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Game Changers: Plastic and Reconstructive Surgery Innovations of the Last 100 Years

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Background: Innovation is an essential aspect of plastic and reconstructive surgery (PRS), whether it involves improving current processes or implementing radical change that disrupts the status quo. Collaborating and sharing innovations help advance the field of PRS as a whole.
Methods: An anonymous survey was administered to members of the American Association of Plastic Surgeons on their opinions of the top five innovations in PRS of the last 100 years.
Results: A list of 69 unique innovations were compiled; the top five innovations overall were microsurgery, myocutaneous flaps, craniofacial surgery, negative pressure wound therapy, and organ transplantation. This list was reviewed by the American Association of Plastic Surgeons Technology Committee, and expanded to 100 unique innovations.
Conclusions: We discuss why the above innovations were essential to the development of PRS, as well as the unique factors that can make a new product or procedure into something that remodels the field of PRS. *(Plast Reconstr Surg Glob Open 2023; 11:e5209; doi: 10.1097/GOX.0000000000005209; Published online 16 August 2023.)*

INTRODUCTION

Plastic and reconstructive surgery (PRS) was founded on and has thrived due to innovation. The World Intellectual Property Organization defines medical innovating as "increasing knowledge and transforming existing processes and business models to better serve changing needs and expectations."[1] The Merriam-Webster dictionary differentiates between invention and innovation in that invention can be "a device, contrivance, or process originated after study and experiment," whereas innovation is "something new or a change made to an existing product, idea, or field."[2] Innovation in PRS saves energy and increases efficiency. There are two main types of innovation: stepwise innovation involves the improvement upon current processes in a linear manner, whereas transformative innovation involves radical change that disrupts the current status quo.[3] Both are important for the improvement of the medical industry as a whole, especially for PRS. Unlike other surgical specialties focusing on specific organ systems, PRS treats all regions of the body at all ages. As plastic surgeons innovate, they continue to elevate the specialty and push past known boundaries to improve patient care and outcomes.

Brief History of Plastic Surgery

An example of innovation in PRS can be traced through the evolution of nasal reconstruction and rhinoplasty. The Indian surgeon Sushruta (ca. 1000–800 BC) is believed to have pioneered the skin flap technique and performed nasal reconstruction using a pedicled forehead flap, termed the "Indian Method."[4] It is hypothesized that Arab surgeons brought his text the *Sushruta Samhita* to Europe. In the 15th century, a father–son duo in Sicily named Branca improved upon Sushruta's nasal reconstruction technique by using forearm skin, later termed the "Italian Method." The 16th century Italian surgeon Gaspare Tagliacozzi authored *De*

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Curtorum Chirurgia per Insitionem, largely considered the first plastic surgery textbook, describing the technique and tools for nasal reconstruction. This introduction of autotransplantation was perhaps ahead of its time, as the procedure was largely abandoned after the death of Tagliacozzi until its reintroduction in the 19th century by Giuseppe Costantino Carpue. At this point in history, rhinoplasty and the broader field of reconstructive plastic surgery were widely accepted.[5]

Perhaps one of the greatest advances in PRS after the refinement of rhinoplasty occurred during wartime. In his 1920 textbook *Plastic Surgery of the Face,* New-Zealand-born English plastic surgeon Sir Harold Gillies described his procedures for facial injuries of World War I soldiers, and featured before and after drawings of his patients. This work is one of the most influential PRS documents to this day.[6]

After World War I, PRS experienced explosive growth and refinement. In 1921, the American Association of Plastic Surgeons (AAPS) was formed when Dr. Truman W. Brophy and Dr. William L. Shearer recognized a need for plastic surgeons to have a forum to share innovations in PRS.[7] AAPS is a national organization consisting of leaders in plastic surgery who have been recognized for their meaningful contributions to research, education, and clinical practice. Since its founding, AAPS members have gathered for yearly meetings to discuss the latest research and innovation in PRS.

With the centennial meeting of AAPS, we sought to reflect upon the innovations in PRS. Although prior studies have examined innovations in PRS, the influx of new products and methods devised every year necessitates an updated study. Given that PRS is a specialty that relies heavily on innovation, this study was formulated to synthesize and analyze a collection of the most important innovations in PRS. We aimed to recognize the hard work of past and current plastic and reconstructive surgeons and stimulate a desire for future innovation in PRS.

