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State-of-the-art biomaterials in the nasal cavity: hemostats and spacers following sinus surgery

K.-S. CHO [1], A. E. ZAJAC [2], A. R. RASHAN [3], P. H. HWANG [3], J. V. NAYAK [3]

[1]*Department of Otorhinolaryngology and Biomedical Research Institute Pusan National University School of Medicine Busan, South Korea*
[2]*Rosalind Franklin University of Medicine and Science North Chicago, IL, USA*
[3]*Department of Otolaryngology-Head and Neck Surgery Stanford University School of Medicine Stanford, CA, USA*

The aim of this paper to review recent advances in biomaterials used as hemostats and spacers in the nose and to differentiate their effects on hemostasis, prevention of adhesions, and wound healing by evaluating their respective properties. Selective review of literature from query of multiple disparate database sources. Articles were selected for their relevance to the effects of biomaterials in the nose on hemostasis, prevention of synechiae/adhesions, and wound healing. Biomaterials have been extensively researched for many years, particularly in their modulation of wound healing, tissue regeneration, and drug delivery. When evaluating the suitability of various biomaterials following sinonasal surgery, their influence on wound healing should be given particular attention. The choice of biomaterials for packing or hemostasis will naturally be dependent on the preferences and experience of the surgeon, and the particular intraoperative findings and details of each patient scenario. When biomaterials are used following sinus surgery, judicious application of biomaterials in the nasal cavity may reduce the incidence of early postoperative bleeding and formation of synechiae/adhesions, and possibly promote healing of mucosa.

KEY WORDS: Hemostasis - Biocompatible materials - Endoscopy.

Postoperative patient care after functional endoscopic sinus surgery (FESS) is essential to minimize discomfort for the patient in the short term and to optimize long term surgical outcomes. After proper execution of FESS, one of the first steps along this path is the decision regarding which, if any, packing/spacer material should be placed in the nose. Postoperative nasal packing or spacers may be used to prevent early adhesion formation between adjacent tissues, avoid lateralization of the middle turbinate (MT), control potential postoperative bleeding, and possibly to enhance wound healing (Table I).[1-4] However, there remains disagreement on the use of nasal packing after FESS, with literature that both advises against,[5, 6] and advocates for [7, 8] the use of nasal packing.

Although typically effective, nasal packing can increase patient discomfort in the perioperative pe-

Corresponding author: J. V. Nayak, MD, PhD, 801 Welch Road, Stanford, CA 94305, USA. E-mail: jnayak@ohns.stanford.edu

TABLE I.—*Goals of nasal packing after sinonasal surgery – summary.*

Control of possible postoperative bleeding
Prevention of adhesions and synechiae
Internal stabilization of cartilaginous-bony skeleton
Prevention of lateralization of middle turbinate
Improvement of postoperative wound healing
Maintenance of patency of the paranasal sinuses
Prevention of septal hematoma formation
Support of septal flap apposition

riod. There are a number of complications, mundane to severe, that have been attributed to use of non-absorbable nasal spacers. These may include mucosal injury with or without creation of septal perforation (presumably from pressure ischemia), pack dislodgement and aspiration, obstructive sleep apnea secondary to nasal obstruction, Eustachian tube dysfunction, infection, toxic shock syndrome, foreign body granuloma formation, and myospherulosis.[3, 14, 15] Non-Absorbable packing materials may also cause significant bleeding [9, 10] or mucosal injury with loss of ciliary function upon removal.[11] In some instances, the removal of nasal packing has been described as one of the more uncomfortable and even distressing features linked with sinonasal surgery.[2, 12, 13]

Because of these associated risks and concerns, the avoidance of packing placement after FESS has been successfully implemented by many practitioners after sinonasal surgery. No packing may have some advantages, including decreased discomfort, lessened chance of postoperative complication associated with packing, and cost savings.[5, 6] However, even with meticulous nasal preparation and surgical technique, FESS without packing may still be associated with some postop bleeding that may increase patient anxiety. Even though most postoperative bleeding is usually inconsequential, ongoing low-grade bleeding from the surgical cavity may lead to gastric irritation and emesis from ingested blood products. These issues can be a potential source of significant anxiety for both physician and patient, and may negatively impact the patient's overall sense of 'healthy recovery'.[16]

