

STRATEGIC APPROACHES in **Coronary Intervention** *Second Edition*

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Management of Vascular Sheath Following PTCA

A. Vascular Closure Devices for Immediate Sheath Removal after Coronary Interventions: Luxury or Necessity?

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Coronary interventions are usually performed by the femoral approach; the brachial approach is showing a continuously declining trend (1). Patients undergoing the femoral approach, however, are usually immobilized overnight, which may result in significant discomfort with increased back pain and need for analgesics (2). Noncompliance of the patients regarding strict bedrest after the procedure has been reported to be a substantial factor for femoral complications after PTCA, increasing the risk of hematoma formation and of rebleeding (3). Sandbags do not reduce vascular complications and even increase patients' discomfort (4). Mechanical compression devices could not effect clinically relevant advantages (3,5).

Reducing the sheath size was presumed to result in fewer local vascular complications (6). Although newer, 6 Fr guiding catheters even allow safe stenting in 3.5 mm-vessels, there was no reduction in bleeding complications related to the reduction in sheath size (1,7,8). This miniaturization of equipment also led to a revival of the transradial approach, which was initially suggested for diagnostic angiography (9). Although the transradial approach for PTCA is more time-consuming and has a considerable

learning curve, it remarkably increases patients' comfort and decreases bleeding complications (10).

With the current standard stent regimen using aspirin and ticlopidine (or clopidogrel), major local bleeding complications may still occur in approximately 2.5% (11,12). It has been estimated that major access site complications increase the hospital length of stay by approximately 2 days, adding roughly \$2,000 to the overall procedural costs (13,14). Furthermore, glycoprotein-IIb/IIIa inhibitors (GP-IIb/IIIa inhibitors) are increasingly used in high- and low-risk patients; although the increased rate of bleeding complications in the EPIC study could be significantly reduced by decreasing the concomitant heparin dosage, the EPILOG and RESTORE trials still revealed a rate of major bleeding of 1.8% and 2.5% respectively in the patients treated with GP-IIb/IIIa inhibitors and of 2.3% to 3.1% in the placebo groups (15,16). The use of low molecular weight heparin in patients at high risk for stent thrombosis may also be associated with a higher bleeding risk (17).

The clinical use of vascular closure devices for rapid hemostasis after femoral access was first reported in 1991 (18). Ever since, these de-

vices undoubtedly have proven to increase patients' comfort and decrease burden for the medical staff; they may also reduce hospital costs by shortening the length of stay. Patients may be ambulated almost immediately after diagnostic coronary angiography. They may also be discharged many hours earlier than the 6-hour supine restriction period enforced by most centers after diagnostic catheterization (14). After coronary interventions, patient comfort is additionally increased by immediate sheath removal (19–21).

The purpose of this chapter is to summarize the basic concepts and the clinical results of the four prevailing vascular closure devices after transfemoral coronary interventions and immediate sheath removal.

THE VASOSEAL DEVICE

Concept

VasoSeal, the "Vascular Hemostatic Device" (VHD, Datascope Corp., Montvale, NJ, USA) works predominantly by collagen-induced thrombus generation. It consists of purified collagen plugs that induce the formation of a hemostatic cap directly over the arterial puncture site. Biodegradable collagen induces platelet activation and aggregation, releasing coagulation factors and resulting in the formation of fibrin and the subsequent generation of a thrombus (22). Collagen is ultimately degraded and resorbed by granulocytes and macrophages. Antigenicity of purified collagen is considerably reduced and, although allergies to collagen are described (23), allergic reactions to collagen used for hemostasis have not been a clinical problem (24–26).

VasoSeal is the oldest of the clinically used

sealing devices (18). It is comprised of four parts: a blunt-tipped, 11 Fr dilator, one of seven differently sized 11.5 Fr sheaths selected by length using a preprocedure needle-depth measurement technique, and two 90 mg collagen cartridges. (Details of these four parts are described elsewhere [25,26].) When the sheath is pulled, a short guidewire is inserted and the existing sheath is removed while maintaining manual compression. Then the blunt-tipped, 11 Fr dilator is inserted via the guidewire just down to the site of the arterial puncture. The 11.5 Fr sheath is advanced over the dilator down to the arterial surface. While still holding pressure, the dilator and the guidewire are removed and the collagen cartridge is deployed with a "push-and-pull" movement. We usually use only one cartridge of collagen, since we know from previous studies that one collagen plug is as effective as two plugs but is better tolerated (27–29). Recently, VasoSeal "ES" was released, introducing an enhanced guidance using a removable J-segment wire.

