Potential Use of NeuRobot (micromanipulator system) in Endoscopic Neurosurgery

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ABSTRACT

NeuRobot, a micromanipulator system with a rigid neuroendoscope and three micromanipulators, was developed for less invasive and telecontrolled neurosurgery. This system can be used to perform sophisticated surgical procedures through a small window 10 mm in diameter. The present study was performed to evaluate the feasibility of using NeuRobot in neuroendoscopy. Four different intraventricular neurosurgical procedures were performed using NeuRobot in three fixed cadaver heads: 1) fenestration of the floor of the third ventricle, 2) fenestration of the septum pellucidum, 3) biopsy of the thalamus, and 4) biopsy of the choroid plexus of the lateral ventricle. Each procedure required less than 2 min, and all procedures were performed accurately. After these surgical simulations using cadaver heads, third ventriculostomy was carried out safely and adequately in a patient with obstructive hydrocephalus due to a midbrain venous angioma. Our results confirmed that NeuRobot is applicable to lesions in which conventional endoscopic neurosurgery is indicated. Furthermore, NeuRobot can perform more complex surgical procedures than a conventional neuroendoscope because of its maneuverability and stability. NeuRobot will become a useful

neurosurgical tool for dealing with lesions that are difficult to treat by conventional neuroendoscopic surgery.

Key words: robotics surgery, micromanipulator, brain tissue, neuroendoscope, intraventricular lesion.

INTRODUCTION

Among the various techniques and instruments that have been developed recently, the neuroendoscope contributes to less invasive neurosurgical procedures.[1-7] The ventricular space is one of the most appropriate sites for neuroendoscopic procedures. Even using an operating microscope, deep-seated intraventricular lesions cannot be reached without large corticotomy and retraction of the surrounding brain parenchyma. In contrast, the neuroendoscope can reach such lesions through only a small corticotomy. There are two types of neuroendoscope, *i.e.*, the rigid and flexible types. The former has higher image quality but can only reach a limited area where the endoscope is inserted, while although the latter has poorer image quality it has a wider operating field because of its flexibility. Current neuroendoscopic intraventricular procedures are limited only to biopsy or membrane opening, such as third ventriculostomy and septostomy. The lack of stability of the shaft in flexible endoscopic procedure causes difficulty in fine movement of the instruments. Furthermore, instruments with a simple structure to facilitate delivery through a narrow working channel have less flexibility. For minimally invasive intraventricular surgery, the cortical incision should be small and both viewer image quality and maneuverability should be high. However, no neuroendoscopes are currently available that satisfy all of these requirements.

NeuRobot is a microscopic-micromanipulator system with a three-dimensional (3D) rigid neuroendoscope and three microinstruments, which was developed to allow less invasive and telecontrolled neurosurgery to fulfill these requirements.[8-12] We confirmed previously that the system is able to perform basic neurosurgical procedures, such as cutting, suturing, coagulating, and controlling bleeding. NeuRobot has already been introduced into clinical use, and satisfactory results were obtained in removing a superficially located brain tumour.[13]

This system was designed specifically for surgery in narrow areas to treat deep-seated lesions, which are difficult to reach with conventional microsurgical procedures. In the present study, we investigated the feasibility of applying NeuRobot for intraventricular procedures using fixed cadaver heads. Here, we will also describe the use of this system in a clinical case based on the cadaveric study.

MATERIALS AND METHODS

NeuRobot was used in this study. The design concept and the system has been reported previously (Fig. 1).[8-12] Briefly, the main feature of the system is a rigid insertion cylinder 10 mm in diameter and 17 cm in length for installing a 3D endoscope, three microinstruments, and five irrigation and suction channels. The insertion cylinder, the slave manipulator, is installed into the supporting device (Fig. 1, left). All movements of the slave manipulator are achieved by an operator from the central console with accuracy in the order of 0.02 mm with steady operation.[9] Microinstruments, such as microforceps, microhook, potassium titanyl phosphate (KTP) laser, monopolar coagulator, *etc.*, with a tip diameter of less than 1 mm are installed in the micromanipulator and can be moved in the operative field with three degrees of freedom: rotation, neck swinging, and forward/backward motion.[11]

