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# Morphological and Histological Effects of Radiofrequency and Laser (KTP and Nd:YAG) Treatment of the Inferior Turbinates in Animals: A Comparative Pilot Study

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**Abstract**
The aim of this study was to evaluate the short and medium-term effects of radiofrequency (RF) and potassium titanyl phosphate (KTP) and neodymium-yttrium-aluminum garnet (Nd:YAG) laser treatment on the inferior turbinate mucosa in a porcine model. Following randomization, the inferior turbinates were treated either with RF submucosally or with the KTP or the Nd:YAG laser on the surface under videoendoscopic control. Tissue samples were taken at the end of postoperative weeks 1 and 6, and were evaluated macroscopically and histopathologically. Scanning electron microscopy was implemented to demonstrate the morphological changes in the respiratory epithelium. Six weeks following the RF procedure, the mucosa was intact in all cases, and the volume of the inferior turbinates was reduced in the majority of the cases. Although a volume reduction occurred in both laser groups, more complications associated with the healing procedure were noted. With hematoxylin and eosin and periodic acid–Schiff staining, intact epithelium, and submucosal glands remained after the RF procedures at the end of postoperative week 6. Following the KTP-laser intervention, necrotizing sialometaplasia and cartilage destruction occurred, and squamous metaplasia was also apparent in the Nd:YAG group. In both laser groups, dilated glands with excess mucus were seen. The scanning electron microscopic findings demonstrated that cilia were present in all cases. In conclusion, the medium-term macroscopic results were similar in all 3 groups, but the postoperative complications were less following the RF procedure. RF procedure is minimally invasive due to the submucosal intervention that leads to a painless, function preserving recovery.

**Keywords**
animal nasal turbinate, histopathology, potassium titanyl phosphate (KTP) laser, neodymium-yttrium-aluminum garnet (Nd:YAG) laser, radiofrequency (RF), scanning electron microscopy (SEM)

## Introduction

Besides septal deviation, hypertrophic inferior turbinates are the other most frequent causes of nasal obstruction.[1] With reference to Scheithauer's classification, lateropositioning, resectioning, and coagulating procedures can be performed on inferior turbinates.[2] If conservative therapy fails to relieve a nasal blockage, functional surgical intervention may be considered as an alternative. The aim of such procedures is to preserve the humidification and cleaning function of the mucosa, thereby reducing the nasal airway resistance. The various methods of surgical turbinate reduction include submucosal diathermia, electrocoagulation of the turbinate mucosa, cryotherapy, argon plasma coagulation, radiofrequency (RF) therapy, and laser surgical procedures.[3-7] Several comprehensive studies have described the histological benefits following various procedures.[8-10] On average, RF instruments generate no more than 75°C in the submucosal layers, inducing thermonecrosis.[11] As a consequence of the high

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amount of energy released during the application of potassium titanyl phosphate (KTP) and neodymium-yttrium-aluminum garnet (Nd:YAG) laser procedures, microvessel occlusion or vasculitis may be induced, with a reduction of the volume of the turbinates as a result of wound healing.[12,13]

The aim of this study was to evaluate the short- and medium-term effects of RF and of KTP and Nd:YAG laser treatment on the histology of the inferior turbinate mucosa in an animal model.

To the best of our knowledge, no other study has reported comparative morphological and histological effects on the inferior turbinate in the short- and mid-term postoperative period in an animal model following the application of RF or KTP or Nd:YAG laser also with comparative examinations by scanning electron microscopy (SEM).

## Materials and Methods

A porcine model was chosen for this study in view of the histological resemblance of porcine ciliated respiratory cells to human respiratory cells.[14]

Twelve Duroc pigs with an average weight of 19.25 kg (range 16-21 kg) were studied. All experiments were implemented in full accordance with the rules and regulations regarding the use of animals in medical research. The study was approved by the Ethics Committee on Animal Research of the University of Pécs under protocol number BA02/2000-1/2004.