Clinical Results

Over 500,000 VasoSeal devices have been deployed worldwide. Reported deployment success rates vary from 88% (30) to 100% (20,24,31) (Table 23.1). Time to hemostasis for sheath removal immediately after the intervention varies from 5 to 8 minutes (20,25,26). A recently published study reported a mean time to hemostasis of 13.1 ± 6.1 minutes for VasoSeal deployment immediately after PTCA in 95 patients (32). Time to ambulation was not the primary endpoint in most controlled studies. The lower range time to ambulation after immediate sheath removal is 6 to 9 hours (20) with a mean

TABLE 23.1. *Relevant characteristics of the four prevailing vascular closure devices*

	VasoSeal	Angio-Seal	Duett	Perclose, Inc.
Deployment success rate	88%–100%	91%–100%	98%–100%	90%–100%
Time to hemostasis	5min–13min	2min–4min	4min–6min	11min–19min
Time to ambulation	6h–9h	6h–8h	2h–6h	4h–7h
Minor complications	8%	5.9%	2.1%	5.3%
Major complications	up to 5.3%	up to 1.3%	up to 1%	up to 4%

Data are based on immediate sheath removal after coronary intervention

value of 8.7 ± 5.3 hours (32). In that "early" mobilization study, 52% of the patients receiving VasoSeal immediately after PTCA were mobilized after 6 hours and 82% after 10 hours (32). None of these patients was mobilized earlier than 6 hours.

Minor local complications have been reported in 8% and major complications in 5.3% of the 2,073 PTCA patients analyzed in 15 studies (20) (Table 23.1). This figure is comparable to a recently published single-center experience with major local complications in 5% of the 204 anticoagulated patients (33). Intraarterial insertions of VasoSeal with resultant leg ischemia have been reported in 0.3% to 2% (15/2,229) of the patients (20).

In our study addressing an identical sheath dwell time, and therefore an identical level of anticoagulation in the VasoSeal and the manual groups, there was no statistical difference regarding local complications. Although the incidence of medium or large hematoma was low, the trend toward decreasing smaller hematomas was counterbalanced by an increased risk of larger hematomas or a major complication, and may in part explain some of the published controversial findings (29).

THE ANGIO-SEAL DEVICE

Concept

Angio-Seal, the "Hemostatic Puncture Closing Device" (HPCD), was originally developed by the Kensey Nash Corporation, Exton, PA, USA, then distributed by Quinton Instruments and Sherwood, followed by Tyco, and now by St. Jude Medical Devices (Minneapolis, MN). It works predominantly by mechanical forces ("sandwich technique") and also by a collagen-induced thrombus formation.

Angio-Seal provides a mechanical block of the arterial puncture site with an anchor from inside the artery, guiding and holding the collagen in the tract (34). It consists of four components within a single delivery device ("carrier") requiring an 8 Fr sheath: an anchor, a collagen plug, a connecting suture, and a tamper. All three components deployed into the patient are com-

pletely resorbable; the anchor is made from polyglycolic and polylactic acids. The small plug contains only about 15 mg collagen. The technique of its deployment has been described in detail elsewhere (35,36). In brief, a short guide-wire is inserted and the existing sheath removed while hemostasis is maintained with manual compression. The location of the end of the 8 Fr sheath is determined by the presence of blood flow through the modified dilator. The sheath-dilator combination is then advanced 1 cm further down the puncture site inside the artery lumen. The dilator is then removed and the carrier device introduced into the 8 Fr sheath. After the collagen is deployed, a tamper is pushed downwards to compress the collagen against the outer arterial wall; and a spring is attached between the tamper and a metal tag fixed to the positioning suture, thus applying continuous pressure on the tamper.

