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Transnasal endoscopic piezoelectric surgery for repair of choanal atresia

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Abstract

The main function of the nose is respiration. The mucosa of the nasal cavity and the para-nasal sinuses carries out the necessary conditioning of inhaled air by warming and moistening it. Birth without breath is the precise description of choanal atresia. The diagnosis and management of it need the combined efforts of both the pediatrician and E.N.T. surgeon. Surgical treatment is one of the challenging endeavors within the realm of pediatric otolaryngology. The symptoms depend on whether the condition is unilateral or bilateral, those with bilateral disease present early with life-threatening respiratory difficulty, whereas those with unilateral atresia may present in childhood or young adulthood with unilateral nasal obstruction. Possible complications of the transnasal approach include pressure necrosis of anterior nares or columella, plugging, displacement of the indwelling stents, cerebrospinal fluid leaks, meningitis and granulation tissues around the stents. Piezoelectricity is the appearance of an electrical potential (a voltage) across the sides of a crystal when you subject it to mechanical stress (by squeezing it). In ultrasound equipment a piezoelectric transducer converts electrical energy into mechanical vibrations. These ultrasound vibrations can be used for scanning and cleaning.

Keywords: Transnasal Endoscopic Piezoelectric Surgery, Choanal Atresia, Mitomycin C.

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1. Introduction

Choanal Atresia is complete obliteration of the posterior nasal aperture which may be congenital or acquired with incidence of approximately 1 in 5000–7000 live births. It is more often unilateral than bilateral (60% vs 40%) and more frequently in females than in males (ratio 2:1) [1]. Symptoms of choanal atresia depend on the side of atresia whether unilateral or bilateral. Since a newborn child is an obligate nasal breather, respiratory distress occurs in patients with bilateral choanal atresia at or shortly after birth [2]. Once the atresia is surgically corrected, the surgeon is faced with the problem of restenosis. Re-stenosis is a problem because of the small dimensions of the atretic area and usually starts from the lateral and cranial borders of the new nasal opening or develops from excessive granulation tissue. The rates vary widely and range from 0% to 85 [3].

Acoustic rhinometry can be used for the diagnosis, but is especially helpful in the postoperative period to follow up patients for restenosis [4]. The aim of this work was to evaluate the safety, easiness and efficacy of trans-nasal endoscopic piezoelectric assisted surgery in repair of unilateral bony or bony membranous choanal atresia as regards; removal of the bony atretic plate, preservation of muco-periosteal flap and soft tissues of the nose, maintaining a blood-free operating area and, minimizing the postoperative complications as granulation tissue formation and restenosis.

1.1 Anatomy of the Nose

The human nose is the most protruding part of the face. It is the first organ of the respiratory system and the main organ in the olfactory system. It represents the middle one third of the face [5].Its shape is determined by the nasal bones and the cartilages, including the nasal septum which separates the nostrils and divides the nose into two cavities. The nose of a male is larger than that of a female [6].

1.2 Nasal Development

Neural crest cells migrate to form the mesenchymal tissue of the pharyngeal arches. By the end of the fourth week, the first pair of pharyngeal arches form five facial prominences as unpaired frontonasal process, paired mandibular processes and paired maxillary processes [7]. The nose is formed by fusion of five facial prominences. The frontonasal process gives rise to the bridge of the nose. The medial nasal processes provide the tip and the lateral nasal processes form the alae or sides of the nose. The frontonasal process is a proliferation of mesenchyme making up the upper border of the stomodeum [8].

1.3 1Bones of the Nose

Palatine bones make up the floor of the nose and form the posterior nasal spine for the attachment of the musculus uvulae. The nasal part of the frontal bone lies between the brow ridges and ends in a serrated nasal notch. The notch articulates at the front with the paired nasal bones at the sides with the small lacrimal bones and with the frontal process of each maxilla [9].

1.4 Cartilages of the Nose

The cartilages are the septal, lateral, major alar and minor alar cartilages. The major and minor cartilages are also known as the greater and lesser alar cartilages [10].The septal cartilage extends from the nasal bones in the midline to the bony part of the septum in the midline posteriorly. It then passes along the floor of the nasal cavity [9].

