OPEN

PRS GLOBAL OPEN

ORIGINAL ARTICLE
Reconstructive

Implantable Doppler Probes for Postoperatively Monitoring Free Flaps: Efficacy. A Systematic Review and Meta-analysis

Tzu-Yen Chang, MD*
Yao-Chou Lee, MD†
You-Cheng Lin, MD*
Stanley Thian-Sze Wong, MD‡
Yuan-Yu Hsueh, MD, PhD†
Yao-Lung Kuo, MD, PhD*
Shyh-Jou Shieh, MD, PhD†
Jing-Wei Lee, MD†

Background: Although clinical assessment remains the gold standard for monitoring the circulation of free flaps, several adjunct techniques promote timely salvage by detecting circulation compromise early. The objective of this systematic review was to evaluate the efficacy of an implantable Doppler probe for postoperatively monitoring free flaps.

Materials and Methods: English-language articles evaluating the efficacy of implantable Doppler probes compared with clinical assessment for postoperatively monitoring free flaps were analyzed. The outcome measures were total flap failure rates, salvage rates, sensitivity, false-positive rates, and positive likelihood ratios.

Results: Of the 504 citations identified, 6 comparative studies were included for meta-analysis. An implantable Doppler probe significantly lowered the flap failure rate (risk ratio: 0.40; 95% confidence interval: 0.21–0.75) and raised the successful salvage rate (risk ratio: 1.73; 95% confidence interval: 1.16–2.59). Pooled sensitivity was higher (1.00 vs 0.98), the positive likelihood ratio was lower (72.16 vs 220.48), and the false-positive rate was higher (0.01 vs 0) in the implantable Doppler probe group than in the clinical assessment group.

Conclusion: An implantable Doppler probe is significantly more efficacious than clinical assessment for postoperatively monitoring free flaps. *(Plast Reconstr Surg Glob Open 2016;4:e1099; doi: 10.1097/GOX.0000000000001099; Published online 28 November 2016.)*

Although the success rate of free tissue transfer has increased to more than 95% since its advent in the 1950s, a small but significant failure rate is still unavoidable.[1,2] Most flap failures are secondary to vascular compromise and usually occur within 3 days after surgery.[3] Early detection of the vascular compromise followed by timely salvage procedures successfully salvage 70% to 80% of flaps.[4–6] However, an accurate clinical assessment of flap pedicle patency has always been a challenge for surgeons and nurses.

An implantable Doppler probe theoretically provides a direct and real-time measurement of the flow of pedicle vessels. A 20-MHz pulsed ultrasonic Doppler probe is mounted on a silicone cuff that stabilizes the probe on the pedicle vessels using direct sutures, sutures passing through a Vicryl mesh, fibrin sealant, or microclips.[7–11] A wire connects the probe's proximal end and exits through the wound. An intermediate cable is used to connect this wire to the transportable monitor.[12] This probe was initially used for arterial monitoring, but it can also be modified to be a venous monitor to facilitate detecting venous thromboses.[8] Since its introduction by Swartz et al,[7] the implantable Doppler probe has become the one of the most popular adjunct free flap monitoring methods used by head and neck (27.3%) and extremity (31.0%) surgeons.[13]

This venous monitoring system, however, was challenged for its high false-positive rate, which was caused primarily by probe dislodgement.[14,15] Moreover, using

*From the *Division of Plastic and Reconstructive Surgery, Department of Surgery, National Cheng Kung University Hospital, Dou-Liou Branch, Yunlin, Taiwan; †Division of Plastic and Reconstructive Surgery, Department of Surgery, National Cheng Kung University Hospital, College of Medicine, National Cheng Kung University, Tainan, Taiwan; and ‡Department of Surgery, Queen Mary Hospital, Pok Fu Lam, Hong Kong.*

The current affiliation for You-Cheng Lin is the Division of Plastic and Reconstructive Surgery, Department of Surgery, Chi Mei Medical Center, Tainan, Taiwan.

Received for publication July 26, 2016; accepted September 2, 2016.

DOI: 10.1097/GOX.0000000000001099

Disclosure: *The authors have no financial interest to declare in relation to the content of this article. The Article Processing Charge was paid for by the authors.*

it to monitor free tissue transfer yields inconclusive results.[9,16–20] Only one systematic review[21] focuses on the cost-effectiveness of the system.

Therefore, we wanted to clarify whether, compared with clinical assessment alone, using an implantable Doppler probe improved flap survival rate by increasing the successful salvage rate. We synthesized study outcomes using a meta-analysis to provide better insight into the efficacy of using an implantable Doppler probe in free tissue transfers.

MATERIALS AND METHODS

Literature Search Strategy

We searched, in January 2016, the PubMed, Ovid Medline, Cochrane, and Embase databases for articles on the efficacy of implantable Doppler probes for postoperatively monitoring free flaps. The controlled keywords were "implantable Doppler" OR "Cook-Swartz Doppler" OR "Cook-Swartz probe." The searches were done in accordance with the PRISMA and MOOSE guidelines. All articles were manually screened to retrieve relevant studies.

Inclusion Criteria

All clinical articles evaluating the outcome of free flap surgery using an implantable Doppler probe for postoperative monitoring were considered candidates. All included citations had to have information on flap salvage and flap failure rates.

Exclusion Criteria

Reviews, case reports, series without comparison groups, letters, communications, animal studies, and non-English–language articles were excluded.

Study Selection Method

Based on the titles and abstracts, 2 authors, using the exclusion criteria, independently reviewed the candidate studies. Articles were excluded when both reviewers agreed that their titles or abstracts excluded them. Full texts for the remaining articles were then retrieved and selected when both reviewers agreed that they met the inclusion criteria.

Data Collection

Data from all of the included studies were extracted as follows: first author, publication, study design, the constitution of control groups, recipient sites, flap types, proportion of buried flaps, and number of patients; total flaps, failure flaps, pedicle compromise flaps, and successfully salvaged flaps. True positive and true negative were recorded. The primary outcomes were flap failure and flap salvage rates. Flap failure was defined as a complete (total) flap failure. The flap salvage rate was calculated as a quotient of all flaps with true pedicle vessel compromise that finally survived and all flaps with true pedicle compromise. The secondary outcomes were the sensitivity, false-positive rate, and positive likelihood ratio (LR) of each monitoring method. The false-positive rate was calculated as a quotient of all flaps with positive monitoring alarms that were found to have no pedicle compromise and all flaps with no pedicle compromise. If the patient totally removed the wire and induced the alarm, it was excluded from further analysis and classified as attrition bias. Despite the possibility that the Doppler probe could be dislodged, all cases returned to the operating room because of an alarm were calculated, and they were defined as false positives if the pedicle vessel was patent.