All the 12 animals were allowed to acclimate for 1 week prior to surgery. They were provided with pig chow and water ad libitum during the acclimation period and throughout the study, with the exception that they were not allowed to eat or drink for 12 hours prior to surgery, and were not fed for 24 hours postoperatively. Pigs were monitored daily for general (eg, fever, amount of chow and water consumed, insomnia) and nasal intervention–related adverse events (nasal bleeding, nasal discharge).

All the pigs were anesthetized for induction and intubation with 1.5 mL of ketamine hydrochloride, including a premedication cocktail consisting of azaperonum (160 mg), ketamine (125 mg), diazepam (10 mg), and atropine sulfate (1 mg). Endotracheal intubation was followed by the maintenance of anesthesia with 0.5% halothane.

The inferior turbinates were randomly treated either with RF device or with a KTP or Nd:YAG laser under videoendoscopic control (Table 1). With the randomization 2 different procedures were compared in each animal (intraindividual examination). Table 1 demonstrates, that among 12 pigs 4 groups (control, RF, KTP, Nd:YAG) were created containing 6 inferior turbinates in each group.

**Table 1.** Randomization of the animals according to the treatment on the right and left inferior nasal turbinate.

| No. | Right Side | Left Side |
|---|---|---|
| 1 | Control | RF |
| 2 | Control | KTP |
| 3 | Control | Nd:YAG |
| 4 | RF | Control |
| 5 | RF | KTP |
| 6 | RF | Nd:YAG |
| 7 | KTP | Control |
| 8 | KTP | RF |
| 9 | KTP | Nd:YAG |
| 10 | Nd:YAG | Control |
| 11 | Nd:YAG | RF |
| 12 | Nd:YAG | KTP |

Tissue samples were taken at the end of postoperative weeks 1 and 6. The narrow passageway of the nasal cavity of the piglets necessitated endoscopy with a 2.7 (outer diameter) × 106 mm otoscope (Karl Storz GmbH & Co, Tuttlingen, Germany).

Prior to the surgical treatment, the nasal mucosa was anesthetized with tetracain-naphasolin solution.

In the RF group, turbinate reduction was achieved with a Surgitron 4.0 MHz Dual Frequency RF device (Ellman International, Oceanside, NY, USA) with a power setting of 20 W for 15 seconds in the COAG mode. The bayonette turbinate electrode was inserted submucosally at the anterior pole of the turbinate.

In both laser groups, the laser beam was applied to the surface from the posterior to the anterior part of the inferior turbinate at 10 W for 15 seconds in CONTACT mode (LaserScope Orion, Santa Clara, CA, USA).

Before and after all procedures, the anatomy of the nasal cavity was assessed in all 3 groups following decongestion of the nasal mucosa, and was compared with the nasal anatomy of the control group (Figure 1A and B).

Biopsies were taken under short-term general and topical anesthesia at the end of postoperative weeks 1 and 6. Nasal forceps were utilized under endoscopic control to acquire larger tissue samples.

Macroscopic changes (mucosal swelling, fibrin deposition, ulceration, hematoma, necrosis, crusting, etc) were examined endoscopically and documented with photos and video records. By the help of a scoring system the anatomical state, the presence of a wound, the turgidity of the inferior turbinates, bleeding, the quality of the nasal secretion and the presence of synechia were assessed for evaluation of the results of the macroscopic findings (Table 2).

Tissue samples were evaluated pathologically from the view of necrosis, remodeling, and other histological changes. SEM (JSM 6300 Scanning Microscope, JEOL,