1.5 Internal Nose

1.5.1 Cavities

The nasal cavity is divided into two cavities known as fossae. This division enables the functioning of the nasal cycle that slows down the air conditioning process. Other nasal cavities are the four paired paranasal sinuses [7].

1.5.2 Lateral Walls

The lateral wall of each cavity has three shell like bones called conchae as superior, middle and inferior conchae. They are also known as turbinates. Below each concha is a corresponding superior, middle and inferior nasal meatus [11].

1.5.3 Roof of Cavity

The roof of the cavity is composed of the horizontal perforated cribriform plate of the ethmoid bone through which pass fibers of the olfactory nerve. There is an area of olfactory mucosa in the roof of the cavity. This region is about 5 square cm covering the superior concha and the cribriform plate [12].

1.5.4 Choanae

At the back of the nasal cavity there are two openings called choanae. The choanae are also called the posterior nostrils and give entrance to the nasopharynx and rest of the respiratory tract [9].

1.5.5 Blood Supply of the Nose

The nose is supplied by branches of both the internal and the external carotid artery. The main branches from the internal carotid are the anterior ethmoidal artery and the posterior ethmoidal artery that supplies the septum and these derive from the ophthalmic artery [13].

1.6 Pathogenesis of Choanal Atresia

Historically 90% of atresia have been described as bony, while the remaining 10% are membranous. Recent literature suggests that mixed membranous-bony atresia are more common up to 70% of the cases of the time [14] There are three distinct forms of CA: bony, membranous or mixed bony-membranous atresia.

1.7 Etiology

Four theories to explain the etiology of the atretic plate have been accepted over the years: Persistence of the buccopharyngeal membrane from the foregut, Abnormal persistence or location of mesoderm forming adhesions in the nasochoanal region, Abnormal persistence of the nasobuccal membrane of Hochstetter and Misdirection of neural crest cell migration with subsequent mesodermal flow [15].

1.8 Diagnosis of Choanal Atresia

1.8.1 Symptoms

Generally, newborns prefer to breathe through their nose. Typically, infants only breathe through their mouths when they cry. Babies with choanal atresia have difficulty breathing unless they are crying [14]. Congenital atresia can be associated with other malformations in 41% to 72% of the cases. Bilateral atresias are frequently associated with disorders of the maxillofacial structures. They have been described as part of the alterations in syndromes (Down's, Treacher Collins and Apert syndromes) and Crouzon's disease [16].Bilateral atresia is an emergency situation showing signs as: Chest retracts unless the child is breathing through mouth or crying, difficulty breathing and respiratory distress following birth resulting in cyanosis. Inability to nurse and breathe at same time. Inability to pass a catheter through each side of the nose into the throat [17]. Patients with unilateral choanal atresia rarely present with immediate or severe airway obstruction. They normally present within the first 18 months of life with feeding difficulties and nasal discharge, but may present with unilateral nasal obstruction and discharge in later life [18].

1.8.2 Signs and diagnostic tests

The diagnosis of this condition should be done immediately after birth. The simplest method is to pass a soft red rubber catheter (no. 6 to 8 French catheter) or 2.6 mm feeding tube through the nose into the nasopharynx. A typical solid feeling will be felt at the level of the posterior choana approximately 3-3.5 cm from the alar rim [6]. Patients may be examined with a rigid or flexible endoscope, operating microscope, mirror examinations or digital examination. The use of flexible fiberoptic endoscope is the preferable method of choice after proper preparation of the nose by nasal decongestion and mucous suctioning allowing visualization of the nasal passage and the nasal patency can be assessed [19]. Retro-palatal endoscopic examination of the nose allows visualization of the choanal atresia and rules out other pathologies of the posterior nasal cavity [20].