In recognition of this ongoing debate, various absorbable biomaterials have been introduced to overcome the disadvantages of non-absorbable nasal packing. Absorbable biomaterials do not require subsequent removal in the post-operative office setting, giving the patient increased comfort while still having positive effects on hemostasis, MT support, and in some cases, wound healing.[8] These sundry biomaterials differ significantly in their composition, physical forms, methods of delivery, mechanisms of action, clearance profiles and cost.[17] This article analyzes the available literature on the types of biomaterials used as hemostats or spacers in the nose. By evaluating and comparing their respective properties, we aim to differentiate their effects on hemostasis, prevention of adhesions, and wound healing

Methods

The literature search used the Medical Subject Heading (MeSH) and Unified Medical Language System (UMLS) of the National Library of Medicine (NLM) for the period of 1951 to 2012. The keywords were "biocompatible materials", "nasal packing", "hemostasis", "adhesion", "spacers", "stents", "wound healing", "endoscopic sinus surgery", "septoplasty", "turbinate surgery", "morbidity", and "complications". The initial search yielded 100 publications for review, of which 79 were referenced herein as they pertained to commonly available, currently manufactured biomaterials in the sinonasal cavity for middle turbinate spacing and hemostasis.

The search was performed in the database of the National Center for Biotechnology Information (NCBI), the Lane Medical Library of Stanford University, Science Direct, Scopus, Current Contents Medicine (CC-Med), Pubmed, and SciSearch. The literature search concentrated on the type of biomaterials in the nose, their effectiveness as hemostats and spacers, and their impact on postoperative wound healing.

Results and discussion

Biomaterials have been researched extensively for years, particularly their modulation of wound healing, tissue regeneration, and drug delivery. There are numerous biomaterials that have been used as topical treatments for the postoperative sinonasal cavity, broadly divided into non-absorbable and absorbable biomaterials.

Non-absorbable biomaterials

Although non-absorbable biomaterials are not the primary focus of this review, a brief mention of these products is included for completeness. The use of non-absorbable nasal packing was first described in the 1950s,[18] and since then there have been a variety of products marketed for their benefits following sinonasal surgery. Non-absorbable biomaterials are utilized not only to control mucosal bleeding from recently-operated nasal mucosal surfaces through direct pressure, but also to act as a physical barrier to the formation of adhesions between de-epithelialized mucosal surfaces.

Some of the available non-absorbable products under this heading include Vaseline-soaked ribbon gauze (Lohmann Corp; Hebron, KY), Rhinotamp (Vostra; Aachen, Germany), Merocel (Medtronic; Jacksonville, FL), Rapid Rhino (Arthrocare; Knaresborough, UK), Doyle Nasal Splint (Medtronic Xomed; Jacksonville, FL) (Figure 1A), Silastic Sheet (Dow Corning; Midland, MI), and Doyle Spacer Splints (Summit Medical; St. Paul, MN) (Figure 1B). Non-Absorbable biomaterials are summarized in Table II.

Non-absorbable biomaterials have three primary drawbacks: 1) the pressure of the pack or trauma of packing removal has been hypothesized to damage the ciliated nasal surface; 2) due to their relative immobility, non-absorbable packing can be uncomfortable for patients immediately following surgery; 3) removal of the pack material can be highly unpleasant for the patient. Despite the many advantages of non-absorbable spacers, the aforementioned problems have led to the ongoing development and application of absorbable biomaterials since their inception in 1969.[19-41]

Absorbable biomaterials as hemostats

Biomaterials under this heading span a wide range of biophysical properties, from those that provide hemostasis through direct pressure, to others that have hemostatic properties, delivered as gels or suspensions. Some biomaterials provide dual activities in both hemostasis and stenting the middle turbinate during the postoperative period. Although a number of resorbable biomaterials are available, few have been tested in head-to-head comparison trials, and some have even failed to exhibit any benefit over the absence of packing. The most commonly used absorbable biomaterials providing hemostasis in sinonasal surgery are summarized in Table III.