Cadaveric study

Four different intraventricular surgical procedures were performed in three fixed cadaver heads: 1) fenestration of the floor of the third ventricle (third ventriculostomy), 2) fenestration of the septum pellucidum (septostomy), 3) biopsy of the thalamus, and 4) biopsy of the choroid plexus of the lateral ventricle. These procedures were selected as they are representative of the intraventricular procedures for which the neuroendoscope is used. After making a burr hole in the right frontal bone, the dura mater was incised and the right lateral ventricle was tapped with the standard surgical technique. The insertion cylinder, which was installed in the supporting device, was then advanced and fixed into the ventricle (Fig. 1, right). The microinstruments, the 0.2-mm fiber of the KTP/532 laser (Laserscope Surgical Systems, San Jose, CA) with a power of 5 W in the center and two microforceps on the bilateral micromanipulators were set in place. The following procedures were performed with NeuRobot alone operated by an experienced neurosurgeon watching the 3D endoscopic monitor. Procedures 1) and 3) were performed in each cadaver under a dry field, and procedures 2) and 4) were performed in one cadaver under a water field with irrigation and suction with 0.9% saline through the irrigation and suction channels.

All procedures were recorded on videotape. The time required, technical quality, and subjective difficulty were investigated.

RESULTS

Procedure 1: Third Ventriculostomy

The tip of the insertion cylinder was placed in the right anterior horn of the lateral ventricle because the foramen of Monro was 8 mm in diameter. Microforceps were then advanced forward to the floor of the third ventricle. A small hole was opened at the floor of the third ventricle using a pair of microforceps. The opened edges of the floor were held in place with bilateral microforceps, and the small hole was widened by rotating the two pairs of forceps in a circle with a diameter of 6 mm (Fig. 2). This procedure was performed in a dry field. It took 35 s to complete the third ventriculostomy.

Procedure 2: Septostomy

The insertion cylinder was inserted into the lateral ventricle via the left posterior horn under a water field. The septum pellucidum was fenestrated in a diameter of 10 mm using the same procedures as in the third ventriculostomy (Fig. 3, left). It took 25 s to complete the septostomy.

Procedure 3: biopsy of the thalamus

The microforceps were inserted into the third ventricle through the foramen of Monro.

The surface of the thalamus, the lateral wall of the third ventricle, was held with a pair of microforceps, and part of the superficial thalamus was irradiated with the KTP laser circumferentially to resect a tiny portion of the thalamus 3 mm in diameter. The ventricle became full of smoke due to KTP laser irradiation, but the operative field was cleared by evacuating the smoke through suction channels. It took 115 s to complete this procedure. In this procedure, the foramen of Monro was left intact but only interthalamic adhesion was partly injured during advancement of the microinstruments (Fig. 3, right).

Procedure 4: biopsy of the choroid plexus

Biopsy of the choroid plexus was performed in a water field. The micromanipulator was inserted into the lateral ventricle. The choroid plexus was pinched with two pairs of microforceps, and the raised portion was coagulated and divided with the KTP laser (Fig. 4, right, left). Air bubbles and debris produced by exposure to the KTP laser were evacuated through suction channels (Fig. 4, left). A piece of the choroid plexus measuring 3 mm in diameter was obtained. It took 110 s to complete this procedure.

NeuRobot was able to perform all scheduled procedures completely. No manual assistance was required throughout the procedures. Each procedure took less than 2 min. The position and direction of the insertion cylinder were not changed during the procedures. No other injuries were induced in these procedures except damage to the interthalamic adhesion in biopsy of the thalamus.

CLINICAL APPLICATION

A 41-year-old man suffering from dysuria and gait disturbance was referred to our service. Radiological examinations revealed obstructive hydrocephalus due to aqueductal stenosis caused by venous angioma in the midbrain (Fig. 5 a,b). Third ventriculostomy was indicated. Prior to surgery, clinical application of NeuRobot had been approved by the Ethical Committee of Shinshu University School of Medicine, and informed consent was obtained from the patient and his family. The setup and the process of the operation were simulated in the operating room the day prior to surgery.