In our study, the reduction of the spring deployment time from 30 minutes to 5 minutes was not related to an increased risk of bleeding or other vascular complications (19). This technique makes handling of Angio-Seal easier, because the suture may be cut while the patients are still on the table in the catheterization laboratory. Furthermore, patients can be transferred much faster to the intermediate care unit, thereby reducing the burden on the personnel in the catheterization laboratory.

Clinical Results

Angio-Seal has been used in over 400,000 patients. Deployment success rates are in the range from 91% (37) to 100% (19,20). Data on time to hemostasis for sheath removal immediately after the intervention are sparse and in the range of 2 to 4 minutes (20), reflecting our own experience in over 2,000 applications. Regarding time to ambulation, no study specifically investigating early ambulation has been fully published. The shortest time interval between deployment and ambulation in a U.S. multicenter trial was 8 hours (36) (Table 23.1). For diagnostic patients, a time to ambulation of 1 hour (38), and even 20 minutes (39) was considered to be safe.

Minor local complications have been reported

in 5.9% (254 patients) and major complications in 0.4% of the 254 PTCA patients (20) (Table 23.1). A recently published report on 411 consecutive patients revealed a major complication rate of 1.3% (40). An inadvertent complete intra-arterial deployment of Angio-Seal with resultant leg ischemia requiring surgical removal of the entire system was not published until recently (41).

Interestingly, the 8 Fr Angio-Seal is also safe and effective for 9 Fr sheaths (42). A newly developed 6 Fr device has been tested in France and is now available in Europe.

THE DUETT DEVICE

Concept

The Duett is a novel vascular sealing device (Vascular Solutions, Minneapolis, MN) which incorporates a unique low-profile balloon-positioning catheter in combination with a biological procoagulant mixture containing collagen and thrombin. It works purely by generating a thrombus.

The low-profile catheter (3 Fr) incorporates a moveable core wire that allows *in vivo* modifications of the balloon dimensions. When the device is inflated, the balloon assumes an elliptical shape with a significantly larger diameter (6 mm) and a relatively short length. This configuration provides optimal temporary sealing of the arterial puncture from the luminal side by ensuring a large surface area of balloon in apposition to the puncture site and at the same time minimizing obstruction to flow through the lumen of the vessel. The procoagulant is a suspension comprised of 250 mg bovine microfibrillar collagen (Avitene, Davol Inc., Woburn, MA) and 10,000 units bovine thrombin (Jones Medical Inc., St. Louis, MO). This combination may be optimal for achieving rapid hemostasis at the arterial puncture site. The suspension incorporating both of these hemostatic agents is designed to have a suitable viscosity for injecting through the side arm of most vascular sheaths, yet have a consistency that would be likely to maintain the procoagulant material at the desired location in the periarterial space at the puncture site.

These aspects of the device may partially explain the remarkable absence of any delayed oozing from the arterial access site, of the sort that frequently plagues other sealing approaches, causing significant nursing and patient concerns. Detailed descriptions of the device appear elsewhere (43,44). In previously reported pre-clinical studies, the Duett was able to achieve rapid and reliable hemostasis in a canine model, regardless of sheath size or degree of anticoagulation (43).

Clinical Results

After the first clinical investigational protocol was approved by the International Ethics Committee in Freiburg, Germany, we applied this novel device for the first time in humans. A total of 24 patients were enrolled (44). For the PTCA patients, mean time to hemostasis, including deployment time and compression time, was 11.4 ± 2.9 minutes with a compression time ("time to hemostasis" in the old sense) of 6.0 ± 2.2 (44) minutes and a time to ambulation of 16.3 ± 4.9 hours (44) (Table 23.1). The most important concern related to the use of this device was the risk of inadvertent intravascular injection. Including measurements of several coagulation parameters, there was no evidence of intraarterial injection or leakage (44). No other major complication occurred (44). Our study was followed by the first U.S. feasibility trial of the device. The preliminary results in 43 patients were recently presented. The 11 interventional patients with immediate sheath removal showed a mean time to hemostasis of 4.6 ± 2.1 minutes with a mean time to ambulation of 5.4 ± 2.0 hours (45). All 40 patients with ultrasound follow-up showed no major complications. Considering the relatively low number of patients, deployment success rates are in the range from 98% to 100% (44,45). In a large, single-center study (46) as well as in the multicenter European registry with a total of 1,587 patients enrolled, patients were ambulated 2 to 6 hours after the intervention. Minor complications have been reported in 2.1% and major complications in 1%. An inadvertent intraarterial injection of the procoagulant occurred in four patients (0.3%) and