Polymer-based products

Nasopore (Polyganics, Inc, Groningen, NL) (Figure 1E) is a fully synthetic, biodegradable, inert polyurethane polymer that comes packaged as a pliable, compressible sponge. Nasopore absorbs local fluids in the surgical bed, and provides gentle pressure to adjacent tissues while spacing tissues from each other to prevent scarring. According to the manufacturer, the product becomes fragmented in 4-6 days, but in practice, Nasopore converts to a low integrity paste or slurry that is usually present 7-14 days postoperatively in the nasal cavity. With regard to hemostasis, Shoman *et al.* reported that Nasopore did not significantly reduce the risk of bleeding or patient discomfort compared to Merocel.[42] Another group has shown evidence that Nasopore was not superior to Vaseline gauze or Merocel in its effect on the formation of synechiae, granulation tissue, and prevention of postoperative bleeding.[43] However

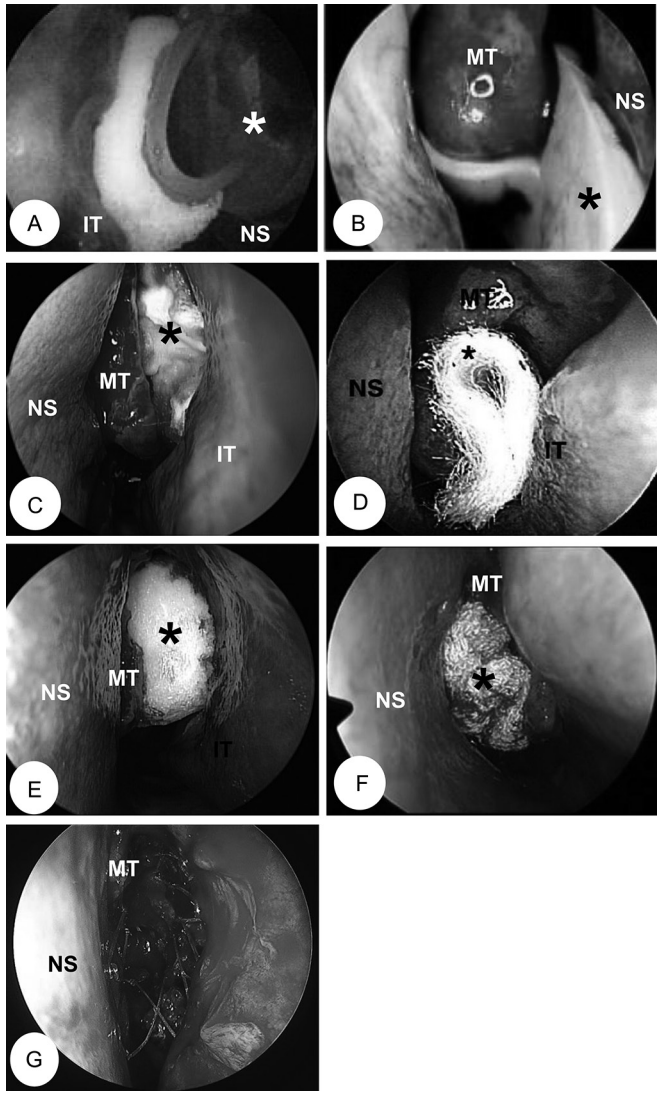

Figure 1.—*In situ* endoscopic image of biomaterials A. Doyle Nasal Splint; B. Doyle Spacer Splint; C. Gelfoam; D. Merogel; E. Nasopore; F. Sinu-Knit; G. Propel Stent.
IT: inferior turbinate; MT: middle turbinate; NS: nasal septum; *biomaterial

TABLE II.—*Non-absorbable biomaterials.*

Trade name	Company	Composition	Hemostasis	Stenting of MT	Pain on removal	Bleeding after removal	Relative cost*
Gauze	Lohmann Corp	Cotton gauze + Vaseline	+++	+++	++	++	$
Rhinotamp	Vostra	Latex rubber + foam	+++	+++	+	+	$
Merocel	Medtronic	Polyvinyl acetate	+++	+++	+++	+++	$
Rapid Rhino	Arthrocare	Inflatable cuff + CMC	+++	+++	+	+	$
Silicone-based products							
DNS	Medtronic	Silicone	+	N/A	+	+	$
SS	Dow Corning	Silicone	+	+++	+	+	$
DSS	Summit Medical	Silicone	+	+++	+	+	$

CMC: carboxymethylcellulose, Gauze: Vaseline-soaked ribbon gauze, DNS: Doyle Nasal Splint, SS: silastic sheet, DSS: Doyle Spacer Splints
*Median US list price for use in one case (Reported by senior author)
$: 0-50 dollars, $$: 51-250 dollars, $$$: 251-1000 dollars