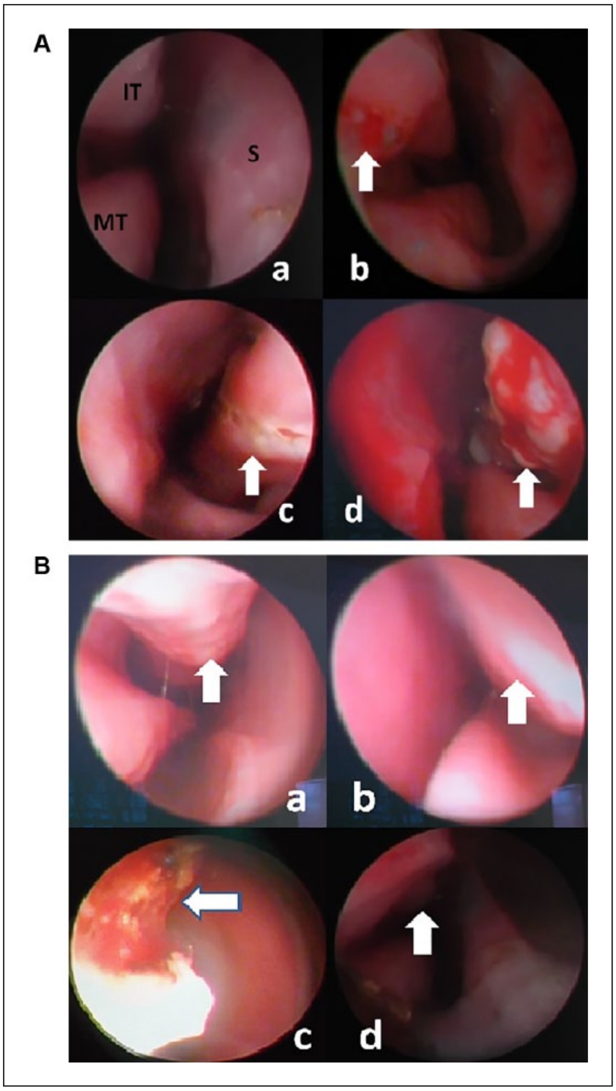


**Figure 1.** (A) Macroscopic changes at the end of postoperative week 1: (a) Control group (piglet in supine position. S, septum; IT, inferior turbinate; MT, middle turbinate. (b) Radiofrequency (RF) group (arrow: point of insertion of the RF electrode). (c) KTP laser group (arrow: thin fibrin along the inferior turbinate). (d) Nd:YAG laser group (arrow: thick fibrin along the inferior turbinate). (B) Macroscopic changes at the end of postoperative week 6: (a) RF group (arrow: reduced inferior turbinate). (b) KTP laser group (arrow: swollen inferior turbinate). (c) Nd:YAG laser group (arrow: riffle with crust). (d) Nd:YAG laser group (arrow: reduced, but deformed inferior turbinate).

Tokyo, Japan) was implemented to demonstrate variations in the respiratory epithelium.

## *Histopathological Investigations*

All tissue samples were routinely fixed in 4% formaldehyde solution and submitted for histology. The histopathologist carrying out the evaluation had no prior information concerning the treatment of the samples. The specimens were embedded in paraffin. Histological sections were cut and mounted on glass slides, stained with hematoxylin and eosin (HE) or periodic acid–Schiff (PAS) and evaluated light microscopically as regards wound healing and mucosal function.

HE staining was used to identify the changes in the structure of the turbinates following the different surgical procedures, including necrosis, fibrin deposition, cartilage defects, morphological changes in the layers of the ciliary epithelium, including metaplastic signs, and the quantification of foreign body giant cells, polymorphonuclear and mononuclear reactive cells and neoformed vessels.

PAS staining was used to quantify the goblet cells, which correlated well with the function or dysfunction of the nasal respiratory epithelium.

**Table 2.** Scoring system: the degree of the lesion (0, 1, 2) depending on the macroscopic findings.

| | 0 | 1 | 2 |
|---|---|---|---|
| Anatomy | Normal | Minimal changes | Pathological |
| Crust formation | No | Fibrin | Crust |
| Turbinate | Intact | Swollen | Atrophic |
| Bleeding | No | Coagulum | Active bleeding |
| Secretion | No | Serous | Purulent |
| Synechia | No | Turbinate-septum | Turbinate-turbinate |

## *Scanning Electron Microscopy*

After fixing in a mixture of 2% formaldehyde and 2.5% glutaraldehyde solution for 24 hours, the samples were carefully washed 3 times in a phosphate buffer (pH 7.4), and dehydrated with increasing concentrations of alcohol (finally with absolute alcohol for 20 minutes). They were then mounted on the worksheet, coated with fine gold, and analyzed by SEM. The surfaces of the samples were photographed in order to view the laser-treated tissue, including its ablation and coagulation zones, and cross-sections of the samples were investigated to reveal the effects of treatment on the deeper tissue layers.

