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# Understanding the Mechanical Forces on the Sacrum Can Help Optimize Flap-based Pilonidal Sinus Reconstruction

Shintaro Kaneyuku, MD*
Teruyuki Dohi, MD, PhD*
Diya′ S. Hammoudeh, MD†
Shigeyoshi Eura, MD, PhD*
Yuta Kurokawa, MD*
Rei Ogawa, MD, PhD, FACS*

**Background:** Pilonidal sinus can be treated with excision and flap reconstruction, but treatment is often complicated by wound dehiscence, infection, and recurrence. Understanding the mechanical forces on the sacrococcygeal area during posture change could help guide optimal flap choice.

**Methods:** Sixteen volunteers underwent measurements of skin-stretching, pressure, and shear stress on the sacrum when sitting relative to standing. Skin-stretching was measured by drawing a 4×4cm square on the sacrum and measuring the vertical, horizontal, and diagonal axes. Pressure and shear stress was measured at six sacral points with a device. The data analysis highlighted the potential of the superior gluteal artery perforator (SGAP) flap for dissipating mechanical forces. Ten pilonidal sinus cases treated with SGAP flaps were retrospectively reviewed for 6-month outcomes.

**Results:** Sitting is associated with high stretching tension in the horizontal direction [estimated marginal mean (95% confidence intervals) = 17.3% (15.4%–22.6%)]. The lower sacrum experienced the highest pressure [106.6 (96.6–116.5) mm Hg] and shear stress [11.6 (9.7–13.5) N] during sitting. The transposed SGAP flap was deemed to be optimal for releasing the horizontal tension and providing sufficient subcutaneous tissue for ameliorating pressure/shear stress during sitting. It also has high blood flow and can therefore be used with large lesions. Moreover, its donor site is above the high-pressure/stress lower sacrum. Retrospective analysis showed that no patients experienced complications.

**Conclusions:** Sitting is associated with high mechanical forces on the sacrococcygeal skin. The transposed SGAP flap may ameliorate these forces and thereby reduce the risk of complications of pilonidal sinus reconstruction for large defects.
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## INTRODUCTION

The pilonidal sinus is a small fistulous tract in the skin at the top of the natal cleft. It contains hair and debris and can fill with fluid or pus, thus generating a cyst or abscess. It was initially thought to be a congenital disorder but is now considered to be largely an acquired condition[1–4] because its risk factors include young age, obesity, male sex, hairiness, and a deep natal cleft.[5,6] Two main etiological mechanisms have been proposed. One was suggested by Patey and Scarff[2]: they propose that pilonidal disease is caused by hair shafts that are generated by mechanical trauma to the hair (eg, friction and pressure from a car seat by body weight) and are then sucked into the subdermal tissue by the motion of the gluteal folds. These shafts then induce foreign body reactions and the formation of granuloma.[2,7] The second hypothesis was proposed by Bascom[3] and suggests that pilonidal disease originates from follicular hyperkeratosis; the lesion then obstructs

*From the *Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan; and †Division of Plastic, Reconstructive and Aesthetic Surgery, American University of Beirut, Beirut, Lebanon.*

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the hair follicle infundibulum and promotes follicle infection.[3] Which of these etiologies is most likely is still being debated.

Pilonidal sinus presents initially as a painful, foul-smelling infection or asymptomatic noninflamed pits in the natal cleft. Infected cases require incision and drainage. Small lesions can be eliminated with pit-picking, phenol instillation, endoscopic treatment, or laser ablation.[8–10] Because these approaches are associated with high recurrence rates for larger lesions (≥3 cm), such lesions are generally treated with complete excision. Complete excision options include direct midline closure and flap reconstruction; the latter is associated with a lower risk of recurrence.[11] The flaps can be classified as midline and off-midline flaps according to the postoperative wound site. The off-midline flap methods, which include the Karydakis technique and the Limberg flap, have been shown to yield better results than midline suturing in most studies.[12–16] However, there is no consensus yet regarding the optimal reconstruction technique for large pilonidal lesions.[6,17–19]