TABLE III.—*Absorbable biomaterials as hemostats.*

Trade name	Company	Composition	Hemostasis	Stenting of MT	Retention time	Relative cost*
Polymer-based products						
Nasopore	Stryker	Polyurethane	++	+++	4-6 days	$$
Fibrin-based products						
Quixil	Omrix	Human thrombin + fibrinogen	++	+	1-2 weeks	$$$
Platelet Gel	PPAI	Fibrin tissue adhesive	++	+	-	$$$
Gelatin-based products						
Gelfoam	Upjohn	Porcine skin gelatin	++	++	4-6 weeks	$
Floseal	Baxter	Bovine gelatin matrix + thrombin	+++	+	6-8 weeks	$$
Collagen-based products						
Avitene	Davol	Bovine microfibrillar collagen	++	+	8-12 weeks	$$$
Surgiflo	Ethicon	Porcine gelatin + human thrombin	+++	+	6-8 weeks	$$
Polysaccharide-based products						
Surgicel	J&J	Oxidized cellulose polymer	++	+	1-2 weeks	$
Sepragel	Genzyme	HA	+	+	7-10 days	$$
Merogel	Medtronic		+	+		
Sinu-Foam	Arthrocare	CMC	+	+	5-7 days	$$
Sinu-Knit			+	++		
Trade name	Company	Composition	Hemostasis	Stenting of MT	Retention time	Relative cost*
Arista**	Medafor	MPH (potato starch)	+++	+	24-48 hours	$$
Posisep**	Hemostasis	Chitosan	+++	++	-	$$

CMC: carboxymethylcellulose, HA: hyaluronic acid, J&J: Johnson & Johnson, MPH: microporous polysaccharide hemispheres, MT: middle turbinate
*Median US list price for use in one case (Reported by senior author)
$: 0-50 dollars, $$: 51-250 dollars, $$$: 251-1000 dollars

Nasopore impregnated with triamcinolone improved postoperative wound healing up to 6 months,[44] and was comparable to oral steroids in the management of early nasal polyposis after FESS.[45]

FIBRIN-BASED PRODUCTS

Fibrin glue (Quixil, Omrix Co.; Brussels, Belgium) is a combination of human thrombin and fibrinogen mixed with amino acids and salts. It was first used in 1944 to fix human skin grafts.[10] Quixil attaches firmly to tissue, achieving virtually instant hemostasis. Quixil is metabolized naturally within 7-14 days. Quixil has been shown to be more effective than Merocel in controlling perioperative bleeding [10, 20, 21] and has been found to have a similar incidence of adhesion formation.[20]

Platelet Gel (PPAI Medical; Fort Myers, FL) is a

fibrin tissue adhesive produced from the centrifugation of autologous whole blood. Platelet gel differs from fibrin glue in that it contains a higher concentration of platelets and also has fibrinogen factors like platelet-derived growth factor and transforming growth factor. Platelet Gel has been used in many medical disciplines since the 1990s. Pomerantz *et al.* showed no significant difference between Merocel and Platelet Gel, apart from a slight increase in quality of life in the Platelet Gel group.[53] Use of platelet gel notably can be an involved undertaking in the surgical theater, taking about 30 minutes and requiring additional personnel as well as centrifugation of the active ingredients. Therefore, routine use in sinonasal surgery has not been widely implemented.

Gelatin-based products

Commercial gelatin-based hemostatic agents have been used to stop bleeding since 1945,[22] and are available under different names and compositions. Gelfoam (Pharmacia & Upjohn Company; New York, NY) (Figure 1C) and Surgifoam (Ethicon Inc.; Somerville, NJ) are resorbable, water-insoluble, porous, and pliable gelatin sponges obtained from purified pork skin gelatin. Surgifoam can be applied in the form of a powder or paste. Its surface plays a role in the intrinsic coagulation pathway causing contact activation involving platelets.[22] Gelfoam is gradually broken down through both the action of intranasal irrigations, and/or absorbed through phagocytosis within 4-6 weeks. Some human studies suggest that gelatin products may promote the formation of granulation tissue,[23-25] whereas others suggest the opposite.[26]