# Results

## *Macroscopic Findings at Postoperative Week 1 and Postoperative Week 6*

*In the RF group*, at the end of postoperative week 1 (Table 3), the turbinates generally presented a normal epithelium, except at the points of insertion of the RF electrodes: in 2 such cases smooth fibrin was observed, and in

**Table 3.** Macroscopic findings at the postoperative week 6 (0-2 according to the scoring system) (No: serial number of the animals).

| | Right Inferior Turbinate/No. | Anatomy | Crust Formation | Turbinate | Bleeding | Secretion | Synechia | Left Inferior turbinate/No. | Anatomy | Crust formation | Turbinate | Bleeding | Secretion | Synechia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Control | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 1 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| RF | 5 | 0 | 1 (thin fibrin) | 0 | 0 | 0 | 0 | 8 | 0 | 1 (thin fibrin) | 0 | 0 | 0 | 0 |
| | 6 | 1 | 2 | 1 | 0 | 0 | 0 | 11 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 7 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| KTP | 8 | 1 | 1 (thin fibrin) | 1 | 0 | 0 | 0 | 5 | 0 | 2 | 1 | 0 | 0 | 0 |
| | 9 | 0 | 1 (thick fibrin) | 1 | 0 | 0 | 0 | 12 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 1 | 0 | 0 | 0 |
| Nd:YAG | 11 | 0 | 1 (thick fibrin) | 1 | 0 | 0 | 0 | 6 | 0 | 1 (thick fibrin) | 1 | 0 | 0 | 0 |
| | 12 | 0 | 2 | 1 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 |

1 case a slight crust. In 2 instances, the turbinates were somewhat swollen, but there was no apparent bleeding, synechia or pathological discharge (Figure 1Ab). At the end of postoperative week 6 (Table 4), the epithelium of all the turbinates appeared to be intact; in 1 case it was swollen, but in the remaining cases the volume was considerably reduced (Figure 1Ba).

*In the KTP laser group*, at the end of postoperative week 1 (Table 3), a thin fibrin deposit was seen along the inferior turbinates in 2 cases (Figure 1Ac) and a dense crust in 1 case. Four of the inferior turbinates were swollen. At the end of postoperative week 6 (Table 4), the turbinates were damaged, and crust-covered in 2 cases, and 1 was swollen (Figure 1Bb), but 5 were diminished.

*In the Nd:YAG laser group*, a thick fibrin deposit was observed along the inferior turbinates in 2 cases (Figure 1Ad) and there was a thick crust in an additional 2 cases at the end of postoperative week 1 (Table 3). Four turbinates were markedly swollen. At the end of postoperative week 6 (Table 4), all the turbinates were damaged, to various degrees, including extreme riffling and shrinkage of the soft tissue, and in 1 case (Figure 1Bc, 1Bd) synechia was apparent.

## Microscopic Findings

Light microscopy of the HE- and PAS-stained control sections revealed a situation corresponding to the human conditions from 1 to 6 weeks following treatment, and the normal histological conditions were subsequently compared with the microscopic changes following the various treatments (Table 5). The histological analysis indicates possible changes in the epithelium, the lamina propria, the submucosa and, if present, the bone or cartilage.

As a result of the RF treatment, HE-stained sections with an intact epithelium, a focal torn stratum, intact glands, and an intact cartilaginous skeleton were observed at the end of postoperative week 1 (Figure 2Aa). No further histological changes were detected at the end of postoperative week 6, apart from minimal submucosal chronic inflammation (Figure 2Ba).

