

Research Article

Long-term clinical outcomes of innervated digital artery perforator flap in the treatment of fingertip injuries

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ARTICLE INFO

Article history:

Submitted August 22, 2020

Received in revised form

January 25, 2021

Last revision received

March 17, 2021

Accepted June 1, 2021

Keywords:

Fingertip

Reconstruction

Digital artery

Perforator flap

Neurovascular

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ABSTRACT

Objective: The aim of this study was to evaluate the long-term clinical outcomes of innervated digital artery perforator (IDAP) flap in the treatment of patients with fingertip injuries.**Methods:** Eighty-three patients (93 fingers; 70 male, 13 female; mean age = 35.2 years, age range = 5-65) with fingertip injuries who underwent acute or late reconstruction with IDAP flap between 2011 and 2016 were retrospectively reviewed. The mean age was 35.2 (range = 5-65) years. Reconstructions performed in 85 fingers (91.4%) were acute, and 8 fingers (8.6%) were late. Hypersensitivity, cold intolerance, and patient satisfaction were questioned as subjective evaluation parameters. The objective patient outcome evaluations consisted of static two-point discrimination (s2PD) test, the Semmes-Weinstein monofilament (SWM) test, and range of motion of the reconstructed fingers.**Results:** The mean follow-up period was 33.1 (range = 12-62) months. The smallest flap size was 1.6 x 0.7 cm; the largest flap size was 4 x 2 cm. All flaps survived completely. There was no postoperative infection or donor site morbidity. Hyperesthesia was observed in 4 fingers (4.3%), of which 3 were mild and 1 was moderate. Eighteen patients (18 fingers, 19.3%) experienced mild cold intolerance on reconstructed fingertips. 75 patients (90.3%) were highly satisfied, and 8 patients (9.7%) were satisfied with functional and aesthetic results of their fingertip reconstructions. No range of motion limitation was observed in any joints of 90 fingers (96.8%). The s2PD in the flaps ranged from 2 mm to 6 mm (mean = 3.71 ± 0.97 mm), compared with 2 mm to 5 mm (mean = 2.73 ± 0.66 mm) on the contralateral hand. The SWM test results of the flaps ranged from 2.44 to 4.56, compared with 2.44 to 4.31 on the contralateral hand. The difference regarding s2PD and SWM test was statistically significant ($P < 0.001$).**Conclusion:** IDAP flap seems to be a sensate, reliable, and versatile flap that can be used in acute and late reconstructions of any type of fingertip defects. Satisfactory functional and aesthetic results can be achieved with better sensorial results and lower complication rates compared to other conventional reconstruction techniques.**Level of Evidence:** Level IV, Therapeutic Study

Introduction

Fingertip injuries are one of the most common causes of emergency department admissions and frequently encountered by hand surgeons in their daily practices. The main goal in the treatment of such injuries is to achieve painless and aesthetic fingertip with stereognosis and proprioception properties, which sense heat, pain, and pressure. Moreover, type of the injury, expectations of the patient, surgeon's abilities, and experience should be considered while choosing the most appropriate treatment method.

Various reconstructive techniques have been described for fingertip injuries including composite flaps, local advancement flaps, homodigital/heterodigital neurovascular island flaps, perforator flaps, and free flaps. However, all of these techniques have shortcomings and disadvantages that include, inadequate sensation, donor site morbidity, limited flap size, prolonged immobilization, flexion contractures, and prolonged times to return to work.¹⁻⁴

In 2006, Koshima et al. described the Digital Artery Perforator (DAP) flap, which was designed to be elevated over single perforator closest to the defect.⁵ Complicated detection of perforators, venous congestion problems, and to be insensate are major shortcomings of the DAP flap.⁵⁻⁷ In 2013, a new reconstruction technique for the treatment of fingertip injuries was described, and it is the "Innervated Digital Artery Perforator" (IDAP) flap.⁸ The IDAP flap is a proximally based neurovascular island flap that provides sensate reconstruction for defects of the fingertip. Pedicle of the flap includes perforators and final segment of digital artery and nerve, and there is no need to isolate the perforator. This makes the flap more reliable and less technically demanding than DAP flap.⁸

Aim of the present study was to evaluate the long-term clinical outcomes of patients who underwent reconstruction with IDAP flap in the treatment of fingertip defects.