Takeaways

Question: What are the greatest innovations in plastic surgery in the past 100 years?

Findings: An anonymous survey was administered to American Association of Plastic Surgeons members on their top five plastic surgery innovations in the last 100 years. A list of 69 unique innovations were compiled; the most popular innovations were microsurgery, myocutaneous flaps, craniofacial surgery, negative pressure wound therapy, and organ transplantation.

Meaning: The most popular innovations in plastic surgery are those that make reconstruction simpler, more efficacious, less invasive, and less morbid with improved functional and aesthetic outcomes.

METHODS

An anonymous SurveyMonkey survey consisting of three general, nonvalidated questions was emailed to all AAPS members three times during December 2021 and January 2022 (Table 1). To calculate the significance of each innovation ranked by the respondents, the authors calculated weighted scores for each innovation. This was done by first assigning points to the position of each item on a respondent's list in descending order, such that the first item received five points, the second item received four points, the third item received three points, the fourth item received two points, and the last item received one point. Weighted scores were then calculated by dividing the total number of points per innovation by 15 (the sum of all possible points: 5 + 4 + 3 + 2 + 1). For example, if one innovation was ranked first from three respondents, second from five respondents, and fifth from ten respondents, the weighted score for that innovation would be three (([3*5] + [5*4] + [10*1])/15).

Table 1. Survey Questions Administered Anonymously to AAPS Members via SurveyMonkey

Survey Questions
1. According to you, what are the top five innovations in Plastic Surgery of the last 100 years?
2. How many years have you been in practice?
a. Under 10 years
b. 10–20 years
c. 21–30 years
d. 31–35 years
e. More than 35 years
f. Retired after ____ years in practice (please provide number of years)
3. What is your current practice model?
a. Academic
b. Employed
c. Private
d. Other (please specify)

The list of innovations from the survey was reviewed and approved by the AAPS Technology Committee, who by consensus contributed additional items to create a list of 100 innovations. To present the data from a broader perspective, the authors also stratified the innovations into categories: (1) subspecialty, (2) instruments/consumable products, (3) surgical procedure/technique, (4) technology, and (5) knowledge/education.

Data were analyzed using the SPSS for Windows, version 28.0 (IBM Corp, Armonk, N.Y.). Frequencies were computed to evaluate response rates, which were used to determine the top innovations. Chi-square tests of independence were utilized to evaluate differences between the five innovations amongst respondents with varying practice models and years of practice. Results with P less than 0.05 were considered statistically significant.

RESULTS

Of the 937 AAPS members, 138 completed the survey, for a response rate of 14.7%. Of the respondents, 11.6% (n = 16) provided four or fewer distinct innovations. Review of the responses by the AAPS Technology Committee yielded a list of 69 unique innovations, as represented by weighted ranks in Supplemental Digital Content 1. (**See table, Supplemental Digital Content 1,** which displays the list of innovations in plastic and