A newer hemostatic gelatin product is FloSeal (Baxter International Inc; Deerfield, IL), composed of bovine-derived gelatin matrix combined with human-derived thrombin. Although FloSeal was first introduced to the market in 2000 and has been successfully used for promoting rapid hemostasis,[47-49] it also appears to have potential unfavorable effects on wound healing. A significant increase in granulation tissue and adhesion formation has been reported in both short and long term studies in animal models and patients after FESS; FloSeal particles have been shown to be incorporated within the healing mucosa, perhaps inciting a local inflammatory process.[34, 50-52]

Collagen-based products

Avitene (Davol Inc; Warwick, RI) is a microfibrillar collagen derived from bovine skin. Collagen-based hemostats were first introduced in 1970. Avitene is most commonly used in a light powder form that can be made into a slurry/paste in combination with saline, but this biomaterial also exists in a non-woven, web form. Contact of Avitene onto a bleeding surface attracts platelets, which adhere to the collagen fibrils and degranulate to trigger platelet activation. Avitene is frequently used following sinus procedures, but might be avoided for use in closed cavities given reports of its propensity to cause a severe foreign body reaction and adhesion formation.[46]

Another collagen-based hemostatic matrix is Surgiflo (Ethicon Inc.; Somerville, NJ), an absorbable porcine gelatin that is admixed with human thrombin. It is prepared using several provided mixing accessories, and delivered through a syringe along with applicator tips. Surgiflo hemostatic matrix has proven successful in promoting hemostasis after endoscopic sinus surgery (ESS) and has not been shown to increase the incidence of synechiae formation, adhesions, and infection.[27]

Polysaccharide-based products

Oxidized cellulose polymer, such as Surgicel (Johnson & Johnson Medical; Arlington, TX), is a thrombogenic biomaterial that is typically provided as a pliable sheet. The knitted cellulose matrix can be placed directly onto the site of bleeding. Although Surgicel was introduced into clinical practice in 1949, it was first used for epistaxis in 1963,[28] and later in endonasal surgery.[29] The mechanism of hemostasis is related to thrombus formation, which is thought to be a result of the physical matrix-like properties of this material rather than an alteration of the normal clotting mechanism.[30] Surgicel is usually resorbed within 7-14 days, although absorption times may vary depending on the amount of material used, degree of saturation with blood, and condition of the tissue bed.[31] One notable study found Surgicel to be equally effective in achieving hemostasis compared to Vaseline gauze and Merocel non-absorbable spacers.[32] However, to date there has been no published literature on the wound healing properties of Surgicel after sinonasal surgery.

Hyaluronic acid (HA) agents are biodegradable

linear polysaccharides normally found in the extracellular matrix, which in theory will be well accepted by local post-surgical tissue environments. HA can be cross-linked to form water insoluble gels in order to alter its biomechanical properties and increase duration of action.[33] Two products in this category are Sepragel sinus (Genzyme Co.; Cambridge, MA) and Merogel (Medtronic Inc.; Jacksonville, FL). Sepragel is a cross-linked sulfonated-HA material, while Merogel (Figure 1D) is an esterified derivative of HA in the form of a square sheet with a cloth consistency. Once placed in the nasal cavity, these biomaterials expand to form a transparent gel for hemostasis and act to separate mucosal surfaces, until ultimately being resorbed. Remnant undissolved material can be uneventfully suctioned at 7-10 days after application. There is only one trial that has explored the hemostatic efficacy of HA products following ESS, which concluded that there was no significant difference in hemostasis time or volume of bleeding between Sepragel sinus and no hemostatic treatment.[33] Recent studies in both animal and human tissue models have shown conflicting results regarding the efficacy of these biomaterials in wound healing. Merogel was found to cause extensive fibrosis in a rabbit model [34] and also displayed osteogenic potential in a mouse model.[35] In a sheep model of chronic rhinosinusitis, Merogel had no significant effect on adhesion formation and wound healing,[36] although Merogel improved mucosal healing in these normal mucosal surfaces.[37] Sepragel sinus significantly reduced synechiae formation and middle meatal stenosis when compared to no packing.[38] A recent study performed by Berlucchi *et al.* found a significant reduction in adhesions in the Merogel group at 4 and 12 weeks postoperatively, compared to Merocel.[39] However, several previous human studies demonstrated no significant difference in adhesion formation when Merogel was compared with Merocel or no treatment.[8, 40, 41] These differences may be explained by inherent disparities between the animal models used in each experiment and the timing of pack removal.

