Transoral robotic surgery for sellar tumors: first clinical study

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OBJECTIVE The aim of this study was to confirm the feasibility of an innovative transoral robotic surgery (TORS), using the da Vinci Surgical System, for patients with sellar tumors. This technique was designed to offer a new minimally invasive approach, without soft-palate splitting, that avoids the rhinological side effects of classic endonasal approaches.

METHODS The authors performed a prospective study of TORS in patients with symptomatic sellar tumors. Specific anatomical features were required for inclusion in the study and were determined on the basis of preoperative open-mouth CT scans of the brain. The main outcome measure was sellar accessibility using the robot. Resection quality, mean operative time, postoperative changes in patients’ vision, side effects, and complications were additionally reported.

RESULTS Between February and May 2016, 4 patients (all female, mean age 49.5 years) underwent TORS for resection of sellar tumors as participants in this study. All patients presented with symptomatic visual deficits confirmed as bitemporal hemianopsia. All tumors had a suprasellar portion and a cystic part. In all 4 cases, the operation was performed via TORS, without the need for a second surgery. Sella turcica accessibility was satisfactory in all cases. In 3 cases, tumor resection was complete. The mean operative time was 2 hours 43 minutes. Three patients had a significant visual improvement at Day 1. No rhinological side effects or complications in patients occurred. No pathological examination was performed regarding the fluid component of the tumors. There was 1 postoperative delayed CSF leak and 1 case of transient diabetes insipidus. Side effects specific to TORS included minor sore throat, transient hypernasal speech, and 1 case of delayed otitis media. The mean length of hospital stay and mean follow up were 8.25 days and 82 days, respectively.

CONCLUSIONS To our knowledge, this is the first report of the surgical treatment of sellar tumors by means of a minimally invasive TORS. This approach using the da Vinci Surgical System seems feasible and constitutes an innovative neurosurgical technique that may avoid the adverse side effects and technical disadvantages of the classic transsphenoidal route. Moreover, TORS allows an inferosuperior approach to the sella turcica, which is a key point, as the tumor is approached in the direction of its growth.

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KEY WORDS transoral robotic surgery; pituitary adenoma; skull base surgery; robotic assisted surgery; da Vinci system; transsphenoidal surgery; surgical technique

OVER the past few decades, endoscopic transnasal procedures have become the gold standard for pituitary adenoma surgery.20,28 Endonasal transsphenoidal approaches have also been performed for the treatment of various skull base lesions.22,23,37 However, some disadvantages are regularly pointed out, such as rhinological side effects and complications,17,19 2D surgical vision,32 and narrowness of the operative corridor. Moreover, the ergonomic discomfort for the surgeon with respect to fine dissection and suturing2,30 and the prolonged learning curve have to be taken into account.6 Finally, the postoperative pitfall remains the CSF leak.21,35

Transoral robotic surgery (TORS) using the da Vinci Surgical System (Intuitive Surgical, Inc.) has been extensively applied, with proven safety and clinical results, especially in head and neck cancers.9,11,14,39 Other special-
ties make use of the advantages of this robotic assistance (3D visualization, motion scaling, tremor filtration, and increased freedom of movement within narrow spaces), including urology, gynecology, and colorectal surgery. Nevertheless, neurosurgeons and especially skull base surgeons have not exploited the da Vinci system. The literature remains very sparse, including 1 odontoidectomy case report and cadaveric studies. As a reminder, the transoral approach described by Crockard “allows access to structures from the sphenoid sinus rostrally to the fourth cervical vertebral body caudally.” Despite this fact, there have been no previous studies of minimally invasive TORS of the sella. Only aggressive approaches have been reported, including transpalatal drilling or wide anterior bilateral maxillary antrostomies. To combine Crockard’s adage and the da Vinci possibilities, we performed and published a cadaveric study of a TORS approach to the sella, thus demonstrating that pituitary adenomas could be operated on with this technique, in a minimally invasive fashion as all endonasal structures are left intact. Moreover, we have conducted a radiological study to predict which anatomical criteria may determine sellar accessibility.