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Materials and Methods

Approval from the ethics committee was obtained, and informed consent was provided by all patients. One hundred fourteen patients (125 fingers) with fingertip injuries who underwent acute or late reconstruction with IDAP flap between August 2011 and October 2016 were evaluated. IDAP flap was preferred in patients with fingertip injuries and exposed distal phalanges where replantation was not feasible due to severely crushed amputation material or absence of it, and local flap was required for soft-tissue coverage. Eighty-three patients (93 fingers; 10 patients had multiple injuries in the same hand) were followed for more than 1 year postoperatively, and their physical examination and measurements were recorded regularly included in the study. Conditions that negatively affect regional blood flow (diabetes mellitus, vasospastic problems, smoking, etc.) were questioned.

The mean age of the patients was 35.2 years (range: 5-65 years). The mean follow-up period was 33.1 months (range: 12-62 months). Most commonly injured finger was the 3rd finger with a rate of 40.8% (38 fingers), and the most common defect type was transverse ($n = 57$; 61.3%). Demographics of the patients are summarized in Table 1.

Acute reconstruction was performed to 85 fingers (91.4%), and late reconstruction was performed to 8 fingers (8.6%). In case of late reconstruction, flap was performed in the same session after debridement. Late reconstructions were performed due to pulp necrosis developed after previous fingertip injury in seven patients and diabetic wound in one patient. The mechanisms of acute injuries were sharp and crush in 11 and 74 patients, respectively.

All operations were performed according to the surgical technique described by Ozcanli et al.⁸ Flap dissections were performed under digital block anesthesia with loupe magnification, and local anesthesia was performed for the donor site of the skin graft when required. An IDAP flap can be designed from either side of the digit; however, elevation from the ulnar side of the index, middle, and ring fingers is preferred; because this, area does not contact the thumb during hand activities. The flap was designed on the midlateral line distally, extending slightly dorsal and oblique to the midlateral line proximally. The distal part of the flap started at the edge of the wound, and the proximal portion can be extended to the dorsal part of the middle phalanx when necessary. The incision can be started from either the dorsal or volar part of the digit; however, dorsal incisions are preferred because of the ease of identifying the neurovascular bundle under the Cleland ligament. The subcutaneous tissue was dissected from the periosteum of the phalanx. The paratenon of the extensor system should be left intact. The Cleland ligament was divided to view the neurovascular bundle.

Table 1. Demographics of the Patients

Patients available for follow-up	83 patients (93 fingers)
Gender	70 (84.3%) male, 13 (15.7%) female
Affected hand	44 (53%) right, 39 (47%) left
Affected finger	
1 st	12 (12.9%)
2 nd	23 (24.8%)
3 rd (most-common)	38 (40.8%)
4 th	16 (17.2%)
5 th (least-common)	4 (4.3%)
Tamai classification	
Zone I	76 (81.7%)
Zone II	17 (18.3%)
Defect types	
Transverse	57 (61.3%)
Volar oblique	17 (18.3%)
Lateral oblique	9 (9.6%)
Dorsal oblique	7 (7.6%)
Pulp defect	3 (3.2%)
Smokers	29 patients (34.9%)
Mean smoking time	21.4 pack years
Diabetics (using oral antidiabetics/insulin)	6 patients (7.2%)

After identification of the neurovascular bundle, the palmar incision was meticulously dissected to the periosteum. The flap was mobilized as a digital artery island flap. The pedicle included the terminal branches of the digital nerve, the terminal digital artery, the perforators, and the subcutaneous venous system. A 2-3 mm cuff of subcutaneous tissue should be left around the pedicle to improve venous return through the venous plexus. Then, flap was rotated to cover the defect. The donor site of the flap was covered with a full-thickness skin graft. If available, graft was taken from amputation material. However, it was taken from the ulnar side of the wrist crease under local anesthesia when there is no amputation material and in late reconstructions. Neither orthosis nor anticoagulant therapy was used. The patients were encouraged to perform active range of motion exercises beginning 72 hours after the operations.