The sacrococcygeal skin is prone to strong mechanical forces, namely, stretching tension and shear stress due to frequent postural changes, and compression and friction during sitting. These may promote pilonidal disease: both etiological theories of pilonidal disease invoke mechanical forces, namely, friction-induced trauma to the hair/hair follicle and a vacuum effect generated by gravity/gluteal muscle movement. These strong mechanical forces likely also explain why patients whose pilonidal sinus has been treated often experience complications such as wound dehiscence and recurrence[20–22]: strong and/or repetitive mechanical tension can impair wound healing.[23] Therefore, to determine the optimal reconstruction technique for pilonidal sinus, it may be necessary to consider the local mechanical forces. Thus, we investigated the effect of postural change on the local skin mechanics of the sacrococcygeal area in healthy volunteers. Given the results, we then qualitatively considered the various flaps that have been and could be used to reconstruct the sacrococcygeal region and selected the superior gluteal artery perforator (SGAP) flap as being the flap that can best ameliorate or withstand the mechanical forces on the wound. These considerations are described in detail in the Discussion. We then retrospectively identified all consecutive cases of pilonidal sinus reconstruction with the SGAP flap to determine its outcomes. These analyses together show that a clear understanding of the mechanical tension on the wound could help surgeons to design and plan the optimal reconstructive method, including for pilonidal sinus cases.

### Takeaways

**Question:** What is the optimal flap choice for reconstruction of large pilonidal sinus defects, taking into consideration the mechanics of the sacrococcygeal region?

**Findings:** Daily sitting increases mechanical tension, particularly horizontally, and shear stress in the sacrococcygeal region, influencing flap selection for pilonidal sinus reconstruction, with the SGAP flap demonstrating beneficial results in addressing these forces.

**Meaning:** Mechanical considerations in pilonidal sinus reconstruction emphasize the SGAP flap's potential to improve outcomes and reduce complications.

## PATIENTS AND METHODS

### Study Ethics

This study was conducted in a tertiary training hospital (Nippon Medical School) according to the good clinical practice and the Declaration of Helsinki. The study was approved by the ethics review committee of Nippon Medical School (approval number 2020-123). All study participants provided informed consent in writing.

### Participant Selection

The study subjects consisted of 16 healthy volunteers and 10 consecutive SGAP cases. The volunteers were eligible if they lacked a history of medical illnesses, including connective tissue disorders, skin diseases, or previous scarring. The 10 SGAP cases were identified by retrospective review of the medical records between 2012 and 2018. The 16 volunteers were randomly assigned into two groups of eight participants each for different mechanical force analyses.

### Measurement of Mechanical Forces on the Sacrococcygeal Region during Postural Change

The 16 volunteers were all young men. On average, these participants were 170.3-cm tall, weighed 63.1 kg, and had an average body mass index (BMI) of 21.7 kg/m$^2$. They were divided into two groups of eight participants each. One group underwent analysis of skin stretching on a 4 × 4-cm area centered at the natal cleft (stretching group), whereas the other group had pressure and shear stress measured at six predefined sacral points (pressure/shear stress group).

Two postural changes were examined in both groups. Thus, the participants were asked to move from the standing position to (1) simulate a half-sitting position on the edge of a chair with knees bent at 90 degrees (edge sitting) and (2) squatting with knees bent at 120 degrees (deep sitting) (Fig. 1).

For the stretching analysis, a 4 × 4 cm square that was centered on the top of the natal cleft was marked while the volunteer was in the standing position (Fig. 2). The subject was then asked to adopt the edge-sitting or deep-sitting position, after which the horizontal, vertical, and diagonal axes of the 4 × 4 cm square were measured using a paper ruler.

For the pressure/shear-stress analysis, six distinct anatomical sites were marked on the skin. The center of the sacrum at the midline (site 1: termed central midline sacrum) was identified first, followed by the top of the natal cleft (site 2: lower midline sacrum). The length between sites 1 and 2 was then measured and used to mark