Quality Assessment

Quality assessment for comparative studies used the Newcastle-Ottawa Scale (NOS),[22] which uses a star system (maximum: 9 stars) to evaluate a study in 3 domains: selection of participants, comparability of study groups, and ascertainment of outcomes of interest. We judged 9-star studies to have a low risk of bias, 7- to 8-star studies to have a medium risk, and ≤6-star studies to have a high risk of bias.

Statistical Analysis

We used risk ratio (RR) and 95% confidence interval (CI) to summarize the effect sizes for dichotomous outcome measures; each outcome was calculated using the Mantel–Haenszel test in RevMan 5.3 (Cochrane Informatics and Knowledge Management Department; Copenhagen, Denmark). A fixed-effect model was used where there was no evidence of heterogeneity between studies, and a random-effects model was used when such heterogeneity was likely. The heterogeneity for each study was assessed using Cochrane Q statistical and I^2 tests. When the I^2 analysis ranged from 50% to 100%, statistical heterogeneity was assumed significant.[23] The pooled sensitivity and positive LR were calculated using Meta-DiSc 1.4 (XI Cochrane Colloquium; Barcelona, Spain).

RESULTS

Study Selection

We found 504 citations for articles about implantable Doppler probes. Abstracts of 395 articles were reviewed after the duplicates had been eliminated. Based on our specified exclusion criteria, the texts of 22 articles were assessed for eligibility. Eight comparative observational studies[9,16–20,24,25] met the inclusion criteria. Because Rozen et al[17] and Whitaker et al[24] shared some patients, the latter was excluded. Because Ho et al[25] selected their patients using specified criteria rather than consecutively, it, too, was excluded. Finally, 6 articles[9,16–20] were included in a quantitative synthesis (Fig. 1).

Study Characteristics

One prospective and 5 retrospective observational comparative studies are summarized in Table 1. The one prospective study, Rozen et al,[18] had a sample of 40 consecutive flaps. The first set of 20 flaps was monitored using clinical assessment, and the second set of 20 flaps was monitored using an implantable Doppler probe. The NOS[22] score for Rozen et al[18] was 8 (Table 2). Three[16,17,19]

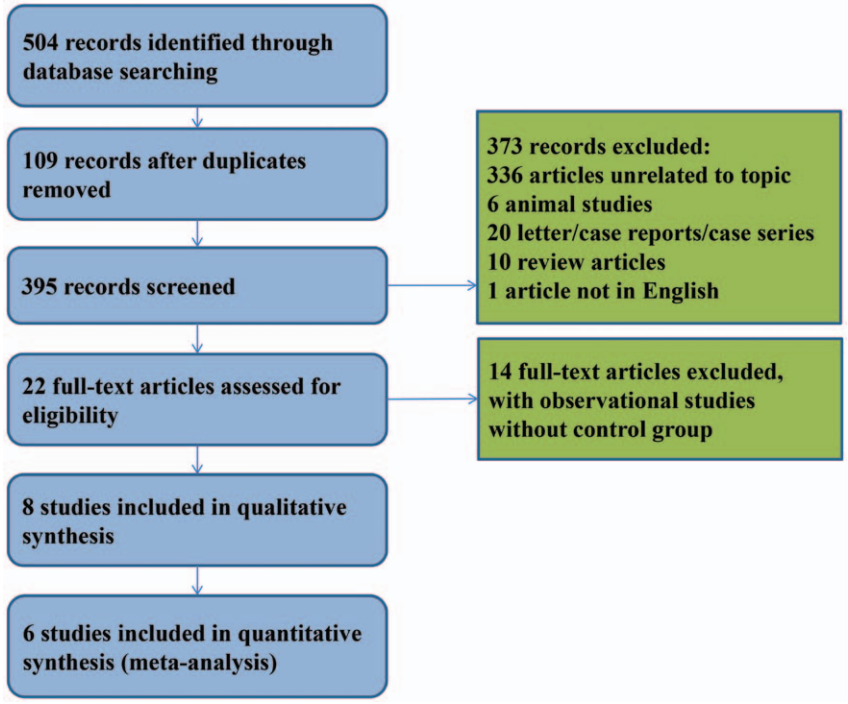

Fig. 1. Study attrition diagram.

Table 1. Characteristics of Included Studies

Study	Study Design, Study Quality	No. Patients		No. Flaps		Recipient Sites	Flap Types
		Implantable Doppler Probe	Clinical Assessment	Implantable Doppler Probe	Clinical Assessment		
Kind et al,[9] 1998	Single center, retrospective, NOS = 6	135	NM	147	1317	HN, UE, LE	Colon, fibula, gracilis, toe, LA, LD, RF, RA, serratus
Ferguson and Yu,[20] 2009	Single center, retrospective, NOS = 6	16	66	16	66	PE, TE	RF, ALT
Rozen et al,[17] 2010a	Single center, retrospective, NOS = 7	121	426	121	426	Breast	DIEP, SIEA, SGAP
Rozen et al,[18] 2010b	Single center, prospective cohort study, NOS = 8	20	20	20	20	LE	ALT, parascapular, LD, gracilis, serratus, LA, RF
Smit et al,[19] 2010	Single center, retrospective, NOS = 8	NM	NM	323	307	Breast, HN, UE, LE	Cutaneous/ fasciocutaneous, musculocutaneous, osteocutaneous
Schmulder et al,[16] 2011	Single center, retrospective, NOS = 7	NM	NM	226	263	HN, breast, UE, LE	NM

ALT, anterolateral thigh flap; DIEP, deep inferior epigastric artery perforator flap; HN, head and neck; LA, lateral arm flap; LD, latissimus dorsi flap; LE, lower extremity; NM, not mentioned; PE, pharyngoesophagus; RA, rectus abdominis flap; RF, radial forearm flap; SGAP, superior gluteal artery perforator flap; SIEA, superficial inferior epigastric artery flap; TE, trachea; UE, upper extremity.

of the 5 retrospective studies monitored consecutive flaps in their experimental groups using an implantable Doppler probe and flaps in their control groups using clinical assessment before the implantable Doppler probe had been introduced. Smit et al[19] monitored 8 flaps by flap type and defect location; the other 2 studies[16,17] monitored 7 consecutive flaps each. Kind et al[9] did not mention whether the flaps were from consecutive cases, but they did say that the control group contained patients clinically monitored before the implantable Doppler probe had been introduced. The NOS score for Smit et al[19] was 6. The fifth retrospective study, Ferguson and Yu,[20] neither consecutively nor randomly but individually compared monitoring methods within 6 years. The NOS score for Ferguson and Yu[20] was also 6. These last 2 studies might have a major bias because the surgeons improved their technique over time; therefore, the outcomes might not have been comparable.