Subjective-objective parameters and satisfaction of the patients were evaluated, and the results in last examination were included in the study. All examinations were performed by a certified hand surgeon. Hypersensitivity, cold intolerance, and patient satisfaction were questioned with Likert-type scale as subjective evaluation parameters. Cold intolerance and hypersensitivity were classified into the following five grades: none, mild, moderate, disturbing, and severe.

Patient satisfaction was questioned in terms of both functional and aesthetic aspects of the procedure, and the degree of satisfaction was evaluated as “highly satisfied, satisfied, moderate, dissatisfied, and highly dissatisfied”.

Static 2-Point Discrimination (s2PD) and Semmes-Weinstein Monofilament (SWM) test were applied in comparison with contralateral intact fingers of the patients as objective evaluation parameters. The s2PD distances were recorded in millimeters. A 20-piece full kit of SWM (Touch-Test, North Coast Medical, Inc., Gilroy, CA, USA) was used to evaluate cutaneous pressure threshold. Metacarpophalangeal (MP), Proximal Interphalangeal (PIP), and Distal Interphalangeal (DIP) joints' range of motion of the reconstructed fingers were evaluated, and existing limitations were recorded.

HIGHLIGHTS

- IDAP flap is a sensate, reliable, and versatile flap that can be used in acute and late reconstructions.
- Surgical procedure is technically straightforward, less demanding, single-stage, and performed under digital block anesthesia. Additional local anesthesia is performed when skin graft needs to be taken from wrist.
- Any type of defect (volar, dorsal, lateral oblique, transverse, pulp defect, etc.) in any finger can be safely reconstructed with IDAP flap.
- Satisfactory functional and aesthetic results can be achieved with better sensorial results and lower complication rates compared to other conventional reconstruction techniques.

Statistical analyses and descriptive statistics were presented with frequencies and percentages. The difference between operated and contralateral fingertip findings regarding s2PD and SWM tests was evaluated with the paired samples *t* test and Wilcoxon signed-rank test.

Results

The smallest flap size was 1.6×0.7 cm, and the largest flap size was 4×2 cm. Seventy-six (81.7%) flaps were designed from the ulnar side of the finger and 17 (18.3%) from the radial side. All flaps survived completely (Figure 1-6). There was no postoperative infection or donor site morbidity. In the early postoperative period, 6 (6.4%) of 93 fingers had transient venous congestion findings. Congestion regressed in two of the patients after elevation and loosening dressing. Superficial epidermolysis was observed in four fingers (4.3%). However, no secondary intervention was needed.

Mild hyperpigmentation was detected in two fingers (2.15%). Hyperesthesia was observed in four fingers (4.3%); three of these were mild and one was moderate. Eighteen patients (18 fingers, 19.3%) experienced mild cold intolerance on reconstructed fingertips. 55.5% ($n = 10$) of the patients with cold intolerance were smoking.

All patients were asked to evaluate their surgical procedure both functionally and aesthetically; 75 patients (90.3%) reported being “highly satisfied” and 8 patients (9.7%) reported being “satisfied” with the results of their fingertip reconstructions.

The s2PD in the flaps ranged from 2 to 6 mm (mean, 3.71 ± 0.97 mm), compared with 2 to 5 mm (mean, 2.73 ± 0.66 mm) on the contralateral hand. The SWM test results of the flaps ranged from 2.44 to 4.56, compared with 2.36 to 4.31 on the contralateral hand. The difference regarding s2PD and SWM test was statistically significant ($P < 0.001$) (Table 2).

No range of motion limitation was observed in any joints of 90 fingers (96.8%). One patient had 20° of flexion limitation in the IP joint of 1st finger, and two patients had 10° and 15° of extension loss, respectively, in the DIP joint of 2nd fingers.

Discussion

The main purpose in the treatment of fingertip injuries is to obtain a painless, firm, aesthetic, and sensory fingertip. Local and regional flaps have become popular in the last decade, with the advances in microsurgical techniques. However, ideal flap for fingertip injuries is still controversial. The ideal flap should be versatile, reliable, sensate, single-staged, and easily performed with few complications and donor site morbidities.