was successfully treated by intraarterial infusion of urokinase in three cases and surgical repair in one. Overall, the Duett has been applied in over 3,500 cases worldwide. Enrollment into the US/European multicenter SEAL trial has just been completed, with 630 patients randomized (5:3) to Duett or manual compression. With 391 Duett applications, the results are pending.

THE PERCLOSE, INC. DEVICES

Concept

The series of Perclose, Inc. devices (Redwood City, CA) does not use collagen or thrombin; it is based solely on nonabsorbable sutures (47). The Prostar devices use four needles (two sutures); the Techstar devices two needles (one suture). The 11 Fr and 9 Fr Prostar devices have been discontinued; 8 Fr and 10 Fr Prostar are available for use with 8 Fr to 10 Fr sheaths; the 6 Fr and 7 Fr Techstar devices are for use with 5 Fr to 7 Fr sheaths.

The Perclose, Inc. devices include a number of components, including a 0.035-in. guidewire, a knot-pushing tool, a predilator for the subcutaneous tissue, and the suture-containing device itself (48). The needles exiting the device just inside the artery are drawn through the arterial wall and reenter the device outside the artery. As the ends of the sutures are pulled out, the suture loop is pulled against the arterial wall. Once it is apparent that hemostasis will be achieved, the guidewire is removed with further sequential tightening of the suture pairs (48).

Recently, the use of Perclose, Inc. devices in the brachial artery after coronary intervention was suggested (49). To enable the insertion in severely scarred groins, a modification of the deployment technique has been proposed (50).

Clinical Results

Perclose devices have been deployed in over 250,000 patients worldwide. After initial experience using Prostar (48), several uncontrolled studies have investigated the safety and efficacy of the Perclose, Inc. series in patients undergoing diagnostic and interventional catheterization

(51,52). The deployment success rate was 90% (53) (Table 23.1). In a randomized trial, the mean time to hemostasis in the interventional group of 95 patients was 11.0 ± 4.1 minutes and time to ambulation 7.1 ± 7.4 hours (54). Minor complications occurred in 5.3%, major complications in 3.2% and 4% (54,55) (Table 23.1). The relatively high vascular complication rates of 9% with a vascular surgery rate of 2.1% (56) may possibly be reduced after a learning curve of more than 250 cases per user (57).

The largest database for interventional procedures was reported in the STAND-II study (58). A total of 515 patients (90% 8 Fr, 10% 10 Fr sheaths) were randomized to either manual compression or Prostar Plus for immediate sheath removal. In the Prostar group the mean time to hemostasis was 19 minutes, time to standing was 206 minutes, and time to ambulation was 240 minutes; these times were significantly shorter compared with the manual group. However, vascular surgery was 1.2% and groin infection rate was 0.8%, with a total major complication rate of 2.4%.

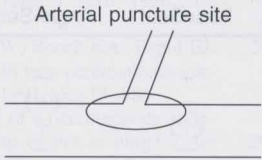
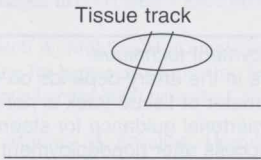
COMPARISON OF THE FOUR DEVICES

Table 23.1 shows the published data on deployment success rates, time to hemostasis, time to ambulation, and minor and major complications.