Operation

The patient was placed in the supine position under general anesthesia, and a burr hole 20 mm diameter was made in the right frontal bone. A guide sheath was inserted into the right lateral ventricle. The sterilized slave manipulator was installed into the draped supporting device, and was introduced into the operative field with the insertion cylinder through the guide sheath (Fig. 5 d). The microforceps were set in the micromanipulator. The insertion cylinder was positioned at the right lateral ventricle. As the foramen of Monro was 8 mm in diameter, the insertion cylinder was not advanced to the third ventricle. The microforceps were extended into the third ventricle, and the thin floor of the third ventricle was fenestrated by the same procedures as used in the cadaveric simulation; the fenestrated floor was held by two pairs of microforceps and the hole was widened to 5 mm in diameter by rotating the microforceps in the micromanipulator (Fig. 5 e). The basilar artery and its perforating arteries were visible beneath the hole, and the third ventriculostomy was achieved without touching them. The patient's postoperative course was uneventful. No signs of infection or other complications related to usage of the system were encountered. His neurological symptoms recovered gradually after the operation, although the ventricle size did not decrease after surgery as determined by computed tomography (CT) scan (Fig. 5 c).

DISCUSSION

Endoscopic fenestration is generally accepted as the procedure of choice for treating non-communicating hydrocephalus.[2,6] The procedure is simple, fast, and safe with conventional neuroendoscopic techniques. However, complications of this procedure were reported in third ventriculostomy, such as injury to the basilar artery or its perforating artery, and herniation syndromes.[6] In the present study, fenestration and biopsy of the intraventricular lesion were performed with a sophisticated method using NeuRobot, a telecontrolled micromanipulator system. With a finer operative field obtained with a 3D rigid endoscope and steadier instrument motion than can be achieved by freehand manipulation or that using a flexible endoscope, NeuRobot can be used to perform endoscopic surgery with higher degrees of both safety and accuracy.

NeuRobot could reach the target in the ventricle through the burr hole. We confirmed previously that NeuRobot can be used to obtain biopsy specimens of living rat brain tissue under water conditions both safely and precisely.[8] Further, we have applied NeuRobot clinically for removal of a superficial brain tumour.[13] The results of the present study indicated that NeuRobot can be applied not only for superficially located lesions, but also for deep-seated lesions in the ventricular system, which was one of the goals in the development of the system.

Ventriculostomy using NeuRobot is a safer procedure because the thin floor of the third ventricle is not punctured but is torn open with both microforceps. This procedure is safer to prevent damage to the structures beyond the membrane. In actual clinical use, ventriculostomy with extended microforceps was performed with the insertion cylinder placed in the upper side of the lateral ventricle, because the foramen of Monro was only 8 mm in diameter. This procedure was achieved without decreasing the maneuverability and without any complications. We consider that biopsy using NeuRobot is also safer because this system can coagulate and divide at the same time using both the KTP laser and microforceps. As each instrument in the NeuRobot system, such as forceps and coagulator, need not be exchanged through the cylinder, unexpected bleeding can be controlled immediately.

Ventricular enlargement is necessary for manipulation in the ventricular space not only for the conventional neuroendoscope but also for NeuRobot.[1,5,7] The interthalamic adhesion was partly injured when conducting biopsy of the thalamus in the cadaveric study. This procedure was simulated for pineal or thalamic tumor biopsy. The third ventricle space in this cadaver was not large enough for this procedure. Thus, this procedure is recommended in cases with ventricular enlargement. For clinical use, the size of the third ventricle is measured preoperatively.