Carboxymethylcellulose (CMC, ArthroCare; Sunnyvale, CA) was developed in 2001, theorized to promote hemostasis via platelet aggregation. CMC can be applied as CMC-gel (Sinu-Foam) or as moistened CMC-mesh (Sinu-Knit) (Figure 1F). It is reported to dissolve through normal outflow in 5-7 days. Published reports suggest no differences in postoperative bleeding,[54] patient discomfort,[55] or wound healing after ESS between CMC *versus* no packing.[56, 57] Thus, while adverse effects were not observed, no notable advantages to using CMC over no packing were reported. However, triamcinolone-infused CMC foam improved symptoms and endoscopic outcomes at 1 week and 1 month.[58]

Microporous polysaccharide hemispheres (MPH; commercially available as Arista, Medafor Inc.; Minneapolis, MN) are a biodegradable substance derived from potato starch, FDA approved for use in 2005. MPH particles have a diameter of 30 to 100 μm and act as a "molecular sieve" to extract fluids from blood. This action concentrates platelets and other procoagulants that promote the formation of a fibrin clot.[59] MPH is fully absorbed and cleared from the wound site within only 24-48 hours. Application of MPH on wounds in rabbit maxillary sinuses showed no indication of increased fibrosis or foreign body reaction.[60] The use of MPH after ESS results in significantly less bleeding,[61] and does appear to contribute to synechiae formation or negatively alter the normal healing process of postsurgical sinus cavities.[62]

Chitosan is derived from a macromolecule known as chitin, an amino-polysaccharide found in the exoskeleton of crustaceans. Chitosan gel was found to significantly improve hemostasis along with wound healing and reduce adhesion formation in a sheep model of chronic rhinosinusitis.[63, 64] Furthermore, chitosan gel was found to expedite hemostasis and prevent adhesion formation in 40 patients following ESS.[65] PosiSep and PosiSep X (Hemostasis LLC; St. Paul, MN) are the first chitosan-based expandable, resorbable biomaterials commercially available in the United States since 2011. PosiSep converts from a firm sponge to a gelatinous substance shortly after insertion, while PosiSep X expands slightly following placement. No published literature has investigated the hemostatic or wound healing properties of PosiSep and PosiSep X. It is also important to note that multiple isoforms of chitosan exist, and the hemostatic properties of each isoform in the nasal cavity have not been assessed.

Absorbable biomaterials as spacers

The formation of postoperative adhesions is considered to be a leading cause of surgical failure and suboptimal outcomes following sinonasal surgery.

TABLE IV.—*Absorbable biomaterials as spacers.*

Trade name	Company	Composition	Hemostasis	Stenting of MT	Retention time	Relative cost*
Gelfilm	Upjohn	Porcine skin gelatin	++	++	4-6 weeks	$$
Propel**	Intersect ENT	Polymer + MF (Polylactide-co-glycolide)	+	+++	30 days	$$$
MTI**	ENTrigue	Copolymer (L-lactide-co-glycolide)	+	+++	2 weeks	$$
Septal Stapler	ENTrigue	Copolymer (L-lactide-co-glycolide)	+	-	3-6 weeks	$$

MTI: middle turbinate implant
*Median US list price for use in one case (Reported by senior author)
$ 0-50 dollars, $$ 51-250 dollars, $$$ 251-1000 dollars
**Clinical use has been limited to an investigational study

Therefore, the prevention of adhesions of the middle turbinate (MT) to the lateral nasal wall or orbit is often cited as a primary reason to place biomaterials in the nose. Various spacers are currently available to address the problem of controlling MT positioning and preventing adhesions (Table IV).

Gelfilm (Pharmacia & Upjohn Co.; Kalamazoo, Michigan) is an absorbable gelatin sheet processed from porcine skin gelatin. Gelfilm can be rolled into a multilayered stent and placed in the middle meatus to reduce the incidence of adhesions. However, two separate studies have suggested that Gelfilm may lead to the postoperative formation of granulation tissue and subsequent adhesions.[66, 67]

Steroid-eluting sinus implants (Propel, Intersect ENT; Palo Alto, CA) were recently FDA-approved for use.[68] Propel is composed of a biodegradable polymer (polylactide-co-glycolide) fashioned into a lattice pattern, and embedded with 370 μg of mometasone furoate (MF), providing for gradual steroid release over 30 days.[69] This device expands in a spring-like fashion once deployed, to conform to the walls of a dissected ethmoid cavity and middle meatus. Propel has two functions: to act as a mechanical scaffold to prop the MT into a favorable medialized position, and to slowly elute topical steroid over the contacted surface area. Several studies demonstrated the safety and efficacy of Propel for use in chronic rhinosinusitis patients following ESS. Propel was effective in improving wound healing by preserving sinus patency, reducing inflammation, and minimizing adhesions.[69-71]