Table 23.2 lists the basic differences between these devices. The hole in the artery is not influenced by the VasoSeal and the Duett, thus depending on sheath size only. The classical VasoSeal does not insert anything into the arterial lumen, whereas the VasoSeal ES and the Duett use a temporary intraarterial device (J-wire or balloon, respectively). Only the Angio-Seal leaves a part (the anchor) in the artery, which will be resorbed during the following weeks. The tissue track is enlarged by the VasoSeal to 11.5 Fr and by the Perclose device to 21 Fr. The VasoSeal seals the tissue track, whereas Perclose and Angio-Seal devices leave the tissue track open (increased risk of oozing). The Duett seals both the artery and the tissue track.

Table 23.3 gives an overview of which sealing device can be used for which sheath size. For 6

TABLE 23.2. Differences in mechanisms for achieving hemostasis

					
	Diameter of the arterial hole	Hemostasis by		Diameter of the tissue track	Hemostasis by
		Intraarterial guidance	Supraarterial closure		
VasoSeal	Depending on sheath size	Temporary J-wire	Collagen (180 mg)	11.5Fr	Collagen
Angio-Seal	8Fr, 6Fr	Resorbable anchor	Collagen (26 mg, 13 mg)	8Fr, 6Fr	—
Duett	Depending on sheath size	Temporary balloon	Procoagulant (thrombin)	Depending on sheath size	Procoagulant (thrombin)
Perclose, Inc.	6Fr/8Fr/10Fr	Guide wire	Suture	21Fr	—

Fr, any of these devices may be used, although immediate post-PTCA sheath removal without a closure device using 6 Fr sheaths and weight adjusted heparin was recently suggested (59). For 7 Fr, VasoSeal, Duett and Perclose devices should be preferred; the Angio-Seal would punch an 8 Fr hole into the “7 Fr” artery, and to date there are no reports on using the 6 Fr Angio-Seal for 7 Fr sheaths. For 8 Fr, all devices are applicable. With 9 Fr sheaths, the Duett and Perclose devices should be preferred, although the 8 Fr Angio-Seal may work as well (42). For 10 Fr, Perclose is the only device to be recommended.

Table 23.4 describes the “ideal” sealing device. Unfortunately, none of the four devices fulfills all of the ideal criteria.

In our catheterization laboratories with many operators, several did not want to experience the rather flat learning curve required for Perclose (59). We have decided to use the Duett as our prevailing sealing device. We based our decision

on the Duett’s ability to leave no sequelae in the arterial lumen and its ability to simultaneously seal the arterial hole and the tissue track, which becomes increasingly more important with the growing use of GP-IIb/IIIa inhibitors. The major reason for our extensive use of sealing devices is not early ambulation or early discharge (in Germany, the hospitals are predominantly paid by the day and not by procedure) but rather immediate sheath removal. Patients and nurses equally appreciate the fact that the groin has already been “cleared” when the patient is transferred to the ward. Patients stopped on heparin or GP-IIb/IIIa inhibitors are usually ambulated after 6 hours, if intervention occurred in the morning or around noon. The afternoon patients as well as all patients on GP-IIb/IIIa inhibitors are ambulated the next day.

Recently, two new sealing devices have been presented. The DISC-Close-Sure (BioInterventional, Pleasanton, CA) developed a 13 Fr disc for 6 and 7 Fr sheaths as well as a 16 Fr disc

TABLE 23.3. Sheath size as criteria for choosing a sealing device

	6Fr	7Fr	8Fr	9Fr	10Fr	11Fr
VasoSeal	+	+	+	—	—	—
Angio-Seal	+	(+)	+	(+)	—	—
Duett	+	+	+	+	—	—
Perclose, Inc.	+	+	+	+	+	—

VasoSeal is recommended up to 8Fr Duett is recommended up to 9Fr; the Perclose series is currently available up to 10Fr.

