Robotics in Sinus Surgery

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4.1 Introduction

In contrast to head and neck surgery or even skull base surgery, robotics in sinus surgery has been limited thus far [1]. The only approved system is the da Vinci robot, which has been successfully implemented in, e.g., thyroid surgery or surgery for oropharyngeal or hypopharyngeal cancers [1]. The biggest challenges are the size of the instruments/robotic arms and the port, which is limited by the nostrils. Another big limitation is that transnasal endoscopic instruments are traditionally rigid, and flexible instruments are required for optimal benefits of robotic surgery, costing space.

4.2 Robotic Endoscope Holders

For those reasons, robotic endoscope holders have received most attention in endoscopic sinus surgery. The advantage of these holders is that the surgeon has both hands free to manipulate instruments. Eichhorn et al. [2] published a trial with 16 procedures with and without robot-assisted guidance and found a learning curve, especially regarding the duration of surgeries. One problem with endoscope holders is their maneuverability, since it is desirable for surgeons to be able to keep their hands free for the instruments, not to steer the scope. Chan et al. [3, 4] designed a Foot-controlled Robot-Enabled EnDOscope Manipulator (FREEDOM) for this purpose. Here, the surgeon has a Bluetooth device fixed on his foot and can guide the robot arm by moving the foot, keeping both hands free. Since the device is braced on the foot, movement in all space directions is granted. This is a clear advantage

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Fig. 4.1 The three electromagnetic locks of the ENDOFIXexo allow any position to be taken within arm range. Reference: Hintschich, C. A., Fischer, R., Seebauer, C., Schebesch, K.-M., Bohr, C. & Kühnel, T. (2021). A third hand to the surgeon: the use of an endoscope holding arm in endonasal sinus surgery and well beyond. *European Archives of Oto-Rhino-Laryngology*, *279*(4), 1891–1898. https://doi.org/10.1007/s00405-021-06935-x

over other systems such as ENDOFIXexo (Fig. 4.1), which is oriented with a control button similar to moving microscopes [5]. Friedrich et al. [6] described a similar robotic arm system with four segments and seven degrees of freedom operated by a foot pedal and a joystick. They published the feasibility of this system on a cadaveric head inclusive of implementing the EndoCAMeleon endoscope, which allows vision angulation to be adjusted freely by a steering wheel on the endoscope shaft (without steps). This is an additional advantage of not having to change endoscopes at the robot arm when angled vision (e.g., frontal sinus) is required.

Another interesting aspect of robotic arm-assisted sinus surgery was explored by Okuda et al. [7]. They investigated the time needed for lens-wiping during surgery, comparing the so-called iArmS Robotic system to standard endoscopy. Since the endpoints were blinded in advance, the surgeons could not know the aim of the study. The surgeries were recorded and intervals for lens-wiping were measured; there was a highly significant prolongation when the iArmS system was used. Here, an automated lens cleaning/flushing system could help; however, this has not yet been investigated. Given the necessity of operating such systems by a foot pedal, it would give the surgeon an additional tool on top of maneuvering the robotic arms.

4.3 Steerable Flexible Endoscopes

Another innovation, especially for maxillary sinus surgery, is steerable flexible endoscopes. Most instruments described share the problem of size; their large diameters would not allow insertion to be atraumatic unless wider resections and antrostomies were performed. Legrand et al. published a feasibility study on the so-called PliENT flexible endoscope (Fig. 4.2) for maxillary sinus surgery [8]. This