Totally, 3252 flaps were analyzed: 853 were monitored using an implantable Doppler probe and 2399 were moni-

Table 2. Quality Assessment Using the NOS

	Selection				Comparability		Exposure			
Study	Adequate Definition of Cases	Representativeness of Cases	Selection of Controls	Definition of Controls	Study Controls for Age and Sex	Study Controls for Additional Factors	Exposure Assessment	Same Method of Ascertainment for Cases and Controls	Nonresponse Rate	Total Quality Scores
Kind et al,[9] 1998	+	–	–	+	+	–	+	+	+	6
Ferguson and Yu,[20] 2009	+	–	–	+	+	–	+	+	+	6
Rozen et al,[17] 2010a	+	+	–	+	+		+	+	+	7
Rozen et al,[18] 2010b	+	+	–	+	+	+	+	+	+	8
Smit et al,[19] 2010	+	+	–	+	+	+	+	+	+	8
Schmulder et al,[16] 2011	+	+	–	+	+	–	+	+	+	7

tored using clinical assessment. The mean flap failure rate was 3.67%, and the mean flap salvage rate was 65.40%.

Efficacy on Flap Failure Rate

Overall, in the implantable Doppler probe groups, 18 flaps totally failed (flap failure rate: 2.11%), and in the clinical assessment group, 101 flaps totally failed (flap failure rate: 4.21%) (Table 3). There was no significant heterogeneity between the trials (I^2: 16%). Therefore, we used a fixed-effects model, which showed a significant difference of flap failure rate between the implantable Doppler probe and the clinical assessment groups (RR: 0.37; 95% CI: 0.23–0.26) (Fig. 2A). When we removed Ferguson and Yu,[20] which consisted of buried flaps, the I^2 fell to 0%, and the flap failure rate still had significant difference between the groups (RR: 0.36; 95% CI: 0.21–0.61) (Fig. 2B). When we removed Kind et al[9] and Ferguson and Yu,[20] the 2 moderate-quality studies, the I^2 was 0%, and the flap failure rate still had significant difference between the groups (RR: 0.38; 95% CI: 0.22–0.65) (Fig. 2C).

Efficacy on Flap Salvage Rate

Overall, in the implantable Doppler probe group, 83 flaps with true pedicle compromise were successfully revised and salvaged (flap salvage rate: 83%). In the clinical assessment group, 157 flaps with true pedicle compromise were successfully revised and salvaged (flap salvage rate: 59%). Ferguson and Yu[20] could not be further synthesized because no thromboembolic event occurred in the control group (Table 4). Because the heterogeneity between the trials was significant and the I^2 was 60%, we used a random-effects model, which showed a significant 57% increase in the salvage rate in the implantable Doppler probe group (RR: 1.57; 95% CI: 1.20–2.06; $\tau^2 = 0.05$) (Fig. 3A). When we removed Kind et al,[9] the I^2 rose to 61%, and the salvage rate in the implantable Doppler probe group rose to a significant 73% increase (RR: 1.73; 95% CI: 1.16–2.59; $\tau^2 = 0.10$) (Fig. 3B).

Sensitivity

Sensitivity was 100% in all implantable Doppler probe groups except for the one in Ferguson and Yu,[20] which reported only one false-negative case (Table 5). Sensitivity ranged from 97.5% to 100% in clinical assessment groups, but only 3 studies[17–19] reported these data. Comparing these 3 studies, the pooled sensitivity for implantable Doppler probe groups was 1.00 (95% CI: 0.92–1.00; I^2: 0%) (Fig. 4A). In contrast, for the clinical assessment groups, it was 0.98 (95% CI: 0.93–1.00; I^2: 0%) (Fig. 4B).

False-Positive Rate and Positive LR

In the implantable Doppler probe groups, the false-positive rate ranged from 0% to 33%, and the pooled false-positive rate was 0.010 (95% CI: 0.003–0.024; I^2: 0%) Only 3 studies[17–19] reported a false-positive rate for their clinical assessment groups: all were 0. Comparing these 3 studies, the pooled positive LR for the implantable Doppler probe groups was 72.16 (95% CI: 31.39–165.87; I^2: 0%) (Fig. 5A). For the clinical assessment groups, it was 220.48 (95% CI: 27.92–740.88; I^2: 40.5%) (Fig. 5B).

Table 3. Flap Failure Rates in Each Article

Study	Implantable Doppler Group		Clinical Assessment Group		RR (95% CI)
	Failed Flaps (*n*)	Total Flaps (*n*)	Failed Flaps (*n*)	Total Flaps (*n*)	
Kind et al,[9] 1998	0	147	41	1317	0.11 (0.01–1.74)
Ferguson and Yu,[20] 2009	1	16	0	66	11.82 (0.50–277.59)
Rozen et al,[17] 2010a	2	121	18	426	0.39 (0.09–1.66)
Rozen et al,[18] 2010b	0	20	3	20	0.14 (0.01–2.60)
Smit et al,[19] 2010	11	323	25	307	0.42 (0.21–0.84)
Schmulder et al,[16] 2011	4	226	14	263	0.33 (0.11–1.00)
Total	18	853	101	2399	

RR, risk ratio.