The maneuverability of the current NeuRobot system is limited by the large insertion cylinder and lack of movement. The 10-mm diameter of the insertion cylinder necessitates a larger corticotomy to reach the ventricle and larger ventricular size for manipulation than for a conventional neuroendoscope. Therefore, size reduction must be considered to improve NeuRobot. The rigid insertion cylinder does not allow the insertion angle to be changed once the cylinder enters the ventricle. The micromanipulator has only four degrees of freedom. If NeuRobot can be improved by inclusion of a flexible endoscopic system and six degrees of freedom of micromanipulator, this will allow more sophisticated procedures to be performed. In the present study, NeuRobot could be used to perform surgical procedures similar to conventional neuroendoscopic procedures but with enhanced safety and greater maneuverability. The NeuRobot system will extend surgical indications for intraventricular lesions that cannot be treated using a conventional neuroendoscope.

CONCLUSIONS

NeuRobot was used for intraventricular procedures in cadaver heads and applied in a patient with obstructive hydrocephalus. Our results confirmed that NeuRobot can be used to perform neuroendoscopic procedures more precisely and safely in the ventricle. The NeuRobot system can be used to perform sophisticated surgical procedures through a narrow space of only 10 mm in diameter. This characteristic of NeuRobot will allow it to be used in the treatment of deep-seated lesions, such as those in the ventricular space.

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FIGURE LEGENDS

Left: Photograph of the micromanipulator system. The slave unit is on the right side, and the three-dimensional monitor and central console are on the left side. Center: Tip of the insertion cylinder. The insertion cylinder, 10 mm in diameter and 17 cm in length, installs a 3D rigid endoscope 4 mm in diameter, and three channels for micromanipulator insertion. The micromanipulators are mounted in the three channels, and move in the endoscopic field with three degrees of freedom. Three microforceps are mounted through the three micromanipulators. Right: Insertion cylinder advanced into the ventricle of a cadaver via a burr hole.

Fig. 2 Photographs of the third ventriculostomy. a) Blunt perforation using a pair of microforceps. b) Pinching the bilateral edges of the perforated hole using two pairs of microforceps. c) Enlargement of the hole by rotation of each forceps. d) Further fenestration. Arrow: The basilar artery observed through the window.

Fig. 3 Photographs of each procedure. Left: Septostomy in the water field. Right: biopsy of the thalamus. Arrow: Interthalamic adhesion injury. Arrowhead: Aqueduct.

Fig. 4 Photographs of biopsy of the choroid plexus. Left: Air bubbles induced by exposure to the KTP laser. Right: Microforceps on the right holding the specimen and the KTP laser in the center cutting the tissue.

Fig. 5 a. Axial CT scan showing hydrocephalus. b. MRI with contrast medium showing aqueductal stenosis and venous angioma in the midbrain. c. Postoperative CT scan showing no hemorrhage with the ventricle size unchanged. Photographs of the third ventriculostomy: d. NeuRobot set through the right frontal burr hole. e. Actual clinical operation and fenestration of the floor of the third ventricle with the tear-open procedure.

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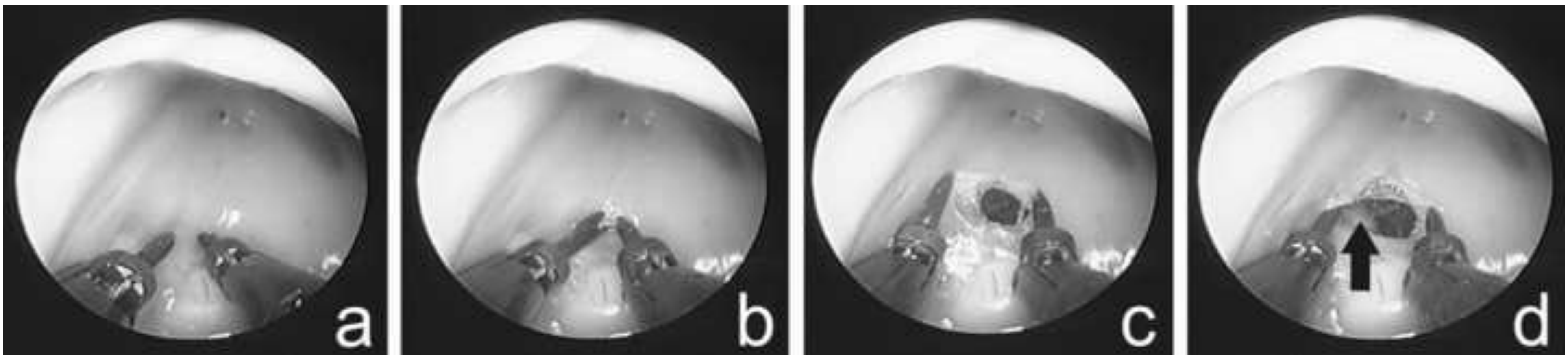