At the end of postoperative week 1, the KTP laser caused a moderate focal thickening of the epithelium, granulocyte penetration, submucosal scar tissue deposition, and dilated blood vessels, and broadening of the perichondrium of the nasal turbinate cartilage (Figure 2Ab). At the end of postoperative week 6, remarkable necrotizing sialometaplasia in the lamina propria, cystic dilated glands with excess mucus production and a widened perichondrium with cartilage destruction were also observed (Figure 2Bb).

At the end of postoperative week 1, an intact epithelium, dilated blood vessels, granulocyte infiltration, and submucosal sialometaplasia were detected after Nd:YAG laser treatment. Interestingly, the cartilage remained intact (Figure 2Ac). At the end of postoperative week 6, squamous metaplasia, including a moderate widening of the epithelium, was seen in the lamina propria, and submucosal dilated blood vessels, dilated glands, and excess mucus were also observed. Following the treatment, the cartilage remained intact (Figure 2Bc).

As noted in connection with the previously detailed histological image, the PAS-stained sections exhibited similar histological states in the RF-treated group and the control group: In most cases, intact states with normal glandular functions were observed. Both the KTP and the Nd:YAG laser treatment worsened both the status and the function of the submucosal glands.

## Scanning Electron Microscopy Findings

The surface of the RF-treated inferior turbinate was similar to that in the control group at the end of postoperative week 1 (Figure 3Ab). After postoperative week 6, the cells were shallower than in the control group, but the cilia were not damaged (Figure 3Ba, 3Bc).

In both the KTP and the Nd:YAG groups, the ablation zone was surrounded by a coagulation area at the end of postoperative week 1 (Figure 3Aa). Additionally, the destruction of the superficial respiratory epithelium was observed.

After postoperative week 6, the attachments between the cells were unrestrained, but the cilia were intact in the KTP group (Figure 3Bb). Interestingly, distinct polygonal-like squamous cells were observed in the Nd:YAG group (Figure 3Bd).

# Discussion

A recent review by Ting and Bing[15] illustrates the ongoing controversy relating to the optimal surgical technique for a hypertrophic inferior turbinate mucosa. Among the laser surgery procedures, $CO_2$ and Nd:YAG lasers are the types most frequently applied, though Ho:YAG, diode and KTP lasers may also be considered. It has been suggested that RF ablation may improve the nasal resistance, the sense of smell, and the nasal mucociliary function.[15]

The RF energy causes fibrosis of the underlying stroma due to submucosal coagulative necrosis, leaving the epithelium intact. Following wound healing, submucosal scar formation and retraction of the tissue, reduction and stiffening of the turbinate evolve. In the course of time, partial resorption of the scar tissue results in a further volume reduction.[16]

The KTP laser emits light at 532 nm (ie, green light), which is absorbed by hemoglobin, resulting in consecutive protein denaturation, endothelium impairment, and microvessel occlusion. As a result, selective coagulation of the surface mucosal vessels is possible to a depth of

**Table 4.** Macroscopic findings at the postoperative week 6 (0-2 according to the scoring system) (No: serial number of the animals).

| | Right Inferior Turbinate/No. | Anatomy | Crust Formation | Turbinate | Bleeding | Secretion | Synechia | Left Inferior Turbinate/ No. | Anatomy | Crust Formation | Turbinate | Bleeding | Secretion | Synechia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 0 | 2 | 0 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 1 | 0 |
| Control | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 7 | 1 | 0 | 0 | 0 | 1 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 10 | 1 | 0 | 1 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 2 | 0 | 1 | 0 |
| RF | 5 | 0 | 0 | 2 | 0 | 1 | 0 | 8 | 0 | 0 | 2 | 0 | 1 | 0 |
| | 6 | 0 | 0 | 2 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 7 | 1 | 0 | 2 | 0 | 1 | 0 | 2 | 0 | 0 | 2 | 0 | 1 | 0 |
| KTP | 8 | 1 | 1 | 1 | 0 | 1 | 0 | 5 | 2 | 2 | 2 | 0 | 1 | 0 |
| | 9 | 2 | 0 | 2 | 0 | 1 | 0 | 12 | 1 | 0 | 2 | 0 | 0 | 0 |
| | 10 | 1 | 0 | 1 | 0 | 1 | 0 | 3 | 1 | 0 | 1 | 0 | 1 | 0 |
| Nd:YAG | 11 | 2 | 0 | 2 | 0 | 1 | 0 | 6 | 2 | 2 | 2 | 0 | 1 | 1 |
| | 12 | 1 | 0 | 0 | 0 | 0 | 0 | 9 | 1 | 0 | 2 | 0 | 1 | 0 |