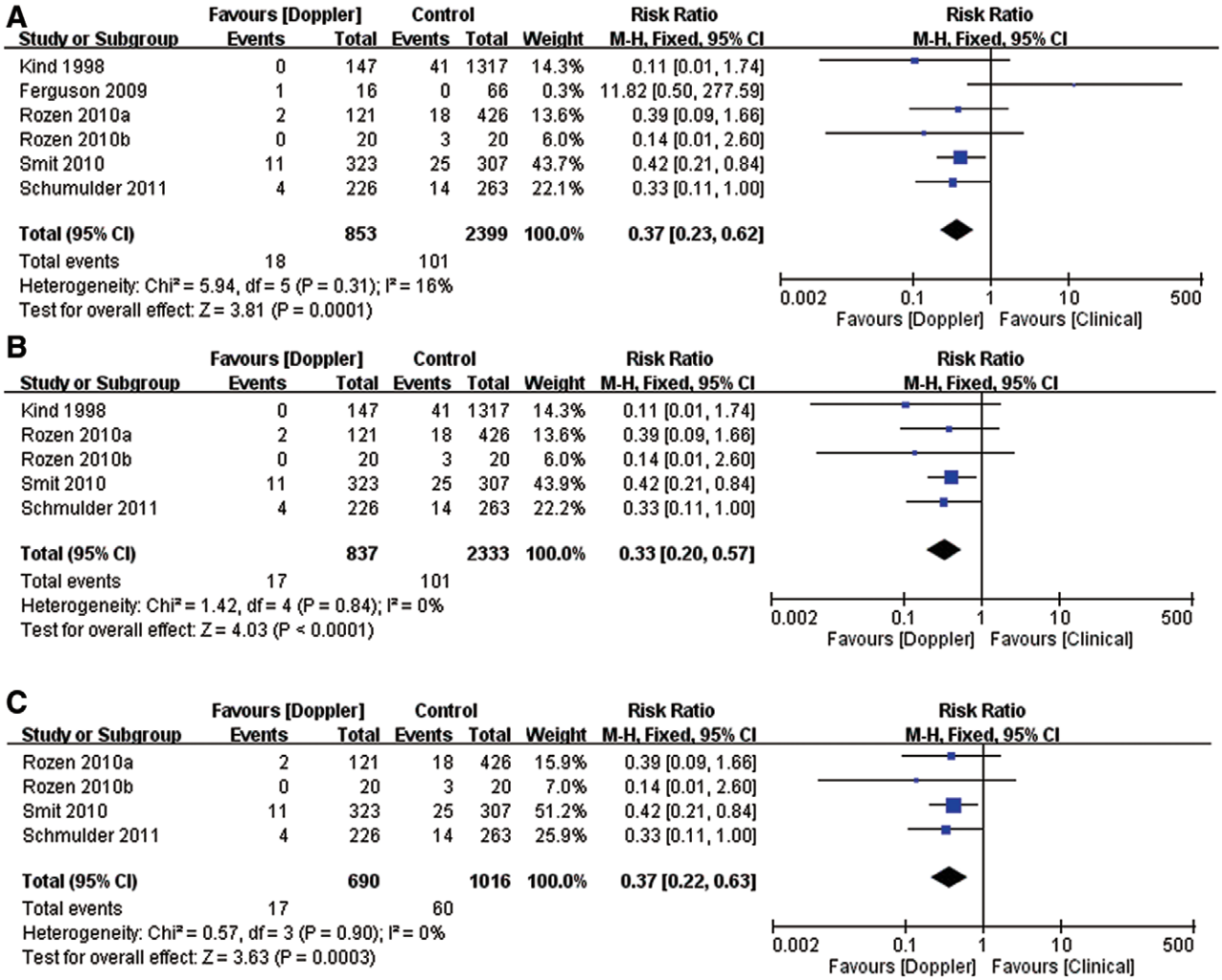

Fig. 2. Forest plots comparing the potential benefits for the flap failure rate when using the implantable Doppler probe and the traditional clinical assessment method. The implantable Doppler probe group had a significantly lower flap failure rate (A). The failure rate was still significantly lower after Ferguson and Yu,[20] the pure buried flap study had been removed (B), and after Kind et al,[9] a study of moderate quality (NOS of 5 or 6) had also been removed (C).

DISCUSSION

We provide evidence that implantable Doppler probes are efficacious for postoperatively monitoring free flaps: flap failure rates were significantly lower, flap salvage rates were significantly higher, and general success rates and microvascular re-exploration success rates were significantly better than for traditional clinical monitoring. Three of the comparative studies[17–19] that we analyzed, however, did not report significant differences between the 2 methods, and one[20] reported an inferior result for implantable Doppler probe monitoring. The latter included only buried flaps, and the implantable Doppler probe group was compared with a clinically monitored group of patients with an externalized flap segment. After we removed this

Table 4. Flap Salvage Rates in Each Article

Study	Implantable Doppler Probe Group			Clinical Assessment Group			RR (95% CI)
	Successful Revision	True Pedicle Compromise	Salvage Rate	Successful Revision	True Pedicle Compromise	Salvage Rate	
Kind et al,[9] 1998	20	20	100%	102	143	71.33%	1.37 (1.21–1.55)
Rozen et al,[17] 2010a	8	10	80%	17	53	32.08%	2.49 (1.51–4.11)
Rozen et al,[18] 2010b	2	2	100%	2	5	40%	2.00 (0.68–5.85)
Smit et al,[19] 2010	24	35	68.57%	24	40	60%	1.14 (0.81–1.60)
Schmulder et al,[16] 2011	29	33	87.88%	12	26	46.15%	1.90 (1.23–2.94)
Overall	83	100	83%	157	267	58.80%	

RR, risk ratio.