1.9 Investigations

A traditional method of diagnosis is radiography using radiopaque contrast material instilled into the nasal cavity with the patient in a supine position [15]. Computed tomography (CT), especially axial plane, is the radiographic procedure of choice as it can demonstrate the nature, position and thickness of the obstructing segment, which helps the surgeon in designing a plan for repair and other abnormalities, such as dermoids, encephalocele, gliomas and anterior skull base defect can be excluded [5]. An axial non contrasts high resolution CT scan with thin sections

(2-5mm) has become the single radiographic study of choice. The knowledge obtained from the CT scan is valuable in the preoperative planning of the method and design of the repair [18].The "Delta Area" is diagnostic of choanal atresia. This Delta widening is best seen on a coronal section of a CT scan where the posterior septal edge widens out into a triangular shape [14].

1.10Management of Choanal Atresia

Surgical treatment is one of the challenging endeavors within the realm of pediatric otolaryngology. The symptoms depend on whether the condition is unilateral or bilateral, those with bilateral disease present early with life-threatening respiratory difficulty, whereas those with unilateral atresia may present in childhood or young adulthood with unilateral nasal obstruction [13]. There are numerous methods for correcting this condition, but the current most commonly used methods are the trans-palatal approach, the trans-septal approach and the endoscopic trans-nasal approach [22].

1.11 Management of Bilateral Atresia

Immediate management of bilateral atresia involves training the infant to breathe through the mouth with the aid of an indwelling oral appliance such as a McGovern nipple or an oropharyngeal airway. A McGovern nipple is an ordinary nipple with a single enlarged hole and can be used for gavage feeding. It is secured with ties or tape around the ears [22]. The infant can be fed and the airway is protected while definitive management is delayed to rule out other anomalies. Endotracheal intubation is usually unnecessary unless the infant requires mechanical ventilation. If there is severe respiratory distress, an emergency tracheostomy should be performed [6].

1.12 Management of unilateral atresia

Unilateral atresia is rarely emergent. The repair is generally delayed for at least 1 year, which allows the operative site to enlarge and reduces the risk of postoperative stenosis, unless there are feeding difficulties. Repair of atresia can be performed any time after the airway has been secured [23]. The main advantage of the trans-nasal procedure is minimally invasive, quick, less traumatic with minimal blood loss, provides excellent visualization and the ability to perform exact surgery on patients of all ages [24]. Disadvantage of trans-nasal procedure is limited field of vision even with a microscope, especially in newborn infants or a case with deviated nasal septum, large turbinates, or small size of the nasal cavity. Inability to adequately remove enough vomerine septal bone to prevent restenosis. Also, creation and maintenance of the flaps can be very difficult [22].

1.13 Transnasal Puncture Technique

The surgeon introduces hegar’s dilators through the nasal passage along the floor of the nasal cavity until reaching the choana. A puncture through the atresia is performed. Serial dilation using hegar’s dilators of various sizes until a large size dilator can go through [24].A 3.5 endotracheal tube is used as a stent in a U-shaped fashion with both ends coming through anterior nares or two size 3.5 endotracheal tubes are used one in each side and tied together anteriorly using a sub-labial suture for fixation to avoid columellar pressure. The stents are removed six weeks later [22].

1.14 Endoscopic Trans-Nasal Technique

The procedure is performed under general anesthesia and the airway is prior controlled by endotracheal intubation or rarely tracheostomy. For transnasal approach, the most precise techniques can be done under an operating microscope or telescope [13]. The use of vasoconstrictor drops and nasal suction provide a good view of anterior nares. The mucosa over the anterior face of the atretic area, posterior portion of the septum and lateral nasal wall are injected with a solution of lidocaine with diluted epinephrine under direct visualization [16].

1.15 Trans-palatal Technique

The palate is exposed and injected with lidocaine with epinephrine. Then a curved or vertical incision is made in the soft and hard palatal mucosa to expose hard palatal bone and the soft palatine muscle. The curved incision starts behind the maxillary tuberosity on one side and is carried medially to the alveolar ridge to the canine region. The same incision is performed on the other side to create U-shaped palatal flap [5]. The mucoperiosteal flaps are elevated posteriorly to the edge of the hard palate with care to preserve the neurovascular bundle from the greater palatine foramen. The soft palate is retracted posteriorly and superiorly to expose the posterior edge of the hard palate and t1he nasopharynx [26].