The present study was undertaken to confirm the feasibility and safety of such an innovative TORS approach, using the da Vinci system, in patients with sellar tumors.

Methods

This prospective study was approved by the Agence Nationale de Sécurité des Médicaments et des produits de santé and the ethics committee CPP–Ile-de-France VI. The study is registered on clinicaltrials.gov (identifier NCT02743442). The patients were referred to our institution after the discovery of sellar tumors, manifesting primarily through visual symptoms. Surgical removal of the tumor was indicated on the basis of standard criteria, taking into account the visual impairment and the fact that prolactinoma was excluded. The inclusion and exclusion criteria for the present study are presented in Table 1. A preoperative open-mouth skull base CT scan was performed to visualize the accessibility of the sella, as previously described. Patients were included after meeting the selection criteria and providing informed consent, with the specific risks of TORS being explained as follows: mastication difficulties, temporomandibular pain, hypernasal speech, and sore throat. The operating room was set up as described in our previous publication. Surgery was performed with the da Vinci Si HD 4-arm system (Intuitive Surgical) even though only 3 arms were used (1 camera arm and 2 instrument arms). General anesthesia was induced with the endotracheal tube placed at the left labial commissure. The robotic arms were at the head of the patient, who was placed supine. A C-arm fluoroscope was installed. A mouth retractor (type Doyen, Landanger) was placed to achieve the usual transoral exposition. The mouth opening was measured. Retraction of the soft palate was performed with soft loops. The 8.5-mm 30° angled binocular endoscope was first inserted into the oral cavity behind the posterior edge of the hard palate to identify the cavum landmarks. Then, 5-mm EndoWrist (Intuitive Surgical) instruments were inserted—a Maryland dissector and a monopolar cautery, respectively, on the right and left labial sides (Fig. 1). During all of these steps, great care was taken to avoid damaging the teeth and the labial commissures of the mouth.

Surgical Procedure

Mucosal Phase

Two surgeons were present during the procedure: a head and neck surgeon (S.H.) at the console and a neurosurgeon (D.C.) next to the patient’s head to ensure suction and to check for the absence of conflict between the robot and the oral cavity. Cavum landmarks were identified: the choanae and the posterior part of the nasal septum superiorly and the eustachian tubes laterally (Fig. 2). The mucosa of the posterior cavum, which covers the sphenoidal rostrum anteriorly and inferiorly, was dissected into a U-shaped flap. The upper extension of the latter was considered large enough when both alae of the vomer were seen (Fig. 2). The mucosal flap was positioned in the right choana to facilitate the sphenoidal approach.

Sphenoidal Phase

For this sequence, the surgeons’ roles changed and 1 robotic arm was removed to allow more space for drilling; the endoscope remained in the midline. The sphenoid sinus was opened by the neurosurgeon at the patient’s side, watching his dissection on the 2D flat-panel screen. The head and neck surgeon sitting at the console offered additional intraoperative control with a 3D view and could perform suction with a dedicated robotic tool—an 8-mm EndoWrist One Suction/Irrigator (Intuitive Surgical). Before drilling the sphenoid, the neurosurgeon had to see a specific key point (Fig. 2) that corresponded to the articulation between the vomer and the sphenoid. The drilling was performed with the Midas Rex Legend Stylus (Medtronic). The sphenoid sinus was thus opened inferiorly (Figs. 3 and 4) and enlarged to provide a wide view of the sella turcica.

Sellar Phase and Adenoma Removal

Depending on the thickness of the sellar wall, it was opened with the drill or robotic arms. The sellar window could be enlarged using Kerrison rongeurs. The dura was opened with a CO2 flexible laser (Lumenis) guided by the robotic instruments, unveiling the tumor, which bulged out of the sella spontaneously. The tumor was then removed by the neurosurgeon at the patient’s side, using curettes.
Closure

After the tumor was removed, oxidized regenerated cellulose was placed against the sellar wall and the mucosal flap was reapplied.