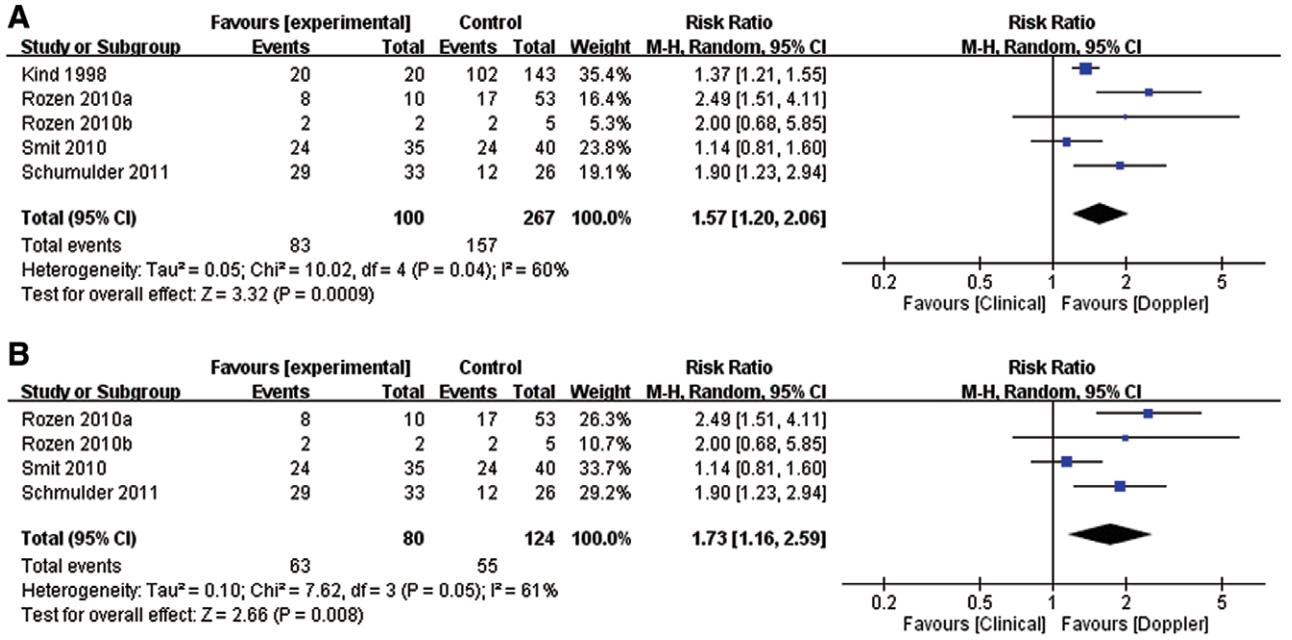

Fig. 3. Forest plots evaluating the potential benefits for the flap salvage rate of using the implantable Doppler probe and the traditional clinical assessment method. The implantable Doppler probe group had a significantly higher flap salvage rate (A). The salvage rate was still significantly higher after Kind et al[9]; a study of moderate quality (NOS of 5 or 6) had been removed (B).

Table 5. Sensitivity and FPR

Study	Implantable Doppler			Clinical Assessment		
	No. Flaps	Sensitivity	FPR	No. Flaps	Sensitivity	FPR
Kind et al,[9] 1998	147	100	3.15	1317	NM	NM
Ferguson and Yu,[20] 2009	16	0*	33.33	66	†	†
Rozen et al,[17] 2010a	121	100	0.9	426	98.11	0
Rozen et al,[18] 2010b	20	100	0	20	100	0
Smit et al,[19] 2010	323	100	1.04	307	97.5	0
Schmulder et al,[16] 2011	226	100	1.55	263	NM	NM

*No true positive and only one false negative.
†Unable to calculate because true positives and false negatives, both = 0.
FPR, false-positive rate; NM, not mentioned.

study[20] to decrease the between-studies heterogeneity, the flap failure rate was still significant. We conclude that using an implantable Doppler probe reduces the flap failure rate and increases the flap salvage rate.

Theoretically, the implantable Doppler probe is beneficial for monitoring buried flaps. However, currently, there is insufficient evidence to prove it. Only 3 studies,[20,26,27] with a sensitivity of 0% or 100% and a false-positive rate of 0% to 37%, focus solely on buried flaps. Only one comparative study, Ferguson and Yu,[20] reported a series with 94 buried flaps that were distributed into a clinical assessment group, an implantable Doppler probe

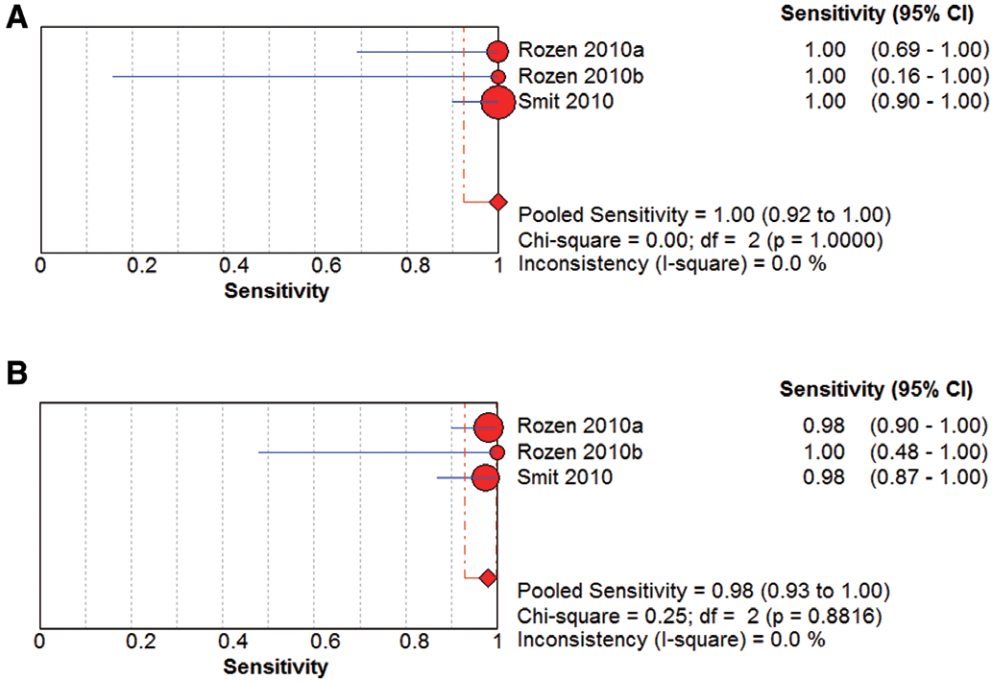

Fig. 4. Forest plots comparing the sensitivity of the implantable Doppler probe group and the clinical assessment group. The pooled sensitivity was higher in the Doppler probe group (100%) (A) than in the clinical assessment group (98%) (B).