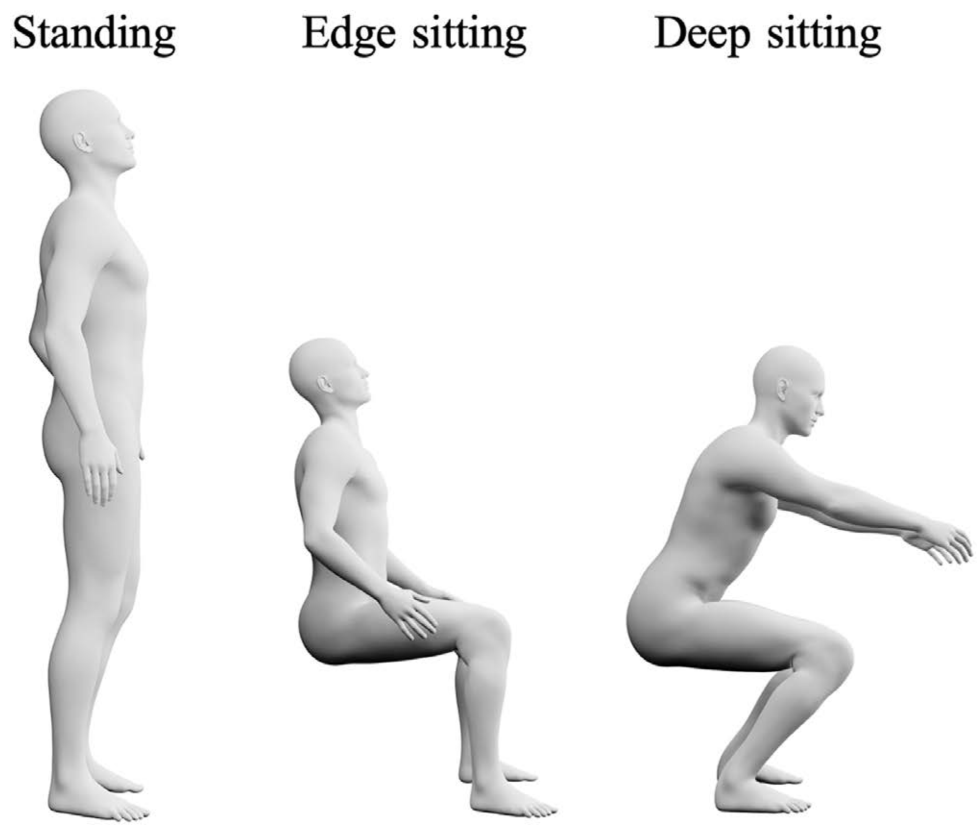


**Fig. 1.** Volunteers were asked to change position from standing to simulate sitting on the edge of a chair with the knees at 90 degrees (edge-sitting position) and from standing to squatting with knees at 120 degrees (deep-sitting position).

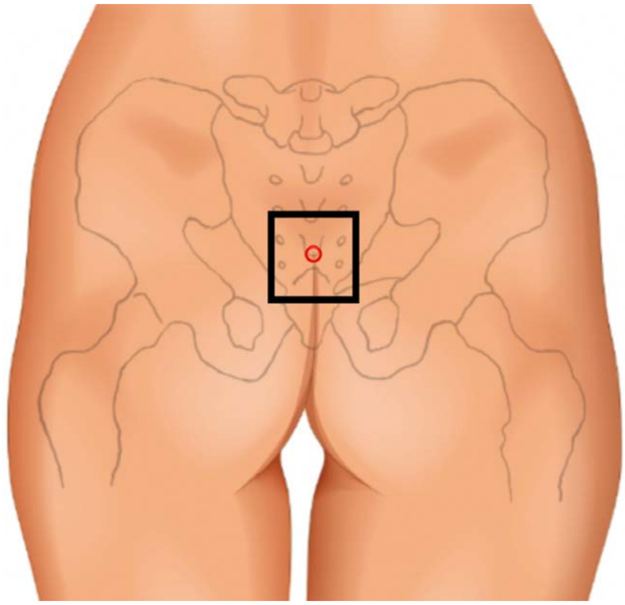

**Fig. 2.** A 4×4 cm square that was centered at the top of the natal cleft was marked while the volunteer was in the standing position. The subject was then asked to adopt the edge-sitting or deep-sitting position, after which the horizontal, vertical, and diagonal axes of the 4×4 cm$^2$ were measured using a paper ruler.

the remaining four sites with reference to site 1, namely, the upper midline sacrum (site 3), the central right sacrum (site 4), the upper right sacrum (site 5), and the lower right sacrum (site 6) (Fig. 3). The elliptical sensor head of the pressure- and shear force-sensing device Predia (Molten Corp., Hiroshima, Japan) was then attached to each sacral site with double-sided tape while the volunteer was in the standing position. (**See figure, Supplemental Digital Content 1**, which shows the Predia pressure and shear-stress sensor by Molten Corp. **http://links.lww.com/PRSGO/D312**.) The volunteer was then asked to adopt the edge-sitting or deep-sitting position. The sensor determined the pressure (mm Hg) by measuring air displacement and the shear force (N) by using a strain gauge. After recording the pressure/shear stress at each of the six sites, the values at sites 3 and 5 (upper sacrum), sites 1 and 4 (central sacrum), and sites 2 and 6 (lower sacrum) were averaged, thus yielding three pressure values and three shear-stress values per person per sitting position.