1.16 Trans-nasal Mucosal Flap Rotation Technique

Adequate exposure of the posterior nasal cavity is challenging so a special effort must be done. The patient is placed in the supine position and intubated with an endo tracheal tube. After draping with a "mastoid drape" the head is positioned with the face rotated 45 degrees to the right facing the surgeon [4].For nasal surgery in older children and adults, a Baron number 7 suction tip with a Pilling fiberoptic light on the side enhances lighting in the deeper portions of the operative field and a Pilling nasal suction cautery is available if necessary for hemostasis [27].The posterior choana is bounded inferiorly by the nasal floor, laterally by the lateral nasal wall, medially by the septum and superiorly by the sphenoid rostrum. An "I" shaped incision is made in the mucosa lining the atresia on the nasal side, but the resulting mucosal flaps are usually too small to cover a significant area of exposed bone surface [28]. A laterally based "C" incision is made starting infromedially and going laterally adjacent to the floor of the nose with a C02 laser. The parallel top incision is made 4 to 6 mm higher [29].

1.17 Stents

Stenting is needed to maintain the patency of the lumen and hold the flaps in place. A No 3.5 or 4 endotracheal tube cut to the appropriate length and shape is commonly used as a stent since it is available in the operating room, easily shaped and trimmed. A 3 to 4 mm section of the middle part of the tube is removed to allow non traumatic positioning across the columella [30].

1.18 Mitomycin C

Topical Mitomycin C can be used as an adjuvant therapy post operatively to prolong nasal patency by preventing scar tissue growth. It was associated with less formation of granulation tissue, less restenosis and fewer surgeries [22]. Mitomycin is an aminoglycoside antibiotic made by the fungus Streptomyces casepitosus. It acts by inhibiting DNA synthesis and breaking DNA strands. It has been long used as an antineoplastic agent. Because of its inhibitory effect on the fibroblast proliferation and migration, it is successfully used to maintain trabecular patency in glaucoma surgeries and preventing scarring and maintain patency [16].

1.19 Other Approaches of Choanal Atresia

1.19.1 Trans-septal Approach

The important aspect of this technique is the resection of the vomer and the anterior shifting of its posterior portion. Resection of the third posterior portion of the vomer creating as such one unified posterior nasal space, along with the removal of part of the medial pterygoid process is crucial for maintaining choanal patency in the long term [31].

1.19.2 Trans-antral Approach

This approach requires the maxillary sinus to be well developed which is not in younger children and even in some adults as this sinus can be hypoplastic causing difficulty in accessing the choana [25].

1.19.3 Recent Trials in Repair of Choanal Atresia

The aim of the surgical treatment of choanal atresia is to achieve permanent functional patency with a minimal trauma and complications in a one-step surgery [19].

1.20 Endoscopic Trans-Septal with a Stentless Folded over Flap Technique

The technique for correction of the atresia is performed according to the following steps: step: 1 Unilateral resection of the mucosa in the back portion of the septum and at the homolateral atretic nasal face up to their border with the pterygoid apophasis and also to the height of the nasal floor up to the level of lower edge of the middle turbinate [17].

1.21 Endoscopic Repair with the Use of Balloon Dilation

Nasal endoscopy and CT scan are done to confirm the presence of atresia and define the anatomic characteristics of the malformation of the nasal cavities, the nature of the atretic plate and possible other anomalies [33].

1.22 Surgical Technique

Surgery is done under general anaesthesia with oral tracheal ventilatory intubation. Inspection of the nasal cavities is done using a 0° endoscope with diameters from 2.7 to 4 mm [4]. The catheters are applied in each nasal cavity for 20 seconds after being floated with saline solution to 10-12 atmospheres by also positioning Hegar dilators of the fit caliber in the other cavity in order to avoid possible misplacement while carrying out the operation [34]. No stent is applied and no nasal packing is necessary to control hemorrhage. Parents are instructed to perform several daily nasal irrigations during the postsurgical period and topical inhalation of mometasone furoate once daily with 0.05 mg for each cavity with nasal spray [33].