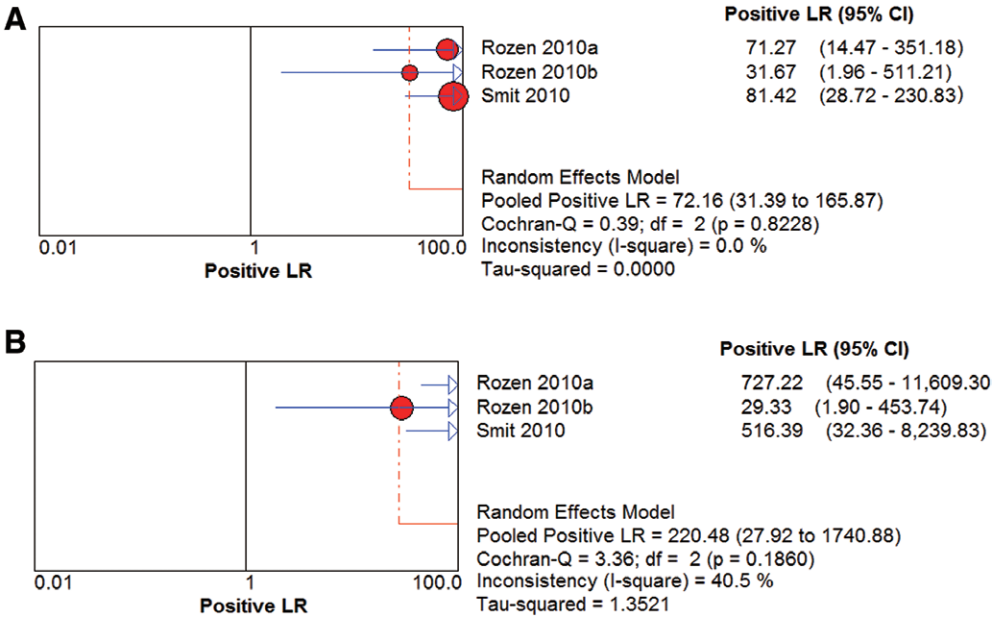

Fig. 5. Forest plots comparing the positive LR between the implantable Doppler probe group and the clinical assessment group. The positive LR was significantly lower in the Doppler probe group (72.16) (A) than in the clinical assessment group (220.48) (B).

group, and an externalized monitoring segment group. Five false positives and 1 false negative were found in 16 cases in the implantable Doppler probe group. Their study queried the efficacy of implantable Doppler in head and neck reconstruction because of the unfavorable geometry, difficult positioning, interference with other vessels, and easy displacement caused by poor immobilization in this area. The other 2 studies[26,27] are not comparative studies. Swartz et al,[7] Ho et al,[25] and Chang et al[28] mentioned and included buried flaps in their

studies, but only Chang et al[28] analyzed them separately as a subgroup. They emphasized the importance of using the monitoring segment in addition to the implantable Doppler probe because of its significantly increased specificity for microvascular complications. We were unable to clarify this because not all of the included studies had their buried flap subgroups further analyzed. More clinical trials are needed to evaluate the efficacy of implantable Doppler probes for monitoring buried flaps.

The most controversial aspect of using an implantable Doppler probe is its high false-positive rate and resultant unnecessary exploration. Initially, the probe was attached to arteries by Swartz et al.[7] However, they pointed out that because of false negatives, the probe was unable to detect venous thromboses early enough. To overcome the false negatives, they did animal experiments, which showed that an arterial probe needed a mean 220 ± 40 minutes to detect a venous thrombosis.[8] In contrast, a venous probe needed only a mean 6.08 ± 2.4 minutes to detect an arterial thrombosis. Their clinical series with 133 cases[8] also reported that the salvage rate rose from 50% to 75% with a venous probe. A venous probe, however, is more easily dislodged and cannot discriminate between a thrombosis and a technical malfunction; therefore, it has a higher false-positive rate. This venous Doppler probe system generated 8 studies[9,12,16–20,29] (Table 6). All but one,[20] with only a venous Doppler probe, showed 100% sensitivity but a 0% to 33% false-positive rate (pooled sensitivity = 0.99; 95% CI: 0.95–1.00) (pooled positive LR = 38.13; 95% CI: 18.13–80.19). This study showed 1 false negative and no true positives but gave no explanation. All false positives reported in these studies were related to probe dislodgement, fibrin coating, or device malfunction. In contrast, a 0% to 100% sensitivity with a 0.75% to 37% false-positive rate was reported in studies in which the probes were not always attached to a vein (pooled sensitivity = 0.87; 95% CI: 0.81–0.92) (pooled positive LR = 15.16; 95% CI: 4.95–46.40).[8,14,15,25,26,28,30,34] Not surprisingly, the pooled sensitivity was higher, but the pooled positive LR was lower for a venous Doppler probe. The authors who favored the arterial Doppler probe system concluded that the venous probe is better when used at body sites that can be immobilized, such as the limbs or breasts.[15] The authors who favored the venous Doppler probe system, however, considered false positives an inevitable part of the learning curve when using a venous probe.[17,19] Chang et al,[28] who published the latest series, concluded that artery monitoring had significantly higher specificity (94% vs 74%) and sensitivity (78% vs 67%).

The sensitivity, false-positive rate, and positive LR for the implantable Doppler probe and clinical assessment groups were reported in 3 comparative studies.[17–19] The implantable Doppler probe group showed superior pooled sensitivity (100%) than did the clinical assessment group (98%), but an inferior positive LR (72 vs 220, respectively). It is noteworthy that a venous probe was used for these 3 studies, the findings of which are consistent with our findings of high sensitivity and a high false-positive rate. In general, clinical assessment might offset false positives in nonburied flaps. It does not do so in buried flaps, however, and thus results in unnecessary re-exploration surgery. The invention of the wireless implantable Doppler probe might decrease the number of probe dislodgements.[32]