### Retrospective Analysis of SGAP Flap Patients

Our analysis of the mechanical forces at the sacral area during postural change led us to retrospectively analyze 10 cases of pilonidal sinus that had been treated with excision and reconstruction of the large defect with an SGAP flap in 2012–2018. These cases had no surgical intervention

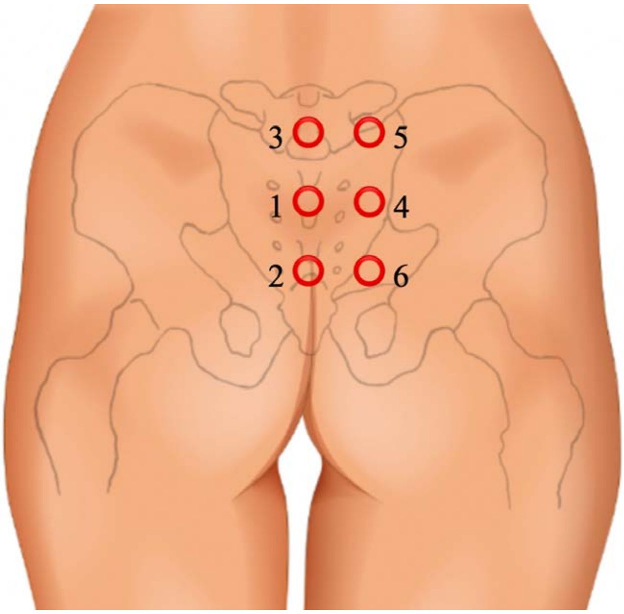


**Fig. 3.** Six distinct anatomical sites were selected to determine the position-associated changes in pressure (mm Hg) and shear force (N). Site 1: central midline sacrum. Site 2: lower midline sacrum (top of the natal cleft). Site 3: upper midline sacrum. Site 4: central right sacrum. Site 5: upper right sacrum. Site 6: lower right sacrum. The values at sites 1 and 4 (central sacrum), 2 and 6 (lower sacrum), and 3 and 5 (upper sacrum) were averaged and used for statistical analysis. The Predia device (Molten Corp.) was used to determine pressure and shear force.

previously and were all operated on at Nippon Medical School Hospital with a mean follow-up period of 1 year. In all cases, the flap was a transposition flap that included the perforator of the superior gluteal artery.

### Statistical Analyses

Linear mixed model (subjects = random effect; stretching direction and sacral areas = fixed effects) was used to generate the estimated marginal means and 95% confidence intervals (CIs). Pairwise comparisons were adjusted with Bonferroni method. For each stretching axis in each sitting position, the percentage stretching rate was calculated as follows: measurement/4 for vertical and horizontal axes; measurement/√32 for the diagonal axis, followed by log-transformation then exponentiation using the Euler constant. All statistical analyses were conducted with IBM SPSS statistics software version 28. A $P$ value of less than 0.05 was considered to indicate statistical significance.

## RESULTS

### Sitting Strongly Stretches the Sacral Area in the Horizontal Direction

The sacral skin stretched in all directions (vertical, horizontal, and diagonal) when the standing volunteers adopted the edge-sitting and deep-sitting positions. The greatest stretching was observed in the horizontal direction, with an estimated marginal mean (95% CI) of 10.1% (8.4%–12.9%) for edge-sitting position and 17.3% (15.4%–22.6%) for deep-sitting position. This horizontal stretching was significantly higher than the stretching in the vertical ($P = 0.001$ for edge-sitting position and $P = 0.019$ for deep-sitting position) and diagonal directions ($P = 0.001$ for edge-sitting position and $P < 0.001$ for deep-sitting position) (Fig. 4A). These observations indicate that the sample size was sufficiently powered to detect differences between the studied groups.