Middle turbinate implants (MTI) (ENTrigue Surgical Inc; San Antonio, TX) were approved for medialization of the MT in sinonasal surgery.[72] MTI is an absorbable anchor-like implant made from copolymer (L-lactide-co-glycolide) that is meant to fixate the MT to the nasal septum through focused piercing of the latter two tissues. Initial clinical results using MTI have demonstrated that middle turbinates were held medially or in the neutral position with no significant synechiae, although FDA approval is still pending in the US.[73]

ENTact Septal Stapler (ENTrigue Surgical Inc; San Antonio, TX) was developed using bioresorbable staples to align and coapt the mucoperichondrial flaps during septoplasty.[74] The staples are composed of absorbable copolymer (L-lactide-co-glycolide). The septal staples are designed to degrade in 3 to 6 weeks with minimal tissue reaction. In all post-septoplasty patients included in one study, coaptation with septal staples was successfully accomplished with no septal hematoma formation.[75] A controlled study using the Septal Stapler has not been undertaken.

The effect of biomaterials on adhesions and wound healing

When evaluating the suitability of various biomaterials for use following sinonasal surgery, the influence on wound healing should be given particular attention. Wound healing may be related to the retention time of each biomaterial as well as the inherent composition of each product. However, it remains unclear what may be optimal for wound healing, remodeling, and regeneration of the nasal cavity mucosa following sinus surgery. On one hand, it is conceivable that the longer that packing material is maintained in the nose, the more that wound healing is negatively impacted. On the other hand, it is conceivable that persistence of a biomaterial may serve

as a type of biologic dressing, aiding the local tissues in the healing process.

Biomaterials that promote hemostasis through stimulation of the intrinsic coagulation cascade may also theoretically incite inflammation.[76, 77] Non-absorbable biomaterials such as ribbon gauze have been demonstrated to result in a 50 to 70% loss of ciliated mucosal surface area,[11] although Merocel was found to neither impair nor promote wound healing in an animal model.[78] Therefore, a transient impairment of the patient's innate immune system or mucociliary clearance, may be associated with the use of non-absorbable biomaterials.

Absorbable biomaterials derived from either cattle or pigs can generate a foreign body reaction when implanted in the nose. Floseal and Avitene have been shown to increase adhesions and produce an adverse effect on wound healing.[46, 50, 51] In one report, Gelfoam was found to have less fibrogenic potential than Floseal.[51] Fibrin glue and platelet gel are comparable to Merocel in adhesion formation rate.[10, 53] Although HA-based products (Sepragel Sinus, Merogel) have yielded conflicting results, HA appears to offer a reduction in the incidence of adhesions.[38-41, 67] CMC seems to have no appreciable effect on postoperative wound healing compared to no treatment.[56, 57] MPH does not increase synechiae formation or pose a detrimental effect to wound healing.[62] Chitosan gel significantly improves microscopic features of wound healing and reduces adhesion formation.[66]

To improve the delivery of early postoperative topical steroid therapy, several studies have evaluated the utility of placing a drug-eluting spacer. Propel was effective in improving wound healing, reducing inflammation, and minimizing adhesions.[69-71] Other spacers have been combined with steroids as an off-label application of the biomaterial. Triamcinolone-impregnated Nasopore and CMC both improved postoperative wound healing in patients with nasal polyposis.[44, 45, 58] SinuFoam laden with dexamethasone was found to have no effect on improving endoscopic outcomes in patients without nasal polyps when utilizing a postoperative protocol.[79] Table V summarizes the data regarding biomaterials effect on adhesion and wound healing.