Table 6. Historical Review

Study	Flaps (*n*)	Take Backs (*n*)	Failure Rate (%)	Salvage Rate (%)	Sensitivity	FPR	Buried Flaps (%)	Placement
Swartz et al,[7] 1988	63	2	0	100	0	3.33	36.5	A
Swartz et al,[8] 1994	133	26	5.25	68.18	91	5.31	NM	A/V*
Kind et al,[9] 1998	147	22	0	100	100	3.15	NM	V
de la Torre et al,[30] 2003	118	9	1	83	100	5.45	NM	A/V†
Oliver et al,[12] 2005	24	1	0	100	100	0	NM	V
Pryor et al,[34] 2006	24	3	4.17	0	100	8.70	NM	A/V‡
Rosenberg,[26] 2006	20	3	0	100	100	36.84	100	A/V§
Guillemaud et al,[14] 2008	384	46	1.82	81.6	86	1.69	NM	A/V¶
Ferguson and Yu,[20] 2009	16	5	6.25	0	0	33.33	100	V
Iblher et al,[35] 2010	52	5	5.77	66.7	100	0	NM	NM
Rozen et al,[17] 2010a	121	11	1.65	80	100	0.9	NM	V
Rozen et al,[18] 2010b	20	2	0	100	100	0	NM	V
Smit et al,[19] 2010	323	35	3.41	68.57	100	1.04	NM	V
Schmulder et al,[16] 2011	226	33	1.77	87.88	100	1.55	NM	V
Lindau et al,[27] 2012	103	1	0	100	100	0	100	NM
Ho et al,[25] 2014	75	13	6.67	61.54	67	4.84	13	A
Um et al,[29] 2014	109	11	1.83	81.82	100	1.02	NM	V
Wax et al,[15] 2014	1142	77	2.4	55.84	87	0.75	NM	A/V‖
Chang et al,[28] 2015	439	56	4.8	62.5	78	12	58	A/V**

A, arterial probe; FPR, false-positive rate; NM, probe location not mentioned; V, venous probe.
*Thirty arterial probes, 103 venous probes.
†One hundred and eighteen arterial probes, 142 venous probes.
‡Twelve arterial probes, 11 venous probes, 1 with simultaneous arterial and venous probes.
§Six arterial probes, 12 venous probes, 1 perforator probe, 1 unspecified probe.
¶Four venous probes, 283 arterial probes, 77 simultaneous arterial and venous probes, 5 with 3 probes because of double flap.
‖Venous probes in first 43 patients, then arterial probes in subsequent 1099 patients.
**Two hundred sixty-seven arterial probes, 101 venous probes, 71 simultaneous arterial and venous probes.

Another drawback of using an implantable Doppler probe is that it costs 1.4% more per case than does the conventional method.[19] Poder and Fortier[21] concluded that if the implantable Doppler probe and extension cable were 19% less expensive, its greater cost could be compensated for by a reduction in redo surgeries. They estimated that 3 redo surgeries were required per 100 patients in the implantable Doppler probe group, but that 5 redo surgeries were required in the clinical assessment group. The expense of the 2 redo surgeries, which were 40% of total redo surgeries, was saved, thus reducing by 120 to 400 Canadian dollars per patient the higher cost for using an implantable Doppler probe. Based on our meta-analysis, using implantable Doppler probes should reduce the number of flap failures by at least 37% (RR: 0.37; 95% CI: 0.23–0.26) (Fig. 2A) and, therefore, 3 redo surgeries would be precluded. If this hypothesis is true, then the higher cost of an implantable Doppler probe might be compensated for by more than Poder and Fortier[21] estimated. However, the cost of implantable Doppler probe may be underestimated because the unnecessary re-explorations, which is estimated to be 1 patient per 100 patients by this study (pooled false-positive rate = 0.01), is not taken into considerations in previous studies. Further study will be necessary to clarify the cost-effectiveness.

Although the present meta-analysis showed that implantable Doppler probe assessment was significantly more efficacious than was clinical assessment, the evidence was not powerful enough. For one thing, none of the studies was randomized, and most were retrospective. Two[9,17] of 6 studies did not examine the heterogeneity between groups. For another, the salvage rate for the clinically assessed groups in 3 of 5 studies ranged from 32% to 46%, which was inferior to the 70% to 80% range in the clinically assessed groups treated by more experienced physicians.[5,6] This finding might suggest that using an implantable Doppler probe might not be significantly more efficacious for physicians with a relatively high salvage rate using clinical assessment. Moreover, the latter group of technically proficient physicians might tend not to report their experience or even not to use the implantable Doppler probe. Given that we found no literature describing randomized control trials, the synthesized data of observational studies might overestimate the efficacy of using a Doppler probe. Finally, although the heterogeneity between these studies has been tested, the number of included studies is limited and it reduces the power of the test. Nevertheless, the result is statistically significant, and this study still provides quantitative data and its clinical application.

We found that using implantable Doppler probes to postoperatively monitor free flaps is significantly more efficacious than using traditional clinical assessment. Although randomized control trials would be required to confirm our findings, our results show that implantable Doppler has significantly lower flap failure and higher flap salvage rates, is significantly more sensitive, but has a significantly higher false-positive rate. We recommend additional studies that focus on subgroup analysis such as buried flaps and on comparing the efficacy of implantable Doppler probes with that of other flap monitoring technology, such as near-infrared spectroscopy and microdialysis.

Jing-Wei Lee, MD
Division of Plastic and Reconstructive Surgery
Department of Surgery
National Cheng Kung University Hospital
College of Medicine
National Cheng Kung University
138 Sheng-Li Road
Tainan 70403, Taiwan
E-mail: jwlee@mail.ncku.edu.tw

