition to this, a surgical assistant can introduce a further 2 surgical instruments and so assist and expedite surgery efficiently. The role of the robot in transoral surgery for obstructive sleep apnea (OSA) will be described.

The da Vinci robot and transoral robot-assisted surgery for OSA

The Intuitive da Vinci robot

The da Vinci robot provides the surgeon with a master–slave relationship. The actions are carried out by the surgeon at the console using pinch grip instruments in a working space of 1 sq ft. These actions are then carried out by the robotic instruments in a much more confined surgical operating space in the patient.

There are 4 main components to the da Vinci robotic system: the surgeon console, the surgical cart, EndoWrist Instruments, and Insite Vision System (Intuitive Surgical, Sunnyvale, CA) with high-resolution 3D endoscope and image processing equipment.

Surgeon console

The surgeon is situated at this console several feet away from the patient on the operating table. The surgeon has his/her head tilted forward, and his/her hands manipulate 2
pinch grip controls, which interface with the wristed instruments at the surgical cart. The surgeon sits viewing a magnified 3D image of the surgical field with a real-time progression of the instruments as he/she operates.

Surgical cart

This component of the system contains the robotic arms that directly contact the patient. It consists of 2 or 3 instrument arms and 1 endoscope arm. The feedback as of today is limited to sensing tool-on-tool collision, so the surgeon can rely almost solely on the visual field when suturing or contacting soft tissue. In transoral robotic surgery (TORS), the surgical cart is usually positioned at an angle of about 30 degrees to the operating table to allow the robotic arms and the telescope to be positioned intraorally.

Detachable instruments (EndoWrist Instruments and Intuitive Masters)

The EndoWrist detachable instruments allow the robotic arms to maneuver in ways that simulate fine human movements. Each instrument has its own function from suturing to clamping and is switched from one to the other using quick-release levers on each robotic arm. The device memorizes the position of the robotic arm before the instrument is replaced so that the second one can be reset to the exact same position as the first. The instruments’ abilities to rotate in full circles provide an advantage over nonrobotic arms. The 7 degrees of freedom (meaning the number of independent movements the robot can perform) offer considerable choice in rotation and pivoting. Moreover, the surgeon is also able to control the amount of force applied, which varies from a fraction of an ounce to several pounds. The Intuitive Masters technology also has the ability to filter out hand tremors and scale movements.

As a result, the surgeon’s large hand movements can be translated into smaller ones by the robotic device. In TORS, generally 2 instruments are used. These are the 5-mm or 8-mm Maryland grasping forceps and the 5-mm or 8-mm spatula diathermy blade. The blade is used as much as a dissecting tool to separate planes as a cutting and coagulating tool. The 8-mm Maryland forceps has the advantage of being able to apply a bipolar coagulating current. If a larger grasping forceps is required, a Prograsp tool can be used, and if a suture is to be used, a needle driver can be used.

The 3D vision system (Insite Vision and Navigator Camera Control)

The camera unit or endoscope arm provides enhanced 3D images. This high-resolution real-time magnification allows the surgeon to have a considerable advantage by providing the ability to drive the camera toward the operative site and so have visual access around corners. The system provides more than 1000 frames of the instrument position per second and filters each image through a video processor that eliminates background noise. The endoscope is programmed to regulate the temperature of the endoscope tip automatically to prevent fogging during the operation. In
TORS, further visual access can be gained by using the 30-degree scope.

The use of robotics in transoral surgery was initially evaluated by Hockstein in a progression from mannequin to a canine model and finally to cadaveric studies. The insights from these studies were then translated into transoral surgery for oropharyngeal malignancy and popularized by Weinstein and O’Malley. TORS is now approved by the Food and Drug Administration for use in the treatment of oropharyngeal cancer. The use of TORS has expanded with its use reported in the management of laryngeal malignancy, surgery of the parapharyngeal space, and for recurrent nasopharyngeal cancer.

Robotic training was initially only available at the Intuitive Training facility in Sunnyvale, California. TORS training is now available at several sites in the United States. An established training program must be completed for accreditation and is required to use the robot (Figures 1-6).