1.23 Trans-nasal Repair with the KTP Laser

The advantage of the KTP laser is its wavelength which enables the surgeon to cut the membranous and bony regions of the choanal atresia with simultaneous hemostasis [35]. Under endoscopic control, the resection of the atresia or stenosis is extended to the intraluminal diameter of a reconstructed choana to guarantee a free nasal passage [36].

1.23.1 Stent

For newborns and small infants the stent size is about 4 mm. For these patients, the stent required a reserve in length for growth and had to be carefully placed to avoid trauma to the tissues of the nose, particularly the septum and columella [6].

1.24 Contact Diode Laser Repair Technique

The nasal mucosa is decongested with 1/1000 oxymetazoline solution. Laser energy is delivered using a handpiece mounted 600 mm diameter flexible glass optical fiber [37]. Laser settings are 5 W power continuous mode. Endoscopic exposure is achieved using 08 and 308, 1.7 mm diameter ultrathin telescopes with an attached 22-gauge suction tube to evacuate the smoke plume [5]. All cases treated with fiber delivered CDL showed successful results as intraoperative blood loss was minimal and no complications were noted [26].

1.25 Piezoelectricity

1.25.1 Discovery and Early Research

The first demonstration of the direct piezoelectric effect was in 1880 by the brothers Pierre and Jacques Curie. They combined their knowledge of pyroelectricity with their understanding of the underlying crystal structures that gave rise to pyroelectricity to predict crystal behavior and demonstrated the effect using crystals of tourmaline, quartz, topaz, cane sugar and Rochelle salt. Quartz and Rochelle salts exhibited the most piezoelectricity [38].

1.25.2 World War I and Post War

The first practical application for piezoelectric devices was sonar, first developed during World War I. In 1917, Paul Langevin and his coworkers developed an ultrasonic submarine detector. The detector consisted of a transducer made of thin quartz crystals carefully glued between two steel plates and a hydrophone to detect the returned echo [39].

1.25.3 What is Piezoelectricity?

Squeeze certain crystals and you can make electricity flow through them. The reverse is usually true as well, if you pass electricity through the same crystals, they "squeeze themselves" by vibrating back and forth, that is piezoelectricity [40]. Piezoelectricity is the electric charge that accumulates in certain solid materials (such as crystals, certain ceramics, biological matter such as bone, DNA and various proteins) in response to applied mechanical stress [41].

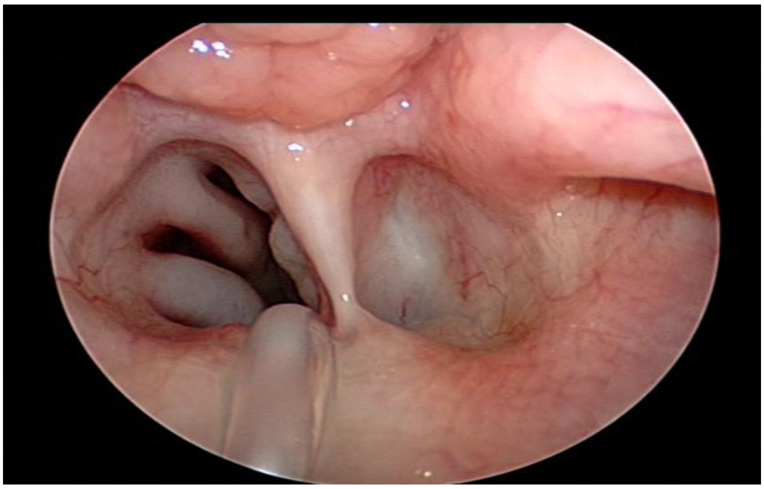

Figure 1: Retro-palatal endoscopic view showing unilateral choanal atresia [21].