### Sitting Imposes Particularly High Pressure and Shear Stress on the Lower Sacrum

Edge-sitting, and particularly deep-sitting, position placed marked pressure and shear stress on the lower sacral area. A similar but less pronounced pattern was also observed for the central sacral area. Thus, the highest estimated marginal mean (95% CI) pressure was at the lower sacrum, namely, 13.8 (10.4–17.2) mm Hg for the edge-sitting position and 106.6 (96.6–116.5) mm Hg for the deep-sitting position. This was significantly higher than the pressure at the central sacrum, with $P$ values of 0.002 for edge-sitting position and less than 0.001 for deep-sitting position, and higher than the pressure at the upper sacrum ($P < 0.001$ for both positions). Moreover, the highest estimated marginal mean (95% CI) shear stress was also at the lower sacrum, namely, 6 (5.1–6.9) N for the edge-sitting position and 11.6 (9.7–13.5) N for the deep-sitting position. This was significantly higher than the shear stress at the central sacrum, with $P$ values of less than 0.001 and 0.004, respectively, and higher than at the upper sacrum ($P < 0.001$ for both positions). Thus, the lower sacrum experienced two- to four-fold more pressure and shear stress than the central sacrum and 10- to 100-fold more pressure and shear stress than the upper sacrum. It also experienced approximately eight-fold more pressure and approximately two-fold more shear stress in the deep-sitting position than in the edge-sitting position (Fig. 4B, C).

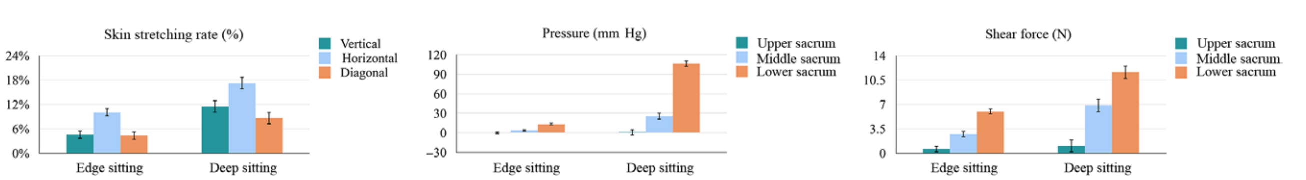


**Fig. 4.** Effect of edge sitting and deep sitting on skin-stretching tension, pressure, and shear stress. The values are estimated marginal means (bars represent standard error of the means), as determined by using a linear mixed model. For each stretching axis in each sitting position, the % stretching rate was calculated as follows: measurement/4 for vertical and horizontal axes and measurement/√32 for the diagonal axis, followed by log-transformation then exponentiation using the Euler constant.

**Table 1. Ten Cases of SGAP Flap Reconstruction after Excision of Pilonidal Sinus**

| Characteristic | Value (%) |
|---|---|
| Age, y | 37.7 ± 11.13 |
| BMI, kg/m$^2$ | 27.4 ± 6.9 |
| Sex | |
| Male | 9 (90) |
| Female | 1 (10) |
| Defect dimensions, cm | 6.9 ± 1.66 × 3.2 ± 0.79 |
| Defect area, cm$^2$ | 17.66 ± 7.95 |
| Flap dimensions, cm | 9.85 ± 1.83 × 5.05 ± 1.4 |
| Flap area, cm$^2$ | 38.88 ± 16.16 |
| Complications | None |

The data are shown as mean ± SD or n (%).

### Reconstruction of Pilonidal Sinus with SGAP Flap Is Associated with Favorable Outcomes

Ten patients were found to have undergone reconstructive surgery with the transposed SGAP flap after excision of large pilonidal sinus. Nine were men and the average age and BMI were 38 years and 27.4 kg/m$^2$, respectively. The defects went down to the periosteum. The average defect and flap sizes were 18 ± 8 cm$^2$ (6.9 × 3.2 cm) and 39 ± 16 cm$^2$ (9.85 × 5.05 cm), respectively. Supine and sitting positions were avoided for 5–7 days postoperatively. None of the patients experienced complications such as wound dehiscence, infection, or recurrence in 6 months after surgery (Table 1 and Figs. 5 and 6).

## DISCUSSION

### The Most Pilonidal Sinus-Prone Body Region Experiences Strong Mechanical Forces

The lower end of the sacrum is a common site of pilonidal sinus formation.[6] This study showed that sitting imposes high stretching tension on this area, particularly in the horizontal direction. Sitting also places much stronger pressure and shear stress on this area compared with the central and upper sacrum. These powerful mechanical forces could directly drive the formation of pilonidal sinus: specifically, they could promote both hair breakage/embedding of the hair shaft in the skin (the Patey and Scarff etiology) and follicular hyperkeratosis (the Bascom etiology). These putative roles of mechanical factors in pilonidal sinus pathogenesis may explain several of its risk factors: they include a young age, obesity, and deep natal cleft.[20,24–26] The strong mechanical forces on the sacrum may also explain wound dehiscence after reconstruction in this area.