A video clip showing selected elements of the surgical procedure is provided (Video 1).

FIG. 1. Intraoperative photographs. A: Case 2. Mouth exposure with loops retracting the soft palate on each side of the uvula, which has been sutured. B: The head and neck surgeon (S.H.) performing the mucosal dissection at the console of the robot. C: Case 3. Operative view during the mucosal phase. The 3 arms are inserted into the mouth cavity and the tongue is retracted downward with a suture. D and E: Cases 3 and 4. Operative views during the sphenoidal phase. The neurosurgeon (D.C.) performs the drilling at the patient's side, with both hands placed at the labial commissure. An additional suction device can be placed in the nasal cavity. Figure is available in color online only.

FIG. 2. Intraoperative view at the console during the mucosal phase. A and B: Case 1. The mucosal flap (+) is progressively dissected and retracted upward using the Maryland dissector (8) and the monopolar cautery (μ). C: Case 1. Visualization of the junction between the vomer, with its two alae (2), and the sphenoid bone (1). D: Case 2. Suction (£) showing the key point to enter the sphenoid sinus. The white triangle in Panel A indicates the right choana. The white arrows indicate the eustachian tubes. Figure is available in color online only.

FIG. 3. Intraoperative view after the drilling phase. A: Case 2. General view of the sphenoid sinus and the sella (#) before opening of the intersinus sphenoid septum ($). B and C: Case 4. Sellar phase, including opening of the dura (dm) with the CO2 laser fiber (L) handled by the monopolar cautery (μ). The white arrow indicates the X-shaped dural aperture and the cyst evacuation; £ indicates the suction device. D: Case 2. Final view after tumor resection showing the sellar diaphragm (white star). Figure is available in color online only.

VIDEO 1. Video clip showing various phases of sellar tumor removal by means of TORS, including retraction of the mucosal flap, drilling of the key point (junction between the vomer and the sphenoid), drilling of the sphenoid sinus to enlarge the opening, opening of the sella, opening of the dura with the CO2 laser, release of the fluid contents of the tumor, and the view of the sellar diaphragm after tumor removal. Copyright D. Chauvet. Published with permission. Click here to view.
Outcome Measures

Intraoperative data were collected, including the size of the mouth opening, quality of exposure of the cavum and the sella, occurrence of CSF leak, operative time for each phase of surgery, mucosal lesions in the oral cavity at the end of the procedure, and necessity of converting to an endonasal approach. Postoperative features were noted and divided into 2 categories: surgical approach side effects (mastication dysfunction, temporomandibular pain, hypernasal speech, sore throat, nasal obstruction, and posterior epistaxis) and usual pituitary adenoma surgery outcomes and complications (vision status, CSF leak, meningitis, diabetes insipidus, and hypopituitarism). At Day 7, before discharge, an ENT examination including nasofibroscopy was performed to assess the mucosal flap.

Results

Population and Clinical Presentation

Four patients, all female, were included in this study and underwent surgery between February and May 2016. The mean patient age was 49.5 years. All patients had a visual presentation with bitemporal hemianopsia, confirmed by Goldmann perimetry.

Preoperative Imaging

On MRI, the 4 lesions were mostly cystic (Fig. 5). All tumors compressed the chiasma. There was no component in the cavernous sinus. The mean size of the tumors’ largest dimension was 27 mm (range 23–30 mm).

Open-mouth skull base CT scan findings are reported in Table 2. All patients had a well-pneumatized sphenoid sinus (also known as sellar type).

Intraoperative Observations

The mean size of the patients’ mouth opening with a retractor was 48 mm (Table 2). The mean duration of the mucosal phase was 19 minutes. Visualization of the cavum
Anatomical structures was good in all cases, including visualization of both choanae and the junction between the vomer and the sphenoid after mucosal dissection. We encountered 1 episode of mucosal bleeding during flap dissection, which was resolved with local adrenaline injection and compression (Case 2). In all cases, the key point at the junction between the vomer and the sphenoid was clearly identified. The mean duration of the sphenoidal phase, which included opening of the sella and tumor removal, was 59 minutes. In all cases we entered directly into the sphenoid sinus and performed a wide sphenoidotomy with drills and Kerrison rongeurs. In Case 1, we left the intersinus sphenoid septum, so the sellar opening was slightly lateralized. In all cases, the sella was identified without any difficulty and the exposure was satisfactory (Fig. 3).