Implications for practice

While the necessity for utilization of packing biomaterials following sinonasal surgery is still a matter of debate, many otolaryngologists prefer to use biomaterials. At present, it is unclear if certain packing

TABLE V.—*Biomaterials effect on adhesions and wound healing.*

Biomaterials	Adhesion potential	Wound healing
Ribbon gauze*	Low	Significant mucosal injury with loss of cilia.[11]
Merocel*	Low	No significant difference in reepithelialization, total amount and maturity of cilia.[78]
Floseal	High	Increased granulation tissue, adhesion formation, and refractory fibrosis.
Avitene	High	Severe foreign body reaction, adhesion formation.
Gelfoam Gelfilm	Moderate	Less granulation tissue and adhesions than Floseal.[51] More synechiae than Merogel.
Fibrin glue	Low	No synechiae formation. Same as Merocel.[10,53]
Platelet gel	Low	No synechiae formation. Same as Merocel.[10,53]
Merogel	Low	Fewer adhesions than Gelfilm. Less/Same adhesions as Merocel and no packing.[38-41,67]
CMC	Low	No granulation tissue, mucosal infection, or adhesions. Same as no packing.[56,57]
MPH	Low	No increase in synechiae and mucosal edema. Same as no packing.[62]
Chitosan gel	Low	Fewer adhesions than no packing. Same as no packing in mucosal edema and granulation tissue formation.[66]
Nasopore	Low	No synechiae formation and granulation tissue. Same as Merocel.
Nasopore + TA	Low	Improved wound healing by Lund-Kennedy and POSE scoring system.[44,45,58]
Biomaterials	Adhesion potential	Wound healing
CMC + TA	Low	Improved wound healing by POSE scoring system.[44,45,58]
Propel	Low	Reduction in inflammation, adhesion, and mucosal edema.[69-71]
MTI	Low	No synechiae formation.

CMC: carboxymethylcellulose, MPH: microporous polysaccharide hemispheres, MTI: middle turbinate implant, POSE: perioperative sinus endoscopy, TA: triamcinolone
*Animal study

biomaterials lead to better results. However, there has been an increasing tendency to move away from non-absorbable biomaterials due to their associated discomfort and bleeding upon removal. The choice of nasal packing materials, or whether packing is used at all after sinonasal surgery, will certainly be dependent on the preference and experience of the surgeon in addition to the particular details of the case. The accepted rationale is that absorbable biomaterials reduce the incidence of early postoperative bleeding and formation of adhesions, promoting faster healing of newly-operated, damaged mucosa. Basic research needs to be aimed at developing absorbable biomaterials capable of both hemostasis and spacing, which also promote healing of damaged mucosa following sinonasal surgery. Prospective human trials will likely improve our understanding of the short and long term effects of these biomaterials, and provide roadmaps to improve quality of care and outcomes for patients requiring sinonasal procedures.

Riassunto

Biomateriali allo stato dell'arte nella cavità nasale: emostatici e distanziali dopo chirurgia sinusale

Lo scopo di questo lavoro è riesaminare i recenti progressi nei biomateriali utilizzati come emostatici e distanziali nel naso e differenziarne gli effetti su emostasi, prevenzione delle aderenze e guarigione delle ferite tramite valutazione delle rispettive proprietà. Riesame selettivo della letteratura dalla ricerca di fonti multiple di database eterogenei. Gli articoli sono stati selezionati per la loro rilevanza agli effetti dei biomateriali nasali su emostasi, prevenzione di sinechie/aderenze e guarigione della ferita. I biomateriali sono ampiamente studiati da molti anni, in particolare nella modulazione della cicatrizzazione delle ferite, la rigenerazione tissutale e la somministrazione di farmaci. Quando si valuta l'idoneità di diversi biomateriali a seguito di chirurgia nasosinusale, è opportuno prestare particolare attenzione alla loro influenza sulla guarigione della ferita. La scelta dei biomateriali per medicazione o emostasi naturalmente dipende dalle preferenze e l'esperienza del chirurgo e dai particolari reperti e dettagli intraoperatori dello scenario di ogni paziente. Quando si utilizzano biomateriali dopo chirurgia sinusale, l'attenta applicazione di biomateriali nella cavità nasale può ridurre l'incidenza di sanguinamento postoperatorio precoce e la formazione di sinechie/aderenze ed eventualmente favorire la guarigione della mucosa.

PAROLE CHIAVE: Emostasi - Materiali biocompatibili - Endoscopia.

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Conflicts of interest.—J. V. Nayak is a member of the Scientific Advisory Board of Polyganics; and a consultant with Olympus America; ENTrigue Systems; Acclarent, Inc. and Stryker Navigation; PH is a share holder in Intersect ENT, and a consultant with Medtronic Inc. and ENTrigue Systems.