### Mechanical Forces on the Sacrum Can Guide Flap Choice for Reconstruction

Our analyses of the mechanical forces on the sacrococcygeal area show that two important factors should be considered when reconstructing a large sacrococcygeal defect. First, body posture changes place stretching tension on the postoperative wound, particularly in the horizontal direction. This tension would be best released by a transpositional flap (Fig. 7). Second, the skin is directly compressed and subjected to shear stress by the underlying bone of the lower sacrum when sitting. Thus, to limit these sitting-associated forces on the wound, it would be best to choose a fascial, vertically oriented flap that has a stable blood flow and includes sufficient subcutaneous tissue.[27–30] In addition, paramedian wound closure using a transpositional flap minimizes wound tension and compression, thus avoiding prolonged dermal inflammation which results in less scarring than midline wound closure.[23] It would also be best to choose a flap whose donor site is not on the high pressure/shear-stress lower sacrum.

### Horizontally Oriented Advancement Flaps with Inadequate Subcutaneous Tissue May Not Be Appropriate for Sacral Wound Reconstruction

Numerous types of local flaps have been used for pilonidal sinus reconstruction. They include the Karydakis flap,[4] the Bascom cleft-lift flap,[3] the gluteus-maximus


**Fig. 5.** A 37-year-old male patient underwent reconstruction with an SGAP flap after the pilonidal sinus was removed. A, A 12 × 5 cm transposition flap was subfascially elevated, including one perforator branch of the right superior gluteal artery. B, One year after the operation.


**Fig. 6.** A 33-year-old male patient underwent reconstruction with an SGAP flap after the pilonidal sinus was removed. A, A 10 × 5 cm transposition flap was subfascially elevated, including one perforator branch of the right superior gluteal artery. B, Eight months after the operation.

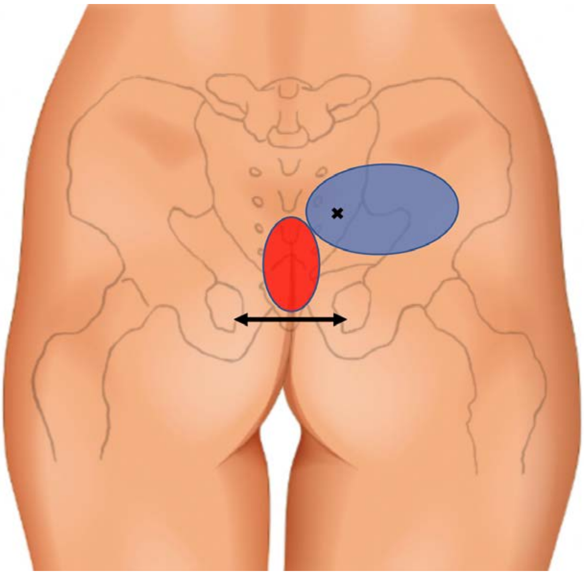

**Fig. 7.** The mechanical force analyses show that the skin from the sacrum to the coccyx is heavily stretched horizontally (black arrow) and loaded with both pressure and shear stress in the sitting position. The SGAP flap (blue oval) releases the horizontal tension on the defect (red oval). The SGAP flap is ~1.5-fold larger than the defects after surgery and included the medial perforator of the superior gluteal artery (X mark) that provided the optimum arc of rotation.

musculocutaneous flap,[27] the V-Y advancement flap,[12] and the Limberg (rhomboid) flap.[15] The Karydakis technique uses a mobilized subcutaneous flap that is secured to the sacrococcygeal fascia: it is used to close small off-midline defects.[4,31] The Bascom flap is a modification of the Karydakis flap. The Limberg flap is well known for its use in pilonidal sinus reconstruction and involves rhomboid excision of the pilonidal sinus followed by rotation of a rhomboid fasciocutaneous or subcutaneous flap that allows primary wound closure and flattening of the natal cleft.[32–35] Several publications, including a meta-analysis, suggest that these flaps have low recurrence rates when they are used for small defects.[36–39] However, the postoperative wound of these flaps runs nearly parallel to the direction of maximum stretching tension: this means they release the more minor vertical tension that is imposed on the wound during sitting but not the powerful horizontal tension. Moreover, these flaps leave a donor-site wound on the lower sacrum, which exposes it to healing complications due to the high mechanical forces on this area. Thus, from a mechanical point of view, these flaps may not be ideal for reconstructing large sacrococcygeal defects.