REFERENCES

1. Nakatsuka T, Harii K, Asato H, et al. Analytic review of 2372 free flap transfers for head and neck reconstruction following cancer resection. *J Reconstr Microsurg.* 2003;19:363–368; discussion 369.
2. Seidenberg B, Rosenak SS, Hurwitt ES, et al. Immediate reconstruction of the cervical esophagus by a revascularized isolated jejunal segment. *Ann Surg.* 1959;149:162–171.
3. Kroll SS, Schusterman MA, Reece GP, et al. Timing of pedicle thrombosis and flap loss after free-tissue transfer. *Plast Reconstr Surg.* 1996;98:1230–1233.
4. Chen KT, Mardini S, Chuang DC, et al. Timing of presentation of the first signs of vascular compromise dictates the salvage outcome of free flap transfers. *Plast Reconstr Surg.* 2007;120:187–195.
5. Al-Dam A, Zrnc TA, Hanken H, et al. Outcome of microvascular free flaps in a high-volume training centre. *J Craniomaxillofac Surg.* 2014;42:1178–1183.
6. Disa JJ, Cordeiro PG, Hidalgo DA. Efficacy of conventional monitoring techniques in free tissue transfer: an 11-year experience in 750 consecutive cases. *Plast Reconstr Surg.* 1999;104:97–101.
7. Swartz WM, Jones NF, Cherup L, et al. Direct monitoring of microvascular anastomoses with the 20-MHz ultrasonic Doppler probe: an experimental and clinical study. *Plast Reconstr Surg.* 1988;81:149–161.
8. Swartz WM, Izquierdo R, Miller MJ. Implantable venous Doppler microvascular monitoring: laboratory investigation and clinical results. *Plast Reconstr Surg.* 1994;93:152–163.
9. Kind GM, Buntic RF, Buncke GM, et al. The effect of an implantable Doppler probe on the salvage of microvascular tissue transplants. *Plast Reconstr Surg.* 1998;101:1268–1273; discussion 1274.
10. Bill TJ, Foresman PA, Rodeheaver GT, et al. Fibrin sealant: a novel method of fixation for an implantable ultrasonic microDoppler probe. *J Reconstr Microsurg.* 2001;17:257–262.
11. Whitaker IS, Smit JM, Acosta R. A simple method of implantable Doppler cuff attachment: experience in 150 DIEP breast reconstructions. *J Plast Reconstr Aesthet Surg.* 2008;61:1251–1252.
12. Oliver DW, Whitaker IS, Giele H, et al. The Cook-Swartz venous Doppler probe for the post-operative monitoring of free tissue transfers in the United Kingdom: a preliminary report. *Br J Plast Surg.* 2005;58:366–370.
13. Bellamy JL, Mundinger GS, Flores JM, et al. Do adjunctive flap-monitoring technologies impact clinical decision making? An analysis of microsurgeon preferences and behavior by body region. *Plast Reconstr Surg.* 2015;135:883–892.
14. Guillemaud JP, Seikaly H, Cote D, et al. The implantable Cook-Swartz Doppler probe for postoperative monitoring in head and neck free flap reconstruction. *Arch Otolaryngol Head Neck Surg.* 2008;134:729–734.
15. Wax MK. The role of the implantable Doppler probe in free flap surgery. *Laryngoscope* 2014;124:S1–S12.
16. Schmulder A, Gur E, Zaretski A. Eight-year experience of the Cook-Swartz Doppler in free-flap operations: microsurgical and reexploration results with regard to a wide spectrum of surgeries. *Microsurgery* 2011;31:1–6.
17. Rozen WM, Chubb D, Whitaker IS, et al. The efficacy of postoperative monitoring: a single surgeon comparison of clinical

monitoring and the implantable Doppler probe in 547 consecutive free flaps. *Microsurgery* 2010;30:105–110.
18. Rozen WM, Enajat M, Whitaker IS, et al. Postoperative monitoring of lower limb free flaps with the Cook-Swartz implantable Doppler probe: A clinical trial. *Microsurgery* 2010;30:354–360.
19. Smit JM, Werker PM, Liss AG, et al. Introduction of the implantable Doppler system did not lead to an increased salvage rate of compromised flaps: a multivariate analysis. *Plast Reconstr Surg.* 2010;125:1710–1717.
20. Ferguson RE Jr, Yu P. Techniques of monitoring buried fasciocutaneous free flaps. *Plast Reconstr Surg.* 2009;123:525–532.
21. Poder TG, Fortier PH. Implantable Doppler in monitoring free flaps: a cost-effectiveness analysis based on a systematic review of the literature. *Eur Ann Otorhinolaryngol Head Neck Dis.* 2013;130:79–85.
22. Wells GA, Shea B, O'Connell D, et al. *The Newcastle-Ottawa Scale (NOS) for Assessing the Quality of Nonrandomized Studies in Meta-analyses.* Ottawa, ON, Canada: Ottawa Hospital; 2008. Available at: http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp. Accessed March 12, 2016.
23. Higgins JP, Thompson SG, Deeks JJ, et al. Measuring inconsistency in meta-analyses. *BMJ* 2003;327:557–560.
24. Whitaker IS, Rozen WM, Chubb D, et al. Postoperative monitoring of free flaps in autologous breast reconstruction: a multicenter comparison of 398 flaps using clinical monitoring, microdialysis, and the implantable Doppler probe. *J Reconstr Microsurg.* 2010;26:409–416.
25. Ho MW, Cassidy C, Brown JS, et al. Rationale for the use of the implantable Doppler probe based on 7 years' experience. *Br J Oral Maxillofac Surg.* 2014;52:530–534.
26. Rosenberg JJ, Fornage BD, Chevray PM. Monitoring buried free flaps: limitations of the implantable Doppler and use of color duplex sonography as a confirmatory test. *Plast Reconstr Surg.* 2006;118:109–113; discussion 114.
27. Lindau RH, Detwiller K, Wax MK. Buried free flaps in head and neck surgery: outcome analysis. *Head Neck* 2013;35:1468–1470.
28. Chang EI, Ibrahim A, Zhang H, et al. Deciphering the sensitivity and specificity of the implantable Doppler in free flap monitoring. *Plast Reconstr Surg.* 2015. [Epub ahead of print.]
29. Um GT, Chang J, Louie O, et al. Implantable Cook-Swartz Doppler probe versus Synovis Flow Coupler for the post-operative monitoring of free flap breast reconstruction. *J Plast Reconstr Aesthet Surg.* 2014;67:960–966.
30. de la Torre J, Hedden W, Grant JH III, et al. Retrospective review of the internal Doppler probe for intra- and postoperative microvascular surveillance. *J Reconstr Microsurg.* 2003;19:287–290.
31. Lohman RF, Langevin CJ, Bozkurt M, et al. A prospective analysis of free flap monitoring techniques: physical examination, external Doppler, implantable Doppler, and tissue oximetry. *J Reconstr Microsurg.* 2013;29:51–56.
32. Unadkat JV, Rothfuss M, Mickle MH, et al. The development of a wireless implantable blood flow monitor. *Plast Reconstr Surg.* 2015;136:199–203.
33. Chae MP, Rozen WM, Whitaker IS, et al. Current evidence for postoperative monitoring of microvascular free flaps: a systematic review. *Ann Plast Surg.* 2015;74:621–632.
34. Pryor SG, Moore EJ, Kasperbauer JL. Implantable Doppler flow system: experience with 24 microvascular free-flap operations. *Otolaryngol Head Neck Surg.* 2006;135:714–718.
35. Iblher N, Eisenhardt SU, Penna V, et al. A new evaluation tool for monitoring devices and its application to evaluate the implantable Doppler probe. *J Reconstr Microsurg.* 2010;26:265–270.