Pulp sensation has been the keystone of successful fingertip reconstruction. A sensate fingertip is important for precise stereognosis object identification and function. This increases efforts to make the

techniques used in fingertip reconstruction more sensate with various modifications.⁹⁻¹¹ Cohen and Cronin defined a sensate cross-finger flap and reported an average of 4.8 mm s2PD with this flap.⁹ Yazar et al. performed homodigital island flap with nerve coaptation to 70 fingers of 66 patients and found a mean of 5.7 mm s2PD.¹⁰ However, although satisfactory sensory results have been obtained with these modifications, microsurgical requirement, technical difficulty, and prolonged operation time are the most important handicaps. IDAP flap is a sensate flap; pedicle of the flap includes branches of the digital nerve. There is no need for neuroorrhaphy, which shortens the operation time and reduces the need for microsurgery. In the present study, mean s2PD in reconstructed fingers was 3.71 ± 0.97 mm, and the SWM test results ranged from 2.44 to 4.56. Although these results were statistically different ($P < 0.001$) from uninjured counterparts, IDAP flap seems to lead to better sensorial properties when compared to previously published studies using different kinds of local or regional flaps for covering the fingertip defects^{7,9-20} (Table 3). Moreover, previous studies have shown that sensory recovery reduces in flaps larger than 1×1 cm without neuroorrhaphy.²¹⁻²⁴ However, the results of the present study showed that IDAP flaps larger than 2×1 cm could also remain sensitive.

Table 3. Comparison of the Sensorial Outcomes of Different Local or Regional Flaps for Covering the Fingertip Defects

	Reconstruction Type	Number (Patients/Fingers)	Mean s2PD (mm)	SWM
Cohen & Cronin ⁹	Innervated cross-finger flap	7/7	4.8	
Yazar et al. ¹⁰	Homodigital island flap	66/70	5.7	2.83-3.61
Lee et al. ¹¹	Cross-finger flap	21/21	7.2	4.08-4.74
	Innervated cross-finger flap	69/69	4.6	3.22-3.84
Rinker ¹²	Thenar flap	15/15	5.5	
Shao et al. ¹³	Dorsal island pedicle flap	11/11	4.4	3.61-6.65
Chen et al. ¹⁴	Heterodigital neurocutaneous island flap	12/12	8.3	3.61-4.56
Acar et al. ¹⁵	Reverse flow homodigital flap	11/22	10.3	
Chen et al. ¹⁶	Dorsal homodigital island flap	166/187		
	• Non-innervated	35 fingers	10.5	3.84-4.56
	• Single-innervated	76 fingers	8.7	3.84-4.56
	• Dual-innervated	17 fingers	5.9	3.22-4.56
Ozcanli et al. ⁷	Digital artery perforator flap	15/15	5.3	3.61-4.56
Kim et al. ¹⁷	Innervated reverse digital artery island flap	25/30	5.9	3.22-4.17
Usami et al. ¹⁸	Oblique triangular flap	17/17	6.4	2.83-4.56
	Reverse digital artery island flap	14/14	8.2	3.22-4.56
Arsalan-Werner et al. ¹⁹	Homodigital neurovascular island flap	28/29	5.1	2.83-4.31
Qin et al. ²⁰	Modified dorsolateral proximal phalangeal island flap	16/16	8	
	Homodigital dorsal perforator flap	11/11	8.5	
Present study	Innervated digital artery perforator flap	83/93	3.7	2.44-4.56

Table 2. Difference between Operated and Contralateral Fingertip Findings Regarding s2PD and SWM

	Operated Fingertip	Contralateral Fingertip	<i>P</i> *
s2PD, mean ± SDa	3.71 ± 0.97	2.73 ± 0.66	<001
SWM, mean ± SDa	3.18 ± 0.37	2.94 ± 0.33	<001
s2PD, median (min-max)b	4 (2-6)	3 (2-5)	<001
SWM, median (min-max)b	3.22 (2.44-4.56)	2.83 (2.36-4.31)	<001

**P* values

^aPaired samples *T* test.

^bWilcoxon signed-rank test

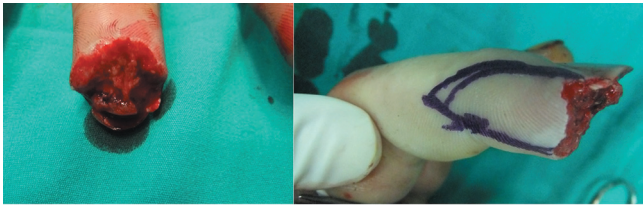


Figure 1. 24 years old, male patient, crush injury in right hand, 3rd finger, and volar oblique defect. An IDAP flap (2 × 1.5 cm) was designed on the ulnar side of the finger.