The sella could be opened with soft drilling by the neurosurgeon at the patient’s side. The dura could be coagulated by the robotic instruments and opened by the robot (via CO₂ laser). Since the tumors were cystic, fluid evacuation occurred spontaneously immediately after dural opening. Sellar curettage was then performed by the neurosurgeon at the patient’s side. During this sequence we encountered a significant cavernous hemorrhage (Case 1) that compelled the surgeon to stop curettage and perform hemostasis with oxidized regenerated cellulose. This led to a partial removal of the lesion, even though chiasmatic decompression was achieved. We observed 2 minor intraoperative CSF leaks (Cases 3 and 4). There was no need to convert the surgery into an endonasal approach, as the decompression of the chiasma was considered good enough in all cases. Because all tumors were cystic, we did not obtain enough tissue for pathological examination. At the end of surgery, we examined the oral cavity and observed minor lesions of the lower lip in Cases 1 and 2 (Fig. 6) and edema involving the uvula and the mucosal cavum in Case 1.

Postoperative Outcomes

The clinical outcomes are summarized in Table 3. The mean duration of follow-up was 82 days. All patients were extubated within the 1st hour after surgery. Three patients had a significant visual recovery just after surgery. One patient (Case 4) had only a slight recovery at Day 1 because of pneumocephalus in the pituitary fossa (Fig. 4D). At the end of a 47-day follow-up, her Goldmann perimetry had improved. This patient also had a delayed CSF leak at Day 7, following a Valsalva maneuver. This was successfully treated with lumbar puncture and acetazolamide, and the patient was discharged at Day 12. Consequently, the mean duration of hospital stay was 8.25 days. With respect to the side effects of TORS, we recorded transient sore throat for all patients and hypernasal speech for 3 patients, which resolved before discharge. Additionally, we observed a delayed instance of otitis media in the patient in Case 1, which was treated with myringoplasty. An ENT examination at Day 7 did not show nasal obstruction, and

FIG. 6. A: Case 1. Immediate postoperative photograph of the patient. The black arrow indicates the lower lip hematoma. B: Case 2. Day 7 postoperative photograph of the patient. The blue arrow and white arrows indicate lower lip and soft-palate lesions, respectively. C and D: Day 7 postoperative nasofibroscopy via the right nostril revealing good healing of the mucosal flap (dotted line) and minor lesions (white arrows) on each side of the uvula (U). The black triangle indicates the posterior part of the vomer. Figure is available in color online only.

### TABLE 2. Summary of patient characteristics and operative data

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yrs), Sex</th>
<th>BMI</th>
<th>MO (mm)</th>
<th>Preop CT Findings</th>
<th>Operative Data</th>
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</thead>
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<tr>
<td>No.</td>
<td></td>
<td></td>
<td>Sinus Type</td>
<td>Sellar Projection*</td>
<td>MO (mm)</td>
</tr>
<tr>
<td>1</td>
<td>63, F</td>
<td>28</td>
<td>38</td>
<td>Sellar Postsellar</td>
<td>45</td>
</tr>
<tr>
<td>2</td>
<td>61, F</td>
<td>38</td>
<td>55</td>
<td>Sellar Presellar</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>45, F</td>
<td>25</td>
<td>41</td>
<td>Sellar</td>
<td>48</td>
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<tr>
<td>4</td>
<td>29, F</td>
<td>23</td>
<td>44</td>
<td>Sellar Presellar</td>
<td>51</td>
</tr>
</tbody>
</table>

BMI = body mass index; MO = mouth opening.
* Sellar projection was defined as described by Amelot et al.⁹
† Values are in minutes.
‡ Dead time includes different events as described in successive footnotes.
§ For cavernous sinus hemostasis with compression.
¶ For mucosal hemostasis before flap dissection.
** Includes sellar reconstruction following CSF leak.
nasofibroscopy revealed good healing of the mucosal flap. Two patients (Cases 2 and 3) had minor lesions at the location of the loops on each side of the uvula (Fig. 6).