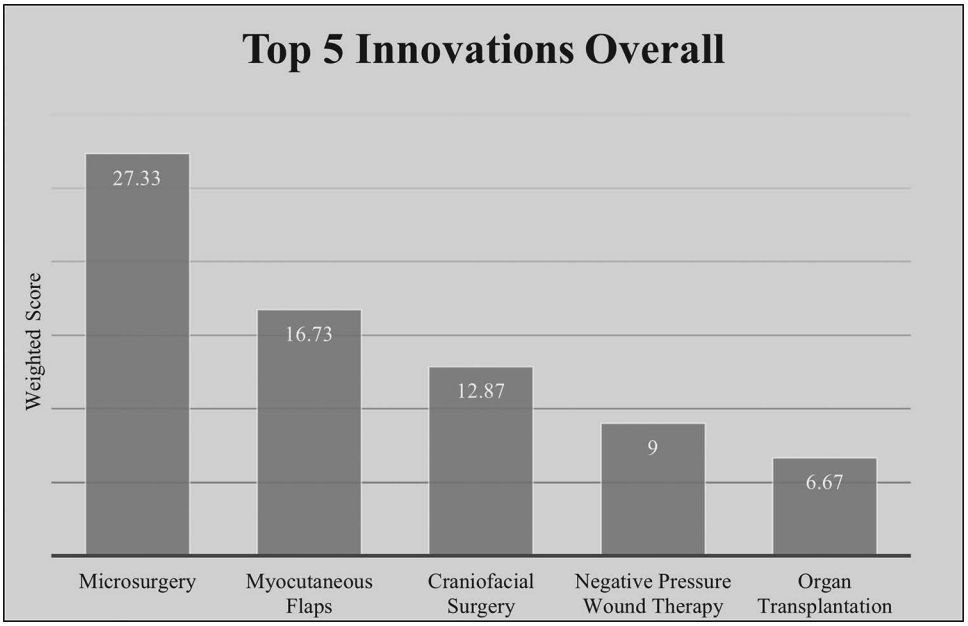

Fig. 1. The top five innovations overall from a survey of AAPS members.

reconstructive surgery in the last 100 years from a survey of AAPS members with ranks and weighted scores. **http://links.lww.com/PRSGO/C743**.) The list of 100 innovations complied by the AAPS Technology Committee is shown in Supplemental Digital Content 2. (**See table, Supplemental Digital Content 2,** which displays the complete list of 100 innovations curated by the AAPS Technology Committee. The asterisk (*) indicates an innovation contributed by the committee. **http://links.lww.com/PRSGO/C744**.)

Figure 1 depicts the top five innovations across all categories. These innovations were all under the subspecialty or surgical procedure/technique category. The innovation with the greatest weighted score of 27.3 was microsurgery, belonging to the subspecialty category. The next innovation was myocutaneous flaps with a weighted score of 16.7, belonging to the surgical procedure/technique category. The subsequent innovations were craniofacial surgery, negative pressure wound therapy (NPWT), and organ transplantation.

Figure 2 represents the top three innovations of each category. Microsurgery was the top choice in the subspecialty category, as well as the overall most chosen innovation. NPWT was the top innovation in the instruments/consumable products category. The top technology innovation was stem cell/tissue regeneration, and the top surgical procedure/technique was myocutaneous flaps. Lastly, the highest ranked innovation of the knowledge/education/people category was the management of burn wounds.

There were no significant overall differences in the top five innovations amongst respondents with varying practice models (eg, academic and nonacademic surgeons), although the groups slightly differed in the order of the top five. However, when analyzing the responses based on years of practice, surgeons with more than 20 years of surgical experience were significantly more likely to name microsurgery and myocutaneous flaps as their top innovations than those with fewer years of practice with $P = 0.003$ (Fig. 3).

DISCUSSION

Innovation allows surgical specialties to optimize and expand practices, which is especially important in aesthetic and reconstructive surgery. Innovation changes the way reality can be manipulated. In the case of microsurgery, vascularized tissue could literally be moved from one part of the body to the next. This created a new field and a new way to think about restoring the human form. This study attempted to find the most significant innovations in PRS from a wide array of plastic surgeons. To our knowledge, this is the largest survey to date regarding this subject. In 2016, Kwasnicki et al attempted to identify the top innovations in PRS by ranking the top-performing patent codes and article citations indices.[8] This offers the latest insight into patented and published innovations in PRS, directly from experts in the field. However, the results are not definitive, as the most active patent codes and cited publications may not directly translate into the most clinically important innovations. A similar study surveyed members of the American Council of Academic Plastic Surgeons (ACAPS) and the Southeastern Society of Plastic and Reconstructive Surgeons (SESPRS) in 2014.[9]

In our survey, respondents expressed considerable support regarding the top five innovations: microsurgery, myocutaneous flaps, craniofacial surgery, NPWT, and organ transplantation. No significant differences were observed among the top five innovations with respect to years of practice or practice settings (academic or nonacademic).