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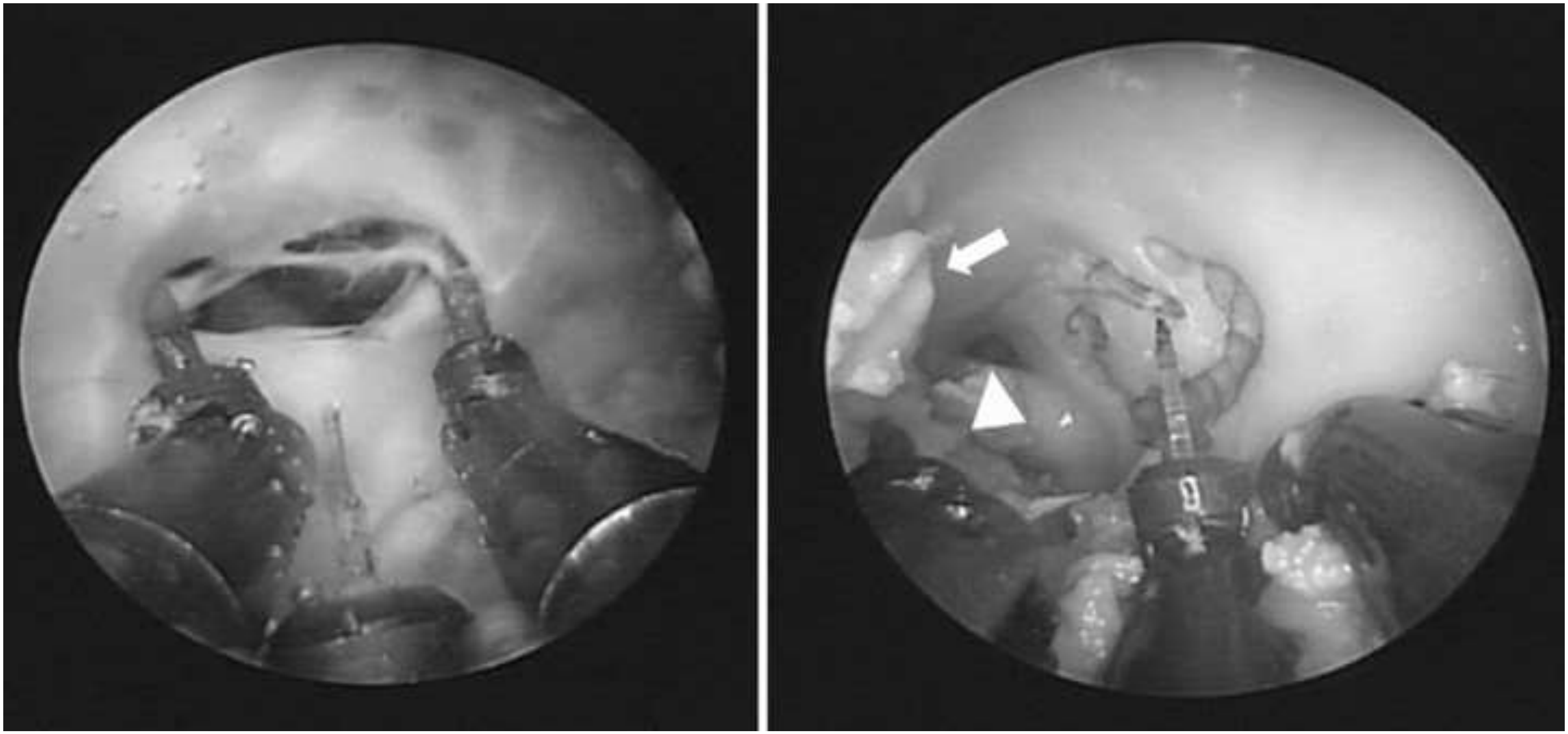