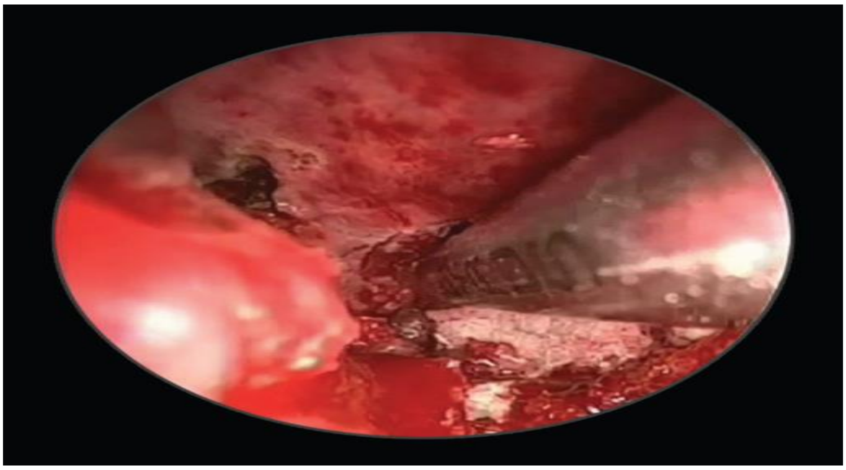

Figure (2): Elimination of choanal atretic plate using a micro-drill [25].

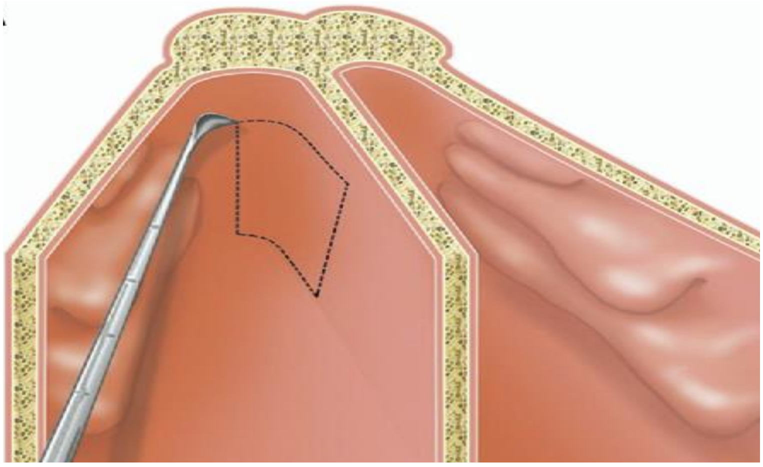

Figure 3: Unilateral resection of the mucosa in the back portion of the septum [17].

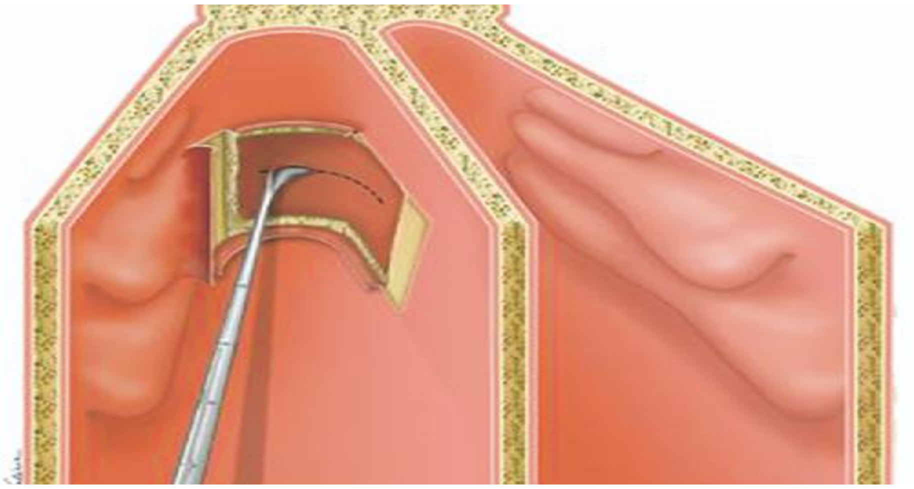

Figure 4: Removal of third posterior portion of the vomer and the bony atretic plates [32].