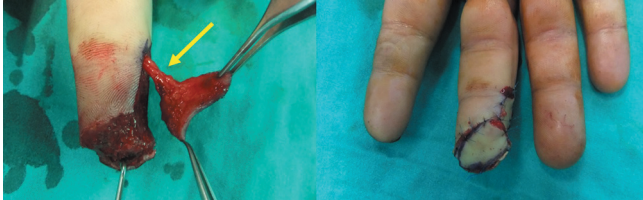


Figure 2. Flap was elevated (yellow arrow shows the pedicle). Flap was rotated 180° to cover the defect.



Figure 3. Postoperative 62nd month. s2PD and SWM test results were 4 mm and 3.22 in reconstructed finger and 3mm and 2.83 in contralateral finger.



Figure 4. 35 years old, male patient, crush injury in right hand, 3rd finger, and dorsal oblique defect. An IDAP flap (3 × 1.5 cm) was designed on the ulnar side combined with an eponychial flap.

Patients can experience subjective sensory complaints such as hypoesthesia, dysesthesia, cold intolerance, and hypersensitivity in most of the fingertip reconstruction techniques, especially the advancement flaps.^{25–27} These sensory problems are encountered due to tension of the digital nerve and its branches after advancement.² In the present study, hyperesthesia was observed in 4.3%, and cold intolerance was observed in 19.3%. Hyperesthesia rate in our study was significantly lower than similar studies involving other fingertip reconstruction techniques. In a study evaluating volar V-Y advancement flap, 7 out of 10 patients (70%) had hypoesthesia or dysesthesia. The same

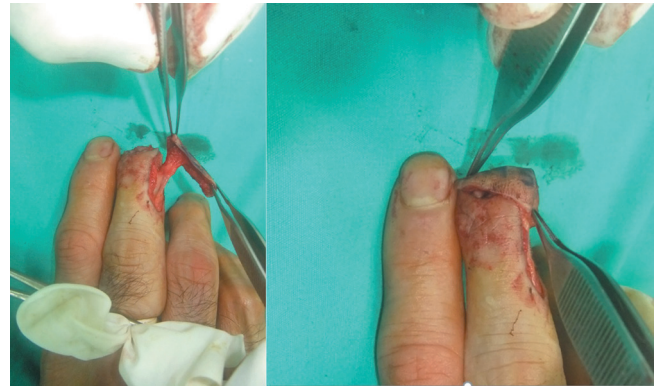


Figure 5. IDAP flap was elevated and rotated 180° to cover the defect.

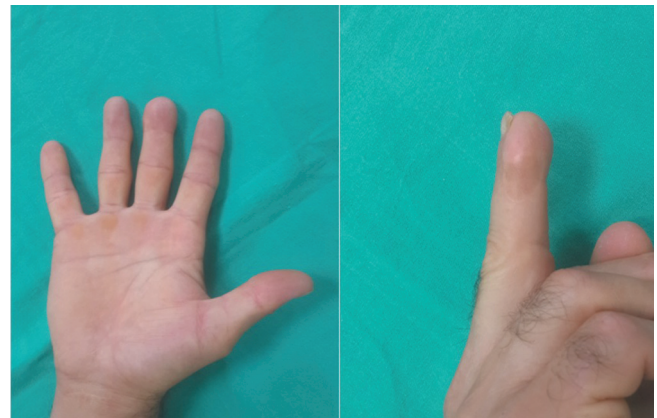


Figure 6. Postoperative 48th month. s2PD and SWM test results were 4 mm and 3.22 in reconstructed finger and 3 mm and 3.22 in contralateral finger.

study reported hypo/hyperesthesia in 10 of 14 patients (71%) whom Kutler flap was performed.²⁶ Usami et al. reported 10% severe hypersensitivity in patients whom oblique triangular flap was performed.¹⁸ In another study, 78% of the patients experienced hypoesthesia.²⁸ Sano et al. evaluated the sensory recovery after oblique triangular flap and hyperesthesia were detected in 50%.²⁹

In our experience, the reason for this low rate of hyperesthesia is extensive arc of rotation of the IDAP flap. Depending on the size and configuration of the defect, flap can be rotated 90° (especially for volar and dorsal oblique defects) or 180° (especially for lateral oblique and transverse defects). Thus, nerve is not under tension after flap is rotated and defect is covered.