TABLE 23.4. Checklist for the "ideal" vascular closure device

	VasoSeal	Angio-Seal	Duett	Perclose, Inc.
<i>Deployment technique:</i>				
• hole in the artery depends on sheath size only	+	—	+	(+)
• diameter of tissue track is not enlarged by device	—	(+)	+	—
• intraarterial guidance for steerability	(+)	+	+	+
• reaccess after nondeployment	—	—	—	+
• no intraarterial sequelae left	+	—	+	+
• single operator	+	+	+	—
<i>Effectiveness:</i>				
▲ Rapid and complete hemostasis	+	+	+	+
▲ no oozing (tissue track sealing)	+	—	+	—
▲ 100% effective	—	—	—	—
▲ 100% safe	—	—	—	—

for 8 Fr sheaths. X-Site Medical (Blue Pell, PA) presented another suture device as a probably lower-cost alternative to the Perclose series. This X-Site PFC (Percutaneous Femoral Closure) system was recently applied in the first 70 patients in South America.

CONCLUSIONS

With a current application rate of approximately 70,000 applications per month, vascular closure devices have become a substantial tool of invasive cardiology. The four major vascular closure devices for immediate sheath removal after coronary interventions have proven to be comparable regarding deployment success rates, time to hemostasis, and time to ambulation. They all satisfy the needs of the patient and the operator (60). Although some differences may exist regarding local complications (21), none of the devices have shown to reduce major local complications. Prospective randomized studies in patients receiving GP-IIb/IIIa inhibitors, addressing early ambulation (61) and cost/effectiveness aspects are needed. Then, in the words of ZG Turi, "the likelihood of routine arterial sealing of nearly all patients is around the corner" (62).

REFERENCES

1. Krone RJ, Johnson L, Noto T, and the Registry Committee of the Society for Cardiac Angiography and Inter-

ventions. Five year trends in cardiac catheterization: a report from the Registry of the Society for Cardiac Angiography and Interventions. *Cathet Cardiovasc Diagn* 1996;39:31–35.

2. Waksman R, Scott NA, Ghazzal ZMB et al. Randomized comparison of flexible versus nonflexible femoral sheaths on patient comfort after angioplasty. *Am Heart J* 1996;131:1076–1078.
3. Bogart DB, Bogart MA, Miller JT, Farrar MW, Barr WK, Montgomery MA. Femoral artery catheterization complications: a study of 503 consecutive patients. *Cathet Cardiovasc Diagn* 1995;34:8–13.
4. Christensen B, Lacarella C, Manion R, Bruhn-Ding B, Meyer S, Wilson R. Sandbags do not prevent complications after catheterization. *Circulation* 1994;90:1-205.
5. Pracyk JB, Wall TC, Longabaugh JP et al. A randomized trial of vascular hemostasis techniques to reduce femoral vascular complications after coronary intervention. *Am J Cardiol* 1998;81:970–976.
6. Resar JR, Prewitt KC, Wolff MR, Blumenthal R, Raqueno JV, Brinker JA. Percutaneous transluminal coronary angioplasty through 6 Fr diagnostic catheters: a feasibility study. *Am Heart J* 1993;125:1591–1596.
7. Cragg AH, Nakagawa N, Smith TP, Berbaum KS. Hematoma formation after diagnostic angiography: effect of catheter size. *J Vasc Interv Radiol* 1991;2:231–233.
8. Waksman R, King III SB, Douglas JS et al. Predictors of groin complications after balloon and new-device coronary intervention. *Am J Cardiol* 1995;75:886–889.
9. Campeau L. Percutaneous radial artery approach for coronary angiography. *Cathet Cardiovasc Diagn* 1989;16:3–7.
10. Kiemenej F, Laarman GJ, Odekerken D, Slagboom T, v.d. Wieken, R. A randomized comparison of percutaneous transluminal coronary angioplasty by the radial, brachial and femoral approaches: The Access Study. *J Am Coll Cardiol* 1997;29:1269–1275.
11. Bertrand ME, Legrand V, Boland J et al. Randomized multicenter comparison of conventional anticoagulation versus antiplatelet therapy in unplanned and elective coronary stenting—the FANTASTIC Study. *Circulation* 1998;98:1597–1603.
12. Leon MB, Baim DS, Popma JJ et al. A clinical trial