Postoperative brain MRI at Day 1 showed significant chiasmatic decompression in 3 patients (Fig. 5). The patient in Case 4 had only moderate decompression because the cyst inside the sella was partially replaced by pnuemocephalus (Fig. 4D). One patient (Case 1) had only partial tumor removal.

Discussion

We demonstrate in this study that approaching the sella turcica by transoral robotic surgery (TORS) is feasible in the context of minimally invasive skull base procedures, when certain caveats are respected. First, the mouth aperture must be normal, which means approximately 45 mm. This was comparable to our intraoperative mouth opening measurements. Furthermore, in this transoral approach, the sphenoid bone is drilled from the bottom up, which means that the sinus constitutes a safe area before entrance into the pituitary fossa. Consequently, we have chosen only patients with sellar sphenoid sinus types, which are the most common. In our opinion, conchal and presellar types would not constitute a suitable setting for first-line TORS. Finally, this preliminary study focused on pituitary tumors with a cystic component to facilitate the resection. This constitutes a limitation of our study, as we could not obtain diagnosis of these tumors. However, we plan to perform this surgery for the resection of solid pituitary adenoma, but to date there is no dedicated instrument on the da Vinci Surgical System. Our partnership with Intuitive Surgical should lead to improvement in this issue in the near future.

Three main advantages of TORS can be emphasized. First, we think this technique can be considered as minimally invasive. Indeed, the robotic sellar approach via the cavum is quite direct without involving dissection of the palate. Specifically, it avoids postoperative nasal discomfort and nasal complications because the endonasal mucosa and the turbinates are left totally intact. In our 4 cases, the usual side effects of an endonasal technique, such as the need for postoperative nasal packing and persistent nasal obstruction, were not observed. These preliminary data should, however, be evaluated in larger series dedicated to side effects of TORS, which appeared to be minor in our study (transient sore throat and transient hypernasal speech). Second, the 3D vision is useful as it offers a “microscopic view” during each phase of the surgery. We observed a wide exposure into the cavum and the sphenoid sinus in all patients, despite their anatomical variations. One could imagine that the TORS learning curve might be shorter than the one for transnasal endoscopy. The videoendoscope is directly controlled by the surgeon at the console, providing good stability. TORS allows increased freedom of movement within narrow spaces. Thus, it was possible to introduce the needle driver into the sphenoid sinus. With the needle driver guiding the flexible CO2 laser fiber, it was possible to incise the dura. The dura was opened in our cadaveric study with an EndoWrist scalpel. Finally, the sella is approached via an unusual inferosuperior axis, in contrast to the classic transsphenoidal techniques in which the working axis is rather anteroposterior. This could be a decisive point because it may create new possibilities for pituitary adenoma resection, especially for those lesions with large suprasellar extension. It is known that the size of the suprasellar portion is a major criterion for the choice of a specific approach. Some authors consider that suprasellar extensions < 30 mm allow transsphenoidal surgery because of the usual softness of pituitary adenomas, while larger extensions are associated with higher risks of incomplete resection. We hypothesize that TORS reaches the sellar tumor in the axis of its growth, which could account for a superior exposure and increased resection in the future. This is in accordance with the global aims of sellar tumor removal: achieving maximal resection, avoiding blind dissection, and working with a real-time vision control.