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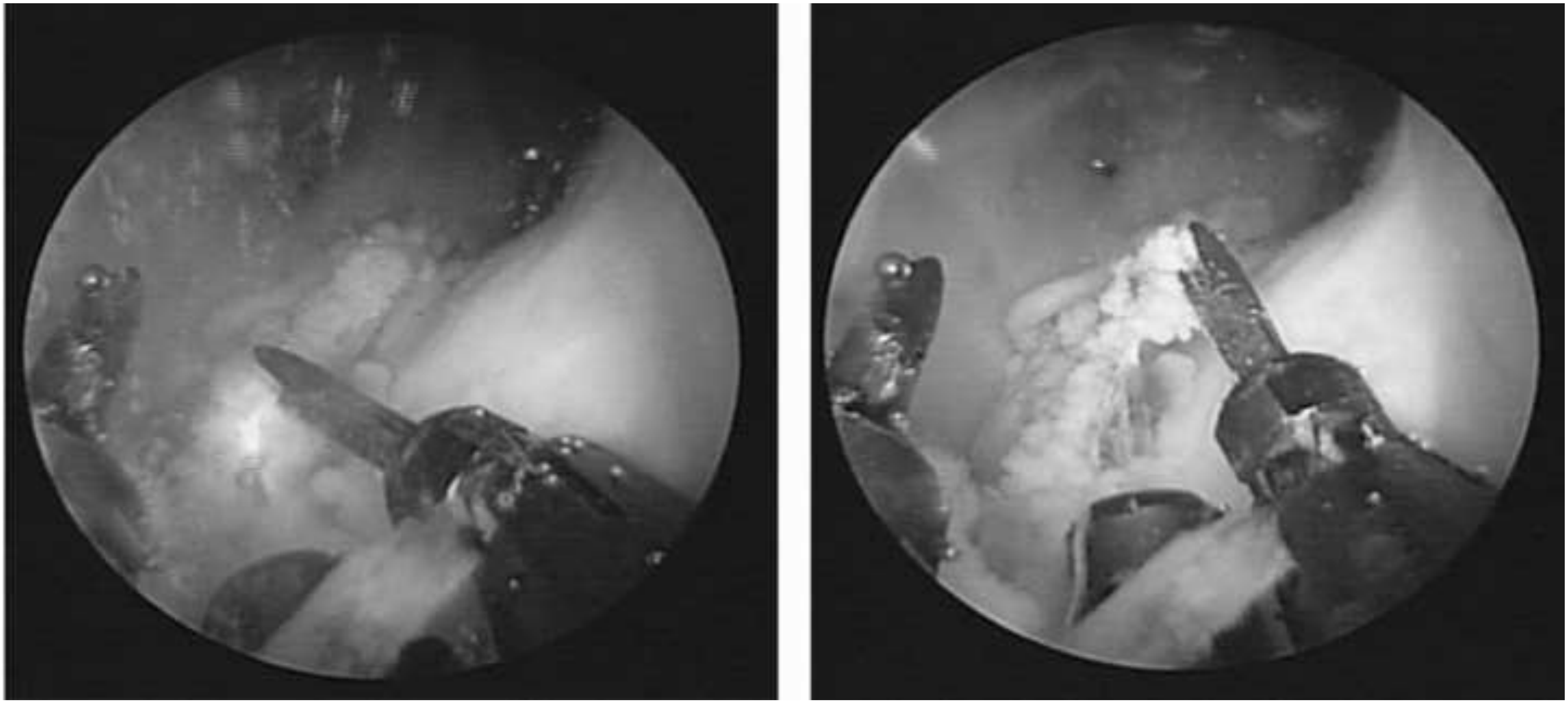

Figure 5

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