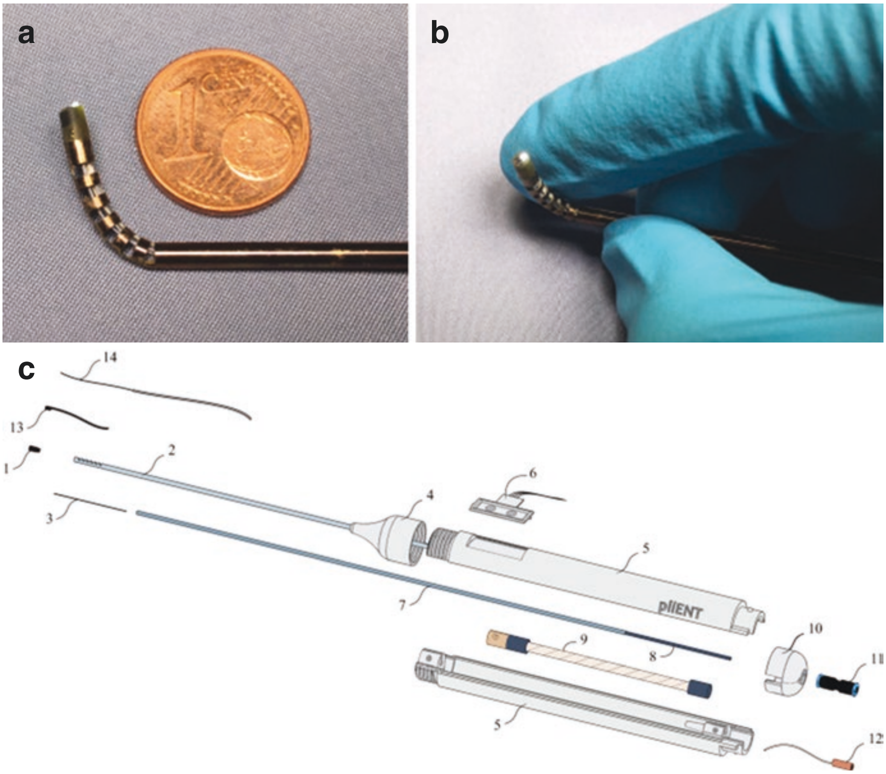

Fig. 4.2 Flexible endoscope for maxillary sinus inspection. (**a**) View of the bending capabilities of the 2.3-mm diameter endoscope; (**b**) detail of the endoscope distal tip with camera and illumination; (**c**) overview of the different components of the single-handed, flexible, steerable endoscope for maxillary sinus surgery. (1) Tip; (2) NiTi shaft; (3) cable; (4) screw-on cap; (5) two-parts handle; (6) button interface; (7) mobile outer tube of the concentric muscle; (8) fixed inner tube of the concentric muscle; (9) McKibben muscle; (10) plug-on cap; (11) pressure source connector; (12) pressure source tube; (13) chip-on-tip camera; (14). light fiber. Reference: Legrand, J., Ourak, M., Gerven, L. V., Poorten, V. V., Poorten, E. V. (2022). A miniature robotic steerable endoscope for maxillary sinus surgery called PliENT. Scientific Reports, 12(1), 2299. 10.1038/s41598-022-05969-3

endoscope is steerable with two buttons and can be inserted into the maxillary sinus without wide antrostomies. Compared to standard endoscopes, the PliENT could provide a wide view of the posterior and lateral walls only by antrostomies, and partial views (>50%) of the medial wall, the floor, and the anterior wall. For standard scopes, this was only possible for types 3 and 4 maxillectomies, respectively, in 0° and 30° lenses. The scope is a single-use design, but it meets the criteria for sterilization.

4.4 Educational Aspect

Another important aspect of robotics in sinus surgery is training. Cadaveric specimens are not always available and can also be costly. Animal models are feasible but do not always reflect the anatomy of human sinuses. To overcome problems with training on cadaver heads, various simulators have been proposed. With a virtual-based haptic system, different surgical tasks could be accomplished, giving the trainee the impression of operating in a natural environment. Here, the haptic feedback can train tissue resistance and potentially give feedback about risks and complications [9]. Future perspectives in training definitely lie in virtual reality environments and 3D printing systems that can simulate real tissues from mucosa to bone optimally [10, 11].

4.5 Conclusion and Future Perspective

At present, the robotic systems available are not suited to endoscopic surgery of the paranasal sinuses and skull base. Major limitations include the lack of a drilling/suction device and the large size of the instruments/robotic arms. With continuing technical developments, the potential of robots for endoscopic sinus surgery will definitely increase in the future.

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