**TORS for OSA**

TORS is a natural adjunct to surgery for OSA because many of these patients have difficult anatomy that limits access to the oropharynx. The standard transoral approaches use either a headlight with magnification provided by a set
of loupes or the use of a microscope. These approaches have the inherent problem of crowding and visualization by straight-line optics. The crowding does not allow more than one surgeon easy access to the oral cavity, and so, it is difficult to provide assistance. Similarly, when using a microscope for transoral surgery, it is difficult for an assistant to comfortably access the operating site. Furthermore, the straight line optics of the microscope and the CO2 laser prevent easy access to lateral structures, and the access is almost impossible when attempting to resect along a curved surface such as the tongue base. Frequently, the surgeon has to either change laryngoscopes or change the position of laryngoscopes during surgery. Finally, the instruments used in transoral microsurgery are long stemmed and exaggerate tremor and have to be used counterintuitively to gain a desired surgical strategy.

The da Vinci system provides excellent visual access to lateral-based structures and allows one to direct the telescope close to and around structures. The 5-mm and 8-mm wristed robotic instruments do not prevent an assistant from introducing 2 further instruments into the operating field. The nurse can also then introduce a sucker into the operating field, allowing for up to 5 instruments working at the operation site.

The system also allows the surgeon to be comfortable during surgery, which may have long-term implications in occupational health and safety for the surgical workforce.

We have used the TORS approach for 5 types of surgical procedures in OSA. These are as follows: (a) uvulopalatopharyngoplasty by the uvulopalatal flap technique as described by Huntley with or without tonsillectomy, (b) expansion sphincter pharyngoplasty as described by Pang and Woodson, (c) transpalatal advancement pharyngoplasty as described by Woodson and Robinson, (d) tongue volume reduction by the submucosal linguaplasty technique as described by Robinson, and (e) the transoral tongue base excision as described by Vicini.

The robot provides excellent visual and instrument access for surgery for OSA. It also allows easy access for an assistant to introduce another 2 instruments, and help by retraction, provision of traction and suction. The assistant uses standard instruments for microlaryngeal surgery. Our preference is the Steiner microlaryngeal set manufactured by Storz (Karl Storz, Tuttingen, Germany). The key instruments in the set are the microlaryngeal vascular clip applicators. The major concern in transoral surgery is the risk of hemorrhage and obsessive hemostasis with the use of these vascular clips, particularly for small-diameter muscular branches of the lingual, facial, and tonsillar arteries is key.

All TORS oropharyngeal procedures are performed under general anesthesia and mostly with a standard orotracheal tube. The patient is positioned supine with some neck extension. Almost all procedures are performed with a Boyle–Davis mouth gag suspended by Draffin rods, as in standard tonsillectomy surgery.

The da Vinci robot surgical cart is docked at an angle of approximately 15 degrees to the left side of the patient operating table. The robotic arms are positioned with min-
imal angulation so that they are approximately parallel to the optical arm. This is to minimize collision with each other, the optical arm, and the teeth. The EndoWrist instruments are then loaded, and it is the distal wristed movements of these instruments that allow surgical incision, dissection, and excision.

The procedures using the robot are otherwise performed as described in the author’s texts.

Uvulopalatopharyngoplasty by the uvulopalatal flap technique

As described by Huntley\(^3\) with or without tonsillectomy, this procedure was originally described by Powell et al.\(^4\) and a similar technique was described by Bresalier and Brandes\(^5\). The technique is an attempt at a reversible uvulopalatopharyngoplasty. A diamond-shaped mucosal flap is excised over the soft palate and uvula (Figure 7). The uvula is then folded forward and sutured on itself (Figure 8).

The robot is used to provide better visual and surgical access. Usually this is not performed in isolation with the robot but in conjunction with tongue volume reduction. The suturing can be performed with a robotic needle driver or may be performed by standard suture holders and forceps but using the robotic optical scope to provide the visual access and the surgeon using the screen image on a visual cart to suture the wound.
Expansion sphincter pharyngoplasty

As described by Pang and Woodson,6 this procedure is mainly indicated in patients with retropalatal obstruction and lateral pharyngeal wall collapse. The operation involves identifying the palatopharyngeus muscle in the tonsillar fossa (Figure 9). The inferior end of the muscle is then transected and mobilized to just above the midpoint of the tonsillar fossa (Figure 10). The muscle is left with some attachment to the posterior horizontal superior pharyngeal constrictor muscles. Superolateral incisions are then made in the soft palatal mucosa, and the anterior arching fibers of palatoglossus are identified. The divided bundles of the palatopharyngeus muscles are then rotated superolaterally and sutured to the arching fibers of palatoglossus (Figure 11). This removes lateral wall bulk and creates lateral wall tension (Figure 12).