The pathophysiology in cold intolerance is different and remains controversial. Van den Berg et al. evaluated 59 fingertip injuries treated with 3 different techniques (secondary granulation, revision amputation, and reconstruction) and detected cold intolerance in 50 fingers (84.7%).³⁰ Cold intolerance rates were reported as 41.6%, 17%, and 16.6% in the studies, in which patients were treated with retrograde homodigital island flap, antegrade homodigital island flap, and innervated cross-finger flap, respectively.^{2,11,31} These high rates even with different reconstruction techniques show that cold intolerance is a complication of injury rather than treatment.

Prolonged immobilization should be avoided in reconstructive surgeries to prevent joint stiffness. Although two-stage flaps like cross-

finger flap and thenar flap are simple, quick, and reliable flaps, patients have a risk of joint stiffness due to prolonged immobilization.^{4,32} Flexion contracture of PIP joint is also a common complication of antegrade homodigital island flaps. In the literature, extension restriction rates in PIP joint were between 8% and 29% on average.³³ One of the advantages of IDAP flap is that it enables early joint motion. Patients were encouraged to undertake active range of motion exercises beginning 3 days after surgery. In our study, 90 (96.8%) of 93 fingers had no restriction in range of motion.

Varying rates of flap loss were reported with different techniques in fingertip reconstructions. Lai et al. reported flap loss in 15% of cases, in which retrograde neurovascular island flap was performed.³⁴ In another study performing retrograde neurovascular island flap, flap loss was observed in 20.8% of 23 patients.³ Takeishi et al. performed innervated dorsal digital island flap to eight patients with fingertip injuries. Six out of eight flaps survived; partial flap loss was observed in two (25%) flaps.³⁵ Chen et al. reported the results of 166 patients' (187 fingers) fingertip injuries reconstructed with dorsal homodigital island flap. Venous congestion was observed in 18 patients (10%) and partial flap loss in 14 patients (8%).¹⁶ IDAP flap has a reliable vascular pedicle including perforators of digital artery and subcutaneous veins.⁸ There is no need to isolate the perforator, so vascularity, especially venous drainage, is improved compared with other flaps. Consequently, the risk of arterial insufficiency and venous congestion is much lower. One noteworthy result in our study was that no total or partial flap loss was observed in any of the patients whom 34.9% were smokers and 7.2% diabetics. This finding also suggest that IDAP flap can be safely performed in conditions that negatively affect regional blood flow such as diabetes mellitus and smoking.

The main limitation of the study is the absence of comparison groups with other reconstruction techniques. Lack of data of the patients' return time to work is another limitation. However, our study is the only study evaluating the long-term clinical outcomes of IDAP flap.

In conclusion, IDAP flap is a sensate, reliable, and versatile flap that can be used in acute and late reconstruction of any type of fingertip defects with satisfactory functional and aesthetic results. Surgical procedure is quick and single-stage, allowing full active range of motion with short hospitalization period. Although sensorial results of operated fingers were statistically different from uninjured counterparts, the IDAP flap seems to lead to better sensorial properties when compared to previously published results of other reconstruction options. Moreover, these long-term results showed us that IDAP flap has lower complication rates compared to other conventional reconstruction techniques.

Ethics Committee Approval: Ethics committee approval was received for this study from the Clinical Researches Ethics Committee of Akdeniz University, School of Medicine (2012-KAEK-20).

Informed Consent: Informed consent was obtained from the all patients.

Author Contributions: Concept - A.C., O.C., H.Ö.; Design - A.C., H.Ö.; Supervision - A.C., O.C., H.Ö.; Fundings - A.C., H.Ö.; Materials - A.C., O.C., H.Ö.; Data Collection and/or Processing - A.C., O.C., H.Ö.; Analysis and/or Interpretation - A.C., O.C., H.Ö.; Literature Review - A.C., O.C., H.Ö.; Writing - A.C., H.Ö.; Critical Review - A.C., O.C., H.Ö.

Conflict of interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

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