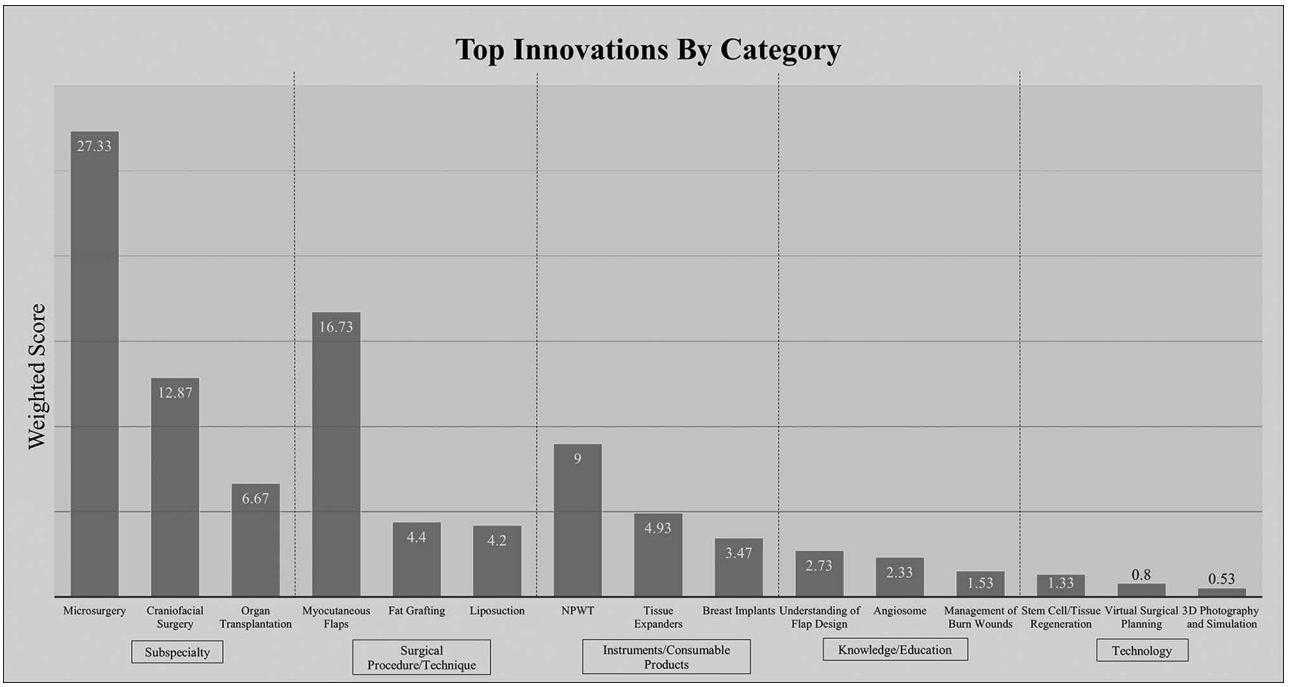

Fig. 2. The top three innovations of each category from the survey: subspecialty, surgical procedure/technique, instruments/consumable products, knowledge/education, technology.

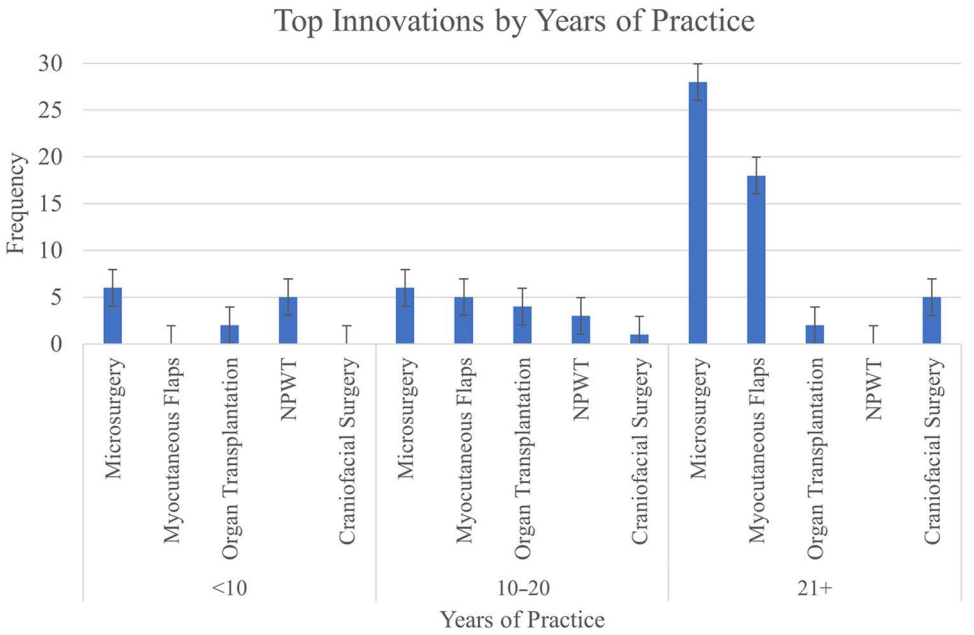

Fig. 3. The top innovations divided by different categories of years of practice: less than 10 years, 10–20 years, and 21 or more years of practice. Those with 21 or more years of practice were more likely to name microsurgery and myocutaneous flaps as their top innovations than those with fewer years of practice ($P = 0.003$).