The robot again provides visual and surgical access with ease and the opportunity for obsessive hemostasis. Suturing can again be performed using the robotic needle drive or standard instruments with the robotic optical scope providing the images of the operative site.

Transpalatal advancement pharyngoplasty

As described by Woodson,7 this is a procedure aimed at improving the narrowed retropalatal airway of the proximal pharyngeal isthmus at the level of the retromaxillary airway. Before surgery, careful evaluation is made at sleep nasendoscopy, recognizing the shape of the retropalatal airway, particularly in patients who have had previous surgery and have stenosis and scarring. The procedure involves resecting a segment of hard palate, pulling the palate forward and superiorly. Conceptually, this aims to reproduce the increase in size of the retropalatal airway achieved by maxillary advancement.

The transpalatal advancement pharyngoplasty is performed with a palatal incision, which may be in the shape of a gothic arch in parallel with the alveolar arch or a trifurcate incision. The flaps are elevated to just expose the palatal surface of the maxilla just up to the insertion of the palatal aponeurosis. The palatal osteotomy is then performed, removing approximately 1 cm of maxillary bone. The osteotomy is performed so as to leave a small segment of bone attached to the periosteal and ligamentous attachments of the soft palate. The soft palate is then mobilized by dividing the tendon of tensor veli palatini. This tendinolysis is performed medial to the attachment of this muscle to the hamulus. The soft palate and attached bone are then advanced forward and sutured in position using a no. 1 Vicryl braided suture. If needed, a tonsillectomy and/or uvulopalatopharyngoplasty can be performed. The robot is particularly useful for the osteotomy and suture by allowing
the assistant or surgeon to work with the displayed images from the optical system (Figures 13-16).

**Tongue volume reduction by the submucosal linguaplasty technique**

As described by Robinson earlier, this technique is a peroral technique that removes the midline tongue musculature via a dorsal mucosal incision. Using ultrasonographic guidance, the lingual artery and neurovascular bundle are identified. Any laterally based tongue muscle between the vascular bundle and dorsal tongue mucosa is removed. The robot again provides visual and surgical access and dexterity with ease for the assistant to provide traction and retraction but most importantly provides obsessive hemostasis with the microlaryngeal vascular clip applicators.

**Transoral tongue base excision**

As described by Vicini, this technique and the results were presented at the World Robotic Symposium in Florida in June 2011. Vicini, from Forli, Italy, presented a series of more than 80 patients who had this procedure with significant improvement in Epworth Sleepiness Scale scores and a 50% reduction of respiratory distress index (RDI) or reduction of RDI less than 20. As usual, patients must be carefully evaluated for suitability for this procedure. Vicini is particularly dependent on the results of sleep nasendoscopy, demonstrating the tongue base as the site of obstruction. The technique involves using a medium tongue blade and a Boyle–Davis mouth gag to displace the redundant tongue mucosa and muscle into the oropharyngeal airway. This redundant tissue is then excised with overlying mucosa until the epiglottis can be clearly visualized. On average, this technique removes 10-20 ml of tongue base tissue with evidence showing no benefit from removing volumes greater than 25 ml. The robot provides good visual and surgical access with the ability to provide good hemostasis. It is the hospital’s practice in Forli to perform a tracheostomy on all these patients, with patients being decannulated within 1 week.

**Conclusions**

Surgery is now an accepted treatment option for patients with moderate and severe OSA. The surgical procedures are complex and have potentially significant immediate postoperative morbidity and risk of mortality from airway obstruction and hemorrhage. Late morbidities including dysphagia and velopharyngeal incompetence can cripple the lives of these patients. It is, therefore, important that patients are evaluated carefully, that the diagnosis of OSA is made with reliable certainty by properly conducted polysomnography, and that the site of obstruction be evaluated with exhaustive examination, appropriate imaging, and fiberoptic assessment by awake and/or sleep nasendoscopy. Many of these patients have significant macroglossia and may need tongue volume reduction. Mucosa-sparing tongue volume reduction surgery performed transorally provides a low morbidity and relatively pain-free approach. The da Vinci robot is an excellent surgical tool for OSA surgery. The excellent visual access and the use of distal-wristed, tremor-free instrumentation and the opportunity of providing easy access for an assistant surgeon means surgery can be performed safely, efficiently, and with ease.
References