- comparing three antithrombotic-drug regimens after coronary-artery stenting. *N Engl J Med* 1998;339:1665-1671.
13. Dick RJ, Popma JJ, Muller DW, Burek KA, Topol EJ. In-hospital costs associated with new percutaneous coronary devices. *Am J Cardiol* 1991;68:879-885.
 14. Krause PB, Klein LW. Utility of a percutaneous collagen hemostasis device: to plug or not to plug? *J Am Coll Cardiol* 1993;22:1280-1282.
 15. Anderson HV, Bertrand M, Whitworth HB, Sax FL, Willerson JT, for the Restore Investigators. Bleeding risk with platelet inhibition using Tirofiban: The Restore Trial. *Circulation* 1996;94:1-553.
 16. Lincoff AM, Tchong JE, Miller DP, Booth JE, Montague EA, Topol EJ. Marked enhancement of clinical efficacy of platelet GPIIb/IIIa blockade with c7E3Fab (Abciximab) linked to reduction in bleeding complications: outcome in the EPILOG and EPIC trials. *Circulation* 1996;94:1-375.
 17. Goods CM, Liu MW, Jain SP et al. Low molecular weight heparin versus standard heparin in patients at high risk for stent thrombosis: clinical outcomes. *Circulation* 1996;94:1-684.
 18. Ernst S, Kloss R, Schröder R, Kaltenbach M, Sigwart U, Sanborn TA. Immediate sealing of arterial puncture sites after catheterization and PTCA using a vascular hemostasis device with collagen: an international registry. *Circulation* 1991;84:1-272.
 19. Silber S, Dörr R, Mühling H, König U. Sheath pulling immediately after PTCA: comparison of two different deployment techniques for the hemostatic puncture closure device. A prospective, randomized study. *Cathet Cardiovasc Diagn* 1997;41:378-383.
 20. Silber S. Rapid hemostasis of arterial puncture sites with collagen in patients undergoing diagnostic and interventional cardiac catheterization. *Clin Cardiol* 1997;20:981-992.
 21. Silber S. Hemostasis success rates and local complications with collagen after femoral access for cardiac catheterization: analysis of 6007 published patients. *Am Heart J* 1998;135:152-156.
 22. Chvapil M, Holubec H. Effect of hemostatic fleece on 14C-Serotonin release by human platelets. *Jpn Pharmacol Ther* 1990;18:57(2913)-62(2918).
 23. Kitamura K, Yasuoka R, Ohara M et al. How safe are the xenogeneic hemostats? Report of a case of severe systemic allergic reaction. *Surg Today* 1995;25:433-435.
 24. Schröder R, Steinbacher S, Burger W, Kadel C, Vallbracht C, Kaltenbach M. Collagen application for sealing of arterial puncture sites in comparison to pressure dressing: a randomized trial. *Cathet Cardiovasc Diagn* 1992;27:298-302.
 25. Ernst S, Tjonjoegin RM, Schröder R et al. Immediate sealing of arterial puncture sites after cardiac catheterization and coronary angioplasty using a biodegradable collagen plug: results of an international registry. *J Am Coll Cardiol* 1993;21:851-855.
 26. Sanborn TA, Gibbs HH, Brinker JA, Knopf WA, Kosinski EJ, Roubin GS. A multicenter randomized trial comparing a percutaneous collagen hemostasis device with conventional manual compression after diagnostic angiography and angioplasty. *J Am Coll Cardiol* 1993;22:1273-1279.
 27. Silber S, Haentsch C, Seidel N, Mühling H. Early ambulation (30 minutes) after cardiac catheterization using the collagen plug. Efficacy and follow-up comparing two different plug dosages in 660 cases. *J Am Coll Cardiol* 1993;21:150A.
 28. Silber S, Dörr R, Rösch A, Mühling H. Complications after collagen plugging for hemostasis following femoral puncture: experience in over 3000 patients. *Circulation* 1995;92:1-56.
 29. Silber S, Björvik A, Mühling H, Rösch A. Usefulness of collagen plugging with VasoSeal after PTCA as compared to manual compression with identical sheath dwell times. *Cathet Cardiovasc Diagn* 1998;43:421-427.