**Table 5.** Microscopic findings at the postoperative weeks 1 and 6 with the histological lesions in the epithelium, lamina propria, submucosa and perichondrium.

| | Epithelium | Lamina Propria | Submucosa | Perichondrium |
|---|---|---|---|---|
| Postoperative week 1 | | | | |
| RF | Intact | Torn stratum, minimum granulocyte infiltration | Intact glands | Intact |
| KTP | Moderate focal thickening | Granulocyte penetration | Granulation tissue, dilated blood vessels | Broadening of perichondrium |
| Nd:YAG | Intact | Granulocyte and lymphocyte infiltration | *Sialometaplasia*, dilated blood vessels | Intact |
| Postoperative week 6 | | | | |
| RF | Intact | minimal chronic inflammation | Intact glands | Intact |
| KTP | Moderate thickening | *Necrotizing sialometaplasia*, chronic inflammation | Cystic dilated glands with excess mucus | *Widened perichondrium with cartilage destruction* |
| Nd:YAG | *Squamous metaplasia*, moderate widening of epithelium | Chronic inflammation | Dilated blood vessels and glands with excess mucus | Intact |

up to 0.5 mm.[2] The Nd:YAG laser produces light at 1064 nm, that is, in the near-infrared (invisible) range. Characteristically, due to the strong backward and forward scattering, thermal coagulation and necrosis may extend up to 4 mm deep and laterally over the surface, making precise control impossible. The KTP crystal gives double the frequency (half the wavelength) of the Nd:YAG laser. The applied laser instrument provides the possibility of varying the wavelength from 1064 nm (Nd:YAG) to 532 nm (KTP laser), with a resulting change in tissue absorbance of the laser beam.[17]

Our extensive clinical experience with RF and KTP and Nd:YAG lasers led us to conduct a comparative histological pilot study of the potential effects of RF and KTP and Nd:YAG laser treatments on the inferior turbinate mucosa in an animal model.

The in vitro examinations of porcine and human ciliated cells by Stennert et al[14] demonstrated that the respiratory mucosa in pigs and humans reacts similarly to the same drugs, and the porcine respiratory mucosa can therefore serve as an ideal tissue for the investigation of different noxious substances. Studies have also been published on other animals (dogs, rabbits, and sheep) as concerns the histopathological effects of RF, lasers, diathermy and ultrasound on the nasal turbinates.[18-21]

Scheithauer[2] divides interventions involving the inferior turbinate into 3 groups: lateropositioning, resectioning, and coagulating procedures, this latter group appearing to be the current trend.

In the present short- and medium-term follow-up investigations, the macroscopic and histologic changes were compared following RF or KTP or Nd:YAG laser procedures in a porcine model.

In the human study by Sapçi et al,[22] the macroscopic and functional changes were compared 12 weeks following RF or $CO_2$ laser ablation of the turbinates and partial turbinectomy. In several cases, a slight crust was observed on the laser-ablated inferior turbinate, but not in the RF-treated group. A slight, transitional swelling appeared in the RF group on postoperative day 1 and 2.[22] No synechia evolved in either the laser or the RF group, in contrast with our findings on the Nd:YAG group, in which synechia occurred in 1 case. The study by Sapçi et al[22] demonstrated that RF ablation is effective in improving nasal obstruction and in preserving an effective nasal mucociliary function. Laser ablation is effective in improving the nasal passageway, but it significantly disturbs the mucociliary transport. The results following partial turbinectomy were similar to those with the RF technique.[22]