### Transposition Fasciocutaneous SGAP Flap is Particularly Suitable for Large Sacral Defect Reconstruction

The transposition SGAP flap addresses both mechanical requirements of large sacral reconstruction: it runs vertically and has sufficient subcutaneous tissue. Indeed, our retrospective analysis showed that the transposition SGAP flap effectively reconstructed 10 large ($18 \pm 8\,cm^2$; $6.9 \times 3.2\,cm$) defects without any complications in 6 postoperative months.

The perforators of SGAP flaps also make these flaps particularly suitable for sacral reconstruction. The vascular territory of the posterior surface of the sacrum is mainly supplied by the lateral sacral arteries and superior gluteal arteries.[20] Perforator flaps were first introduced for lower posterior midline defects by Kroll and Rosenfield,[40] and Koshima et al[27] showed a few years later that the gluteal perforators are always present and have large vessel diameters. This means that SGAP flaps can be up to $30 \times 13\,cm$ in size[41] and have a stable blood flow: this makes them suitable for large sacral defects. The fasciocutaneous SGAP flap can also be firmly fixed to the defect to neutralize the stretching of the wound caused by sitting. In addition, the donor site of the SGAP flap does not involve the lower sacrum and thus avoids exposing the donor-site wound to high pressure and shear stress.

We recommend using the transposition fasciocutaneous SGAP flap for pilonidal sinus defects that are at least 3 cm in the horizontal direction. In our cases, the SGAP flaps were ~1.5-fold larger than the defects after surgery and included the medial perforator of the superior gluteal artery, which provided the optimum arc of rotation.

### Limitations

The main limitation of this study is the small number of patients who underwent SGAP flap reconstruction for large pilonidal lesions. However, the lesions were large, which tested our theory that the SGAP may be an optimal flap for pilonidal sinus lesions. Nonetheless, a well-conducted randomized controlled trial that compares SGAP with other reconstructive methods is needed to confirm our findings. Another limitation is that our volunteers in the mechanical force analyses were all young men with normal BMI. Although this reflects the predominant profile of patients with pilonidal sinus,[5] it means that we could not examine the effect of obesity, which is a key risk factor for pilonidal disease,[6] on the mechanical forces on the sacral area, which needs to be addressed in future studies.

It should be noted that not all lesions are candidates for flap-based reconstruction. In particular, atraumatic minimally invasive techniques are often useful for relatively small lesions in areas with adequate subcutaneous tissue: these techniques include placing sutures in the deep fascia and the fibrous membrane of the fatty tissue.[42] This will limit the high stretching tension on the lesion that is imposed by daily body activities. Moreover, determining the best approach to take with pilonidal sinus should also be informed by the social situation of the patient. The habits of the surgeon will also play an important role.

## CONCLUSIONS

This study showed that sitting is associated with significant stretching tension of the sacrococcygeal skin, particularly in the horizontal direction. It is also associated with heavy loading of the lower end of the sacrum with both pressure and shear stress. These powerful mechanical forces may explain both the etiology of pilonidal disease and the fact that treated patients often develop complications, such as wound dehiscence, infection, and recurrence. When we considered these mechanical forces together, we concluded that the optimal flap for pilonidal sinus would be a transposed fasciocutaneous SGAP flap. Indeed, our analysis of a series of such flaps in patients with large pilonidal sinus revealed no complications. Thus, we recommend this flap for pilonidal sinus reconstruction. Our study also shows how understanding the local mechanical forces, including skin stretching, pressure, and shear stress, can be used to rationally select an optimal flap for reconstruction in general.

***Teruyuki Dohi, MD, PhD***
Department of Plastic, Reconstructive and Aesthetic Surgery
Nippon Medical School
1-1-5 Sendagi Bunkyo-ku, Tokyo 113-8603, Japan
E-mail: dohiprs@gmail.com

## DISCLOSURE

*The authors have no financial interest to declare in relation to the content of this article.*

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