 30. v. Hoch F, Neumann F-J, Theiss W, Kastrati A, Schömig A. Efficacy and safety of collagen implants for haemostasis of the vascular access site after coronary balloon angioplasty and coronary stent implantation. *Europ Heart J* 1995;16:640-646.
 31. Bartorelli AL, Sganzerla P, Fabbicchi F et al. Prompt and safe femoral hemostasis with a collagen device after intracoronary implantation of Palmaz-Schatz stents. *Am Heart J* 1995;130:26-32.
 32. Brachmann J, Ansah M, Kosinski EJ, Schuler GC. Improved clinical effectiveness with a collagen vascular hemostasis device for shortened immobilization time following diagnostic angiography and percutaneous transluminal coronary angioplasty. *Am J Cardiol* 1998;81:1502-1505.
 33. Carere RG, Webb JG, Miyagishima R, Djurdev O, Ahmed T, Dodek A. Groin complications associated with collagen plug closure of femoral arterial puncture sites in anticoagulated patients. *Cathet Cardiovasc Diagn* 1998;43:124-129.
 34. Kensey KR, Evans DE, McGill LD, Nash JC. In vivo feasibility testing of a bioresorbable hemostatic puncture closure device. *J Am Coll Cardiol* 1991;17:263A.
 35. de Swart H, Dijkman L, Hofstra L et al. A new hemostatic puncture closure device for the immediate sealing of arterial puncture sites. *Am J Cardiol* 1993;72:445-449.
 36. Kussmaul WG III, Buchbinder M, Whitlow PL et al. Rapid arterial hemostasis and decreased access site complications after cardiac catheterization and angioplasty: results of a randomized trial of a novel hemostatic device. *J Am Coll Cardiol* 1995;25:1685-1692.
 37. Aker UT, Kensey KR, Heuser RR, Sandza JG, Kussmaul WG III. Immediate arterial hemostasis after cardiac catheterization: initial experience with a new puncture closure device. *Cathet Cardiovasc Diagn* 1994;31:228-232.
 38. Ward SR, Casale P, Raymond R, Kussmaul WG III, Simpfendorfer C. Efficacy and safety of a hemostatic puncture closure device with early ambulation after coronary angiography. *Am J Cardiol* 1998;81:569-572.
 39. Silber S, Luckas C, Dörr R, Mühling H, Zindler G. Intra-arterial anchoring is superior to plain collagen plugging for sealing arterial puncture sites and ambulating after 20 minutes. *Circulation* 1995;92:1-225.
 40. Cremonesi A, Castriota F, Tarantino F et al. Femoral arterial hemostasis using the Angio-Seal system after coronary and vascular percutaneous angioplasty and stenting. *J Invas Cardiol* 1998;10:464-469.
 41. Silber S, Schön, N, Seidel N, Heiß-Bogner J. Inadvertent occlusion of the common femoral artery following Angio-Seal deployment. *Z Kardiol* 1998;87:51-55.
 42. Wong SC, Papadakos S, Brown M, Gustafson G. A small plug for a big hole: safety and efficacy of eight French Angio-Seal for closure of nine French arte-

- riotomy site immediately following percutaneous coronary interventions. *J Am Coll Cardiol* 1998;31:101-A.
43. Gershony G, Brock JM, Powell JS. A novel vascular sealing device for closure of percutaneous vascular access sites. *Cathet Cardiovasc Diagn* 1998;45:82-88.
 44. Silber S, Gershony G, Schön B, Schön N, Jensen T, Schramm W. A novel vascular sealing device for closure of percutaneous arterial access sites. *Am J Cardiol* 1999; 83:1248-1252.
 45. Mooney MR, Ellis SE, Yehyawi KJ, Gershony G, Mooney JA. Immediate sealing of arterial puncture sites after cardiac catheterization and coronary interventions: initial U. S. Feasibility Trial using the DUETT vascular closure device. *Circulation* 1998;98:1-88.
 46. Müller R, Cattelaens N, Gerckens U, Grube E, Gershony G. Arterial access site closure with a novel vascular sealing device: Duett. *Am J Cardiol* 1998;82[Suppl 7A]: 35S.
 47. Vetter J, Ribeiro E, Hinohara T, Carrozza J Jr, Simpson J. Suture mediated percutaneous closure of femoral artery access