The top three innovations overall were microsurgery, myocutaneous flaps, and craniofacial surgery in that order. These three innovations were consistently mentioned by plastic surgeons with different years of experience and types of practice. Interestingly, when stratifying respondents into different groups with respect to their years of experience, those with more than 20 years of experience were significantly more likely to name microsurgery and myocutaneous flaps as the top innovations than those with fewer years of practice. These innovations

were also the same as the top three innovations from the 2014 ACAPS and SESPRS study, demonstrating the enduring impact that these procedures have had on advancing the field of PRS over many years.[9]

These three innovations emerged throughout the last 100 years, mainly around the mid-1900s. The first and second world wars necessitated the introduction of new surgical innovations, especially craniofacial surgery. The practice of craniofacial surgery was formally introduced by Tessier in 1967, which was aimed at developing techniques for reconstructing trauma-related injuries.[10] This era also saw the expansion of myocutaneous flaps, such as deltopectoral flaps publicized by Aymard in 1917 for staged nasal reconstruction.[11] In 1960, microsurgery, an undeniably disruptive innovation, was first popularized by Jacobson and Suarez through the experimentation of microvascular anastomosis on laboratory animals, using a microscope.[12,13] Work had been performed previously at the turn of the century by both Charles Guthrie and Alexis Carrel, but it was Jacobson that made the leap with the use of better optical microscopes.[14]

In economic environments, innovation drives surgical development. Harvard economics professor Clayton Christensen distinguishes the different patterns of innovation in his book, *The Innovator's Dilemma*. He defines "disruptive innovation" as the application of new knowledge to address underserved market needs, creating new principles and strategies in the process.[15] Genuinely disruptive innovations like microsurgery reset expectations for both medical providers and patients. The introduction of microsurgery has expanded the reconstructive dogma to not only cover defects but also recover functionality and aesthetics as well. Plastic surgeons today continue to develop and refine microsurgical techniques that were previously inconceivable, such as robot-assisted supermicrosurgery (anastomosis of vessels with a caliber <0.8 mm). The use of a dedicated microsurgical robotic platform allows plastic surgeons to overcome physiologic limitations and meet the challenges of lymphedema, digit replantation, and soft tissue reconstruction. Robot-assisted microsurgery has also been adapted in urology and ophthalmology for technically difficult procedures, which demonstrates the ubiquity and generalizability of disruptive innovations. The arrival of cheaper robotic systems will further broaden application, and theoretically, be used to enhance even the simplest surgical procedures.

Some technological innovations cause a paradigm shift, completely changing the wants and needs of the market. These innovations can be referred to as game changers, which transform the delivery of health care. A notable example is NPWT, ranked the number one consumable product in PRS by our survey respondents. Incisional negative pressure wound therapy (iNPWT) systems are practical in an outpatient setting because they can be applied superficially to closed wounds. Moving NPWT to an outpatient setting decreases the time and resources invested in wound care management by patients and healthcare providers. Patients treated with iNPWT after reversal of double loop ileostomy experience a decrease in surgical site infection rate and duration of hospital stay.[16] Surgical site infections are a major financial burden, accounting for 33.7% of the annual national cost of healthcare acquired infections ($9.8 billion).[17] Treatment with iNPWT seems to improve patient satisfaction with the course of wound healing and provide a better value proposition for hospitals over standard sterile dressings.[17,18] In addition to NPWT, hyperbaric oxygen therapy, one of the innovations added to the list by the AAPS Technology Committee, has been shown to improve diabetic wound healing as an adjunct to conventional wound care.[19] Future surgical innovations with the greatest impact will not only improve patient outcomes but also optimize the time and labor costs of all providers, a top priority in ever-growing health care systems.