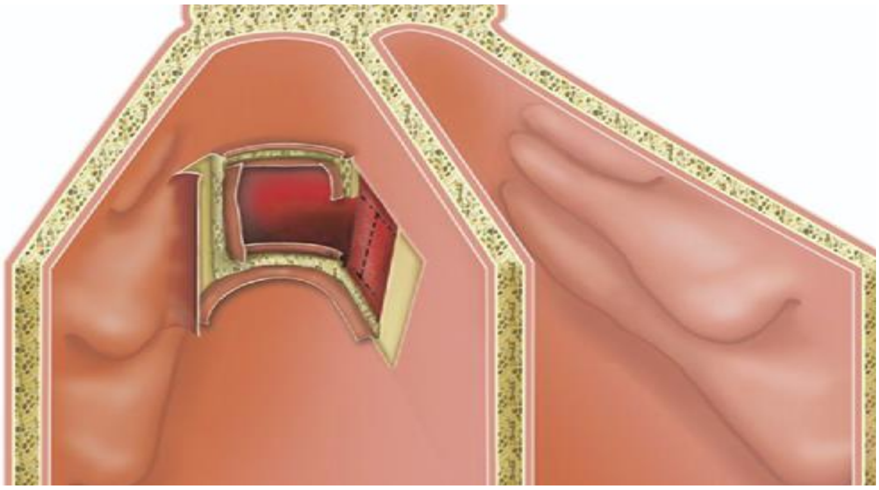

Figure 5: Fashioning of the flaps from the preserved mucosa [1].

1.25.4 Mechanism of Action

The nature of the piezoelectric effect is closely related to the occurrence of electric dipole moments in solids. The latter may either be induced for ions on crystal lattice sites with asymmetric charge surroundings or may directly be carried by molecular groups [42]. The importance for the piezoelectric effect is the change of polarization P when applying a mechanical stress. This might either be caused by a reconfiguration of the dipole inducing surrounding or by re-orientation of molecular dipole moments under the influence of the external stress [43].

1.25.5 What is Piezoelectricity Used for?

All kinds of situations where we need to convert mechanical energy into electrical signals or vice-versa. We can do that with a piezoelectric transducer. A transducer is a device that converts small amounts of energy from one kind into another as converting light, sound or mechanical pressure into electrical signals [44].

1.25.5.1 Device Structure

The device consists of 1) Nanowires, 2) Nano rods, 3) Nanotubes: Nanotube-based PENGs are also well known for powering miniaturized autonomous systems, 4) Nanoparticles and 5) Thin films [45].

1.25.5.2 Biomedical Application

Many PENGs have been used in various medical applications, such as neural systems, stem cell differentiation and the circulatory system [46].

1.25.5.3 Pacemakers

Cardiac pacemakers (CPMs) are small devices that use electrical pulses to regulate heartbeats and stimulate the heart muscles. CPMs have helped patients with sick sinus syndrome [42].

1.25.5.4 Blood Pressure Sensors

An implantable blood pressure sensor could be used for diagnosing disease and evaluating drug efficacy. A self-powered blood pressure sensor is beneficial because it could avoid energy depletion problems [40].

1.25. 5.5 Cardiac Sensors

PENGs have been used to both supply electricity for CPM and as energy autonomous cardiac sensors (CSs). These sensors are implanted inside the body to report heart beat conditions [44]. Soft tissue sparing is one of the advantages of piezoelectric surgery. Piezoelectric surgery is a valuable tool that can improve the performance of endoscopic trans-nasal surgery with direct visual assessment of any bony lesions of the nose [45].

In bilateral cases, the mucosa is removed from the contralateral atretic nasal face, at the same level. Step: 2, Removal of third posterior portion of the vomer and the bony atretic plates, preserving the mucosa of the pharyngeal face of the atresia and of the septum [19]. Step:3, Fashioning of the flaps from the preserved mucosa step: 4, Folding of the flaps over the raw bony areas and fixing them with fibrin glue, which is applied to the raw surfaces using a syringe with a long needle [1].

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