Despite its promising future, the use of TORS for pituitary fossa and skull base lesions presents some limitations. The da Vinci Surgical System has been designed for general surgery, making the size of robotic arms and EndoWrist instruments quite big for neurosurgical applications. Some cadaveric studies have tested the da Vinci system for keyhole craniotomies, but the results have been disappointing. Moreover, instruments that are designed specifically for dissection of bony structures using this system only exist as prototypes. In our study, we have performed the drilling sequence at the bedside. Thus, skull base TORS cannot be a fully robotized technique at the moment. Another concern is the lack of haptic feedback. This problem should be improved by technological developments. However, some authors emphasize that the excellent vision compensates for this issue. Apart from the robotic system itself, special care should be taken to avoid conflicts of the robotic arms that might interfere with the mucosa.

TABLE 3. Postoperative outcomes

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Mastication Dysfunction</th>
<th>TMJ Pain</th>
<th>Hypernasal Speech</th>
<th>Sore Throat</th>
<th>Nasal Obstruction</th>
<th>Epistaxis</th>
<th>Vision</th>
<th>CSF Leak</th>
<th>Meningitis</th>
<th>DI</th>
<th>Hypopituitarism</th>
<th>FU (days)</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Improved</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>136</td>
</tr>
<tr>
<td>2</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Slight</td>
<td>—</td>
<td>—</td>
<td>Improved</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Slight</td>
<td>—</td>
<td>Improved</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>66</td>
</tr>
<tr>
<td>4</td>
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<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Improved (delayed)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>47</td>
</tr>
</tbody>
</table>

DI = diabetes insipidus; FU = follow-up; TMJ = temporomandibular joint; — = not present.
at the opening of the mouth cavity and create lesions. We have not observed any such mucosal lesion in any of our 4 patients. The minor lesions that we have observed were due to loop retraction of the soft palate. In our study, we drilled the sphenoid by placing the handpiece in the labial commissure. We know from the literature\(^\text{22}\) that it entails a risk of burns, and we observed 1 minor lesion of the labial commissure in the patient group. We also acknowledge that the operative time in our series of cases treated with TORS is longer than transnasal endoscopic surgical time. However, between the first and fourth cases, the operative time decreased dramatically (from 3 hours 22 minutes to 1 hour 57 minutes), and one could envision that each surgical sequence will be improved and that dead time will be reduced with further experience. Furthermore, we could not obtain pathology information for these cystic tumors, which were almost entirely fluid, but this is an issue that can occur with standard approaches. We plan to perform TORS for solid sellar lesions, so that it will be easier to obtain pathologic specimens.

Finally, TORS for sellar tumors will benefit from future technological developments, such as integrated neuronavigation. In this study, we only used lateral fluoroscopy to help with the drilling, and it only provides a view in the sagittal plane. Furthermore, augmented reality could be of major interest,\(^\text{30}\) and some authors have proposed applications for the da Vinci system.\(^\text{29}\) Once these technological improvements are made available, we will be able to determine whether TORS can challenge endoscopic techniques with respect to resection quality and whether it provides a global enhancement of the surgical procedure for the patient.

**Conclusions**

To our knowledge, this is the first clinical study to approach sellar tumors with TORS using the da Vinci Surgical System. Following our cadaveric and anatomical works, we confirmed in this case series the feasibility of this innovative minimally invasive technique. The results obtained in these 4 selected cases are encouraging. TORS may provide better postoperative comfort for the patients. Moreover, the sellar tumor is approached via a new infero-superior direction. Larger series must be conducted and technological developments should be explored to compare TORS with endoscopic endonasal techniques.

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**References**


Disclosures
Antoine Missistrano works for Intuitive Surgical, Inc., manufacturer of the da Vinci system.

Author Contributions
Conception and design: Chauvet, Hans. Acquisition of data: Chauvet, Hans, Missistrano, Rebours, El Bakkouri. Drafting the article: Chauvet. Critically revising the article: Lot. Reviewed the submitted version of manuscript: Hans, Missistrano, Rebours, El Bakkouri, Lot. Approved the final version of the manuscript on behalf of all authors: Chauvet. Administrative/technical/material support: Missistrano. Study supervision: Chauvet, Hans, Lot.

Supplemental Information
Videos

Previous Presentations
Portions of this work were presented at the 16th Congress of European Neurosurgery (EANS2016) September 4–8, 2016.

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