Zborayová et al[18] compared the histopathological changes and the healing process in porcine turbinates treated submucosally with a diode-laser fiber or RF in a short-term study. They reported that the histopathological changes were more severe 8 days following laser surgery, including intensive tissue damage and less pronounced regenerative and reparative changes. In RF specimens, features of re-epithelialization were detected, and the necrotizing sialometaplasia was less marked.[18] Interestingly, our findings at the end of postoperative week 1 in each of the RF, and KTP and Nd:YAG laser groups correlate with the results of Zborayová et al.[18]

In a prospective, nonrandomized, case-control study, Garzaro et al[23] compared the histopathological and physiological changes 6 months following RF treatment of the inferior turbinates and partial inferior turbinectomy (PIT). Their examinations demonstrated minimal subepithelial fibrosis and focal squamous metaplasia, with no difference in the superficial morphology within the RF group. Following supraperiosteal resection of the mucosa, diffuse squamous cell metaplasia including the loss of

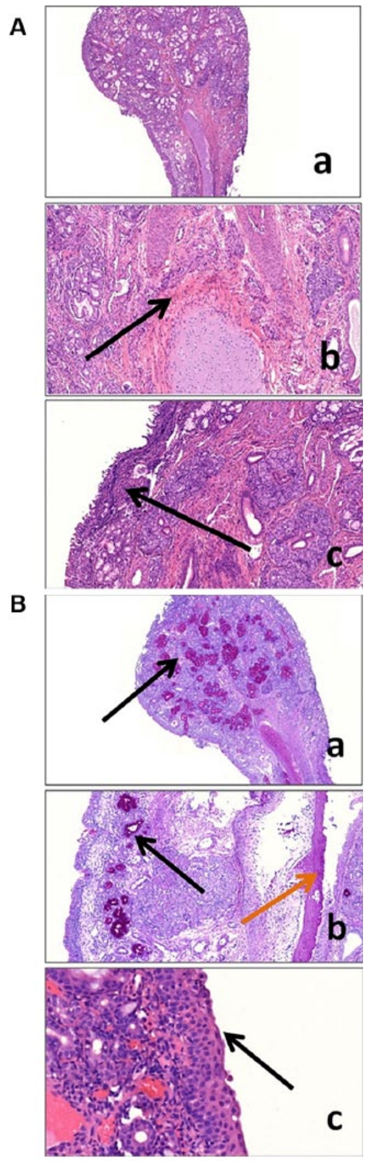


**Figure 2.** (A) Microscopic changes at the end of postoperative week 1: (a) Radiofrequency (RF) group (intact epithelium and cartilage (hematoxylin and eosin [HE]). (b) KTP laser group (arrow: broadened perichondrium, HE). (c) Nd:YAG laser group (arrow: granulocyte infiltration, HE). (B) Microscopic changes at the end of postoperative week 6. (a) RF group (arrow: intact glands, periodic acid–Schiff [PAS]). (b) KTP laser group (black arrow: necrotizing sialometaplasia, red arrow: cartilage damage, PAS). (c) Nd:YAG laser group (arrow: squamous metaplasia, HE).