Organ transplantation was a common response, pointing to how one procedure seemingly outside the realm of plastic surgery can greatly impact the entire field. What drove the importance of this innovation was the understanding of burgeoning field of immune regulation for transplantation.[20,21] Dr. Joseph Murray, a plastic surgeon at Brigham and Women's Hospital, set the foundation of our modern understanding of skin grafting. Murray's grasp of skin grafting techniques and the rejection process allowed him to perform the first successful organ transplantation in 1954 between identical twins. This was an important milestone in the fields of immunology and regenerative medicine, making it feasible for plastic surgeons to transplant vascularized composite allograft tissue today.

Surgical innovations can also come from new ways of understanding anatomy and physiology, not just through technological advances. The angiosome concept, introduced by Taylor and Palmer in 1987, is one of the best illustrations of how expanding basic scientific knowledge is conducive to innovation—understanding this concept provided plastic surgeons with the blueprint for planning incisions, free flaps, and functional limb salvage. This parallels with the development of myocutaneous flaps, one of the top five innovations named by our survey respondents. Analyzing physiology, especially in the perioperative period, has also led to the development of ERAS (enhanced recovery after surgery) protocols, an innovation added to the list by the AAPS Technology Committee. ERAS protocols have contributed to faster recovery from surgery and better postoperative pain control, which subsequently optimize hospital time and costs.[22–24]

This survey study has several limitations. One limitation concerns the exclusive use of the AAPS members as the survey population. AAPS members may be more aware of cutting-edge developments and reviews of established PRS practices in the United States than other plastic surgeons, but this may have excluded some well-established international surgeons. Furthermore, AAPS membership is obtained through nomination, and surgeons must have at least 5 years of experience practicing in the field of plastic surgery after board certification to be nominated, with some exceptions. Thus, AAPS members and survey respondents represent a group of plastic surgeons who are already well-established in the field, and the survey may not capture the opinions of surgeons who are recently board certified and who are new to the field of PRS. As with all

survey studies, there is a potential for responder bias, as the response rate was 14.7% (138 respondents). However, the response rate and the total number of respondents in this survey is greater than those of the 2014 ACAPS and SESPRS surveys combined, which totaled 9.6% and 79 respondents.[9] Additionally, different understanding between respondents of the word "innovation" may have influenced our results, particularly because these questions were not independently validated. Nevertheless, the question on top innovations was also asked on the ACAPS and SESPRS surveys; so this provides an update of general opinion on innovations in PRS. As previously mentioned, 11.6% of respondents provided four or fewer distinct innovations and no analyses regarding missing data were conducted. However, given the vast range of innovations produced from this general survey, missing data would not likely have significant impact on the conclusions. Future studies may expand the survey to other PRS societies (especially international ones), as well as survey their understanding of disruptive innovation and what may drive PRS forward.

Innovation is the backbone of PRS, and the key to our past and future success. The top-ranking innovations in PRS are known to make reconstruction simpler, more efficacious, less invasive, and less morbid with improved functional and aesthetic outcomes. The clinical application of these innovations requires a further act of creativity. Which technology should be used, and in which way should it be applied? Plastic surgeons can be creative in maneuvering the lower rungs of the reconstructive ladder, such as using the simplest tools to achieve the desired aesthetic and functional results. However, oftentimes moving up the reconstructive ladders allows more innovative ways to solve a difficult problem. Over time, these innovative ways have often seemed incredulous, such as free tissue transfer or even organ transplantation. Now these innovations are routine, waiting to be innovated once again.

Evidently, the profile of our specialty serves as a constant stimulus for plastic surgeons to innovate. We constantly search for ways to optimize head to toe cancer, as well as traumatic and aesthetic reconstruction. Utilizing the economic model of innovation discussed above can provide us with a framework for creating and sustaining innovation within PRS. Although new technology can foster optimism bias among plastic surgeons, not all innovations result in improved outcomes. Technological innovations introduce a potential risk to patients; so it is crucial to explore pertinent ethical dilemmas, including validity, informed consent, conflicts of interests, costs, and oversight. A greater understanding of these factors will allow us to make the adoption of surgical innovations ethically acceptable, evidence-based, and financially viable.

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DISCLOSURES

Dr. Justin M. Sacks is a consultant for 3M. All the other authors have no financial interest to declare in relation to the content of this article.

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