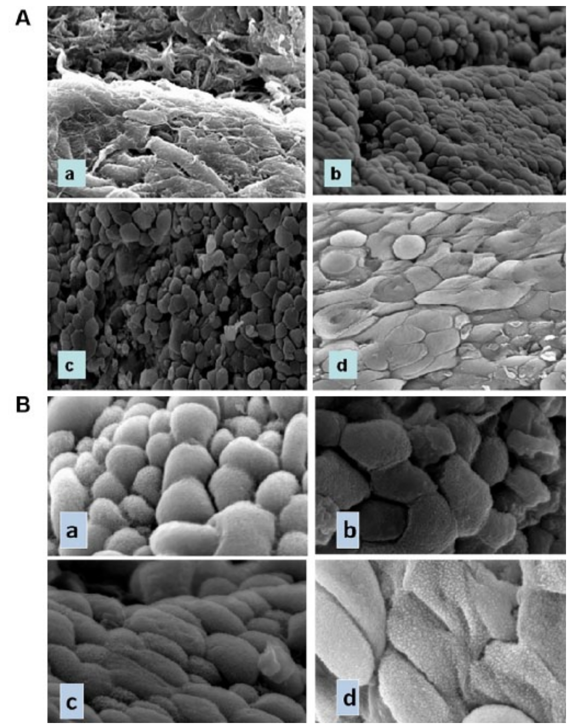


**Figure 3A.** (A) Scanning electron microscopy (SEM) findings. (a) Laser effect (at the end of postoperative week 1): ablation zone is surrounded by a coagulation zone (2000×). (b) RF group (at the end of postoperative week 6): shallower cells with a structurally normal surface (1000×) (dotted surface). (c) KTP laser group (at the end of postoperative week 6): loose attachments between cells (1000×); cilia are intact (dotted surface). (d) Nd:YAG group (at the end of postoperative week 6): polygonal, like squamous cells (focal metaplasia) (1000×). (B) SEM findings at the end of postoperative week 6. At a magnification of 6000× it is seen that, despite the morphological changes, cilia are present in all 4 groups (dotted surface): (a) control, (b) KTP laser group, (c) RF group, (d) Nd:YAG laser group.

epithelial cilia and intensive fibroblast invasion appeared. This resulted in a slight improvement of the mucociliary transport time within the RF group, but a significantly longer duration in the PIT group.[23] It was noteworthy that at the end of postoperative week 6 we did not identify any focal metaplasia within the RF group, whereas focal metaplasia was seen in the Nd:YAG group, which may also prolong the time of mucociliary transport.

Their SEM findings led Janda et al[10] to distinguish 2 groups following the application of 5 different laser types in in vitro turbinate ablation. Nd:YAG, diode and argon ion lasers are characterized by high coagulation capabilities and severe destruction of the epithelium, while $CO_2$ and Ho:YAG lasers display less coagulation capabilities and more precise ablation and vaporization.[10] Our Nd:YAG findings correlate with the results in the study by Janda et al.[10]

As a disadvantage of the use of the Nd:YAG laser, Lippert and Werner[24] report on crust formation with an increased risk of synechia formation. Synechia also developed in 1 case in our Nd:YAG group. Scheithauer[2] concluded that, since the recovery time is similar to that in conventional surgical procedures, which may extend to several months, the Nd:YAG laser procedure no longer appears appropriate. One disadvantage of the KTP laser, that was mentioned by Scheithauer, in accordance with the findings of other authors, is the postoperative obstruction of the nose by mucosal edema and fibrin exudation which lasts for weeks, a situation that we also observed.[2,25,26] Functional examinations have demonstrated that, with the loss of the natural structure of the epithelium, the mucociliary transport time becomes longer following laser treatment as compared with RF treatment of the turbinates.[22]

## Conclusion

Our SEM findings showed the development of cilia at the end of postoperative week 6 in all 3 groups, yet the shape of the cells was changed. These changes most probably do not impair the function of the cells. At the end of the postoperative week 1, marked signs of damage were observed in both laser groups, with potential crust or synechia formation; however, with an increase of control, this can be prevented. The medium-term results at the end of postoperative week 6 were similar histologically in all 3 groups, but the burden on the patient in the postoperative period was less after the RF procedure. This is most likely to be due to the submucosal use of the electrode, as no crust or synechia formation occurs, and hence the patient less often experiences discomfort. RF devices are easier to manipulate. Laser instruments are almost twice as much expensive than RF instruments. For the application of laser equipment, several additional protective accessories (eg, laser intubation tube, protecting surgical mask and eyeglasses, smoke aspirator, etc) are needed. For this reason, the costs of the laser intervention are more expensive than that of the RF procedure.

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### Author Contributions

Study concept and design: Krisztina Somogyvári
Acquisition of data: Krisztina Somogyvári, Péter Móricz and István Szanyi
Analysis and interpretation: Krisztina Somogyvári (macroscopic and SEM findings) and László Kereskai (microscopic findings)
Study supervision: Ildikó Takács and Imre Gerlinger

### Declaration of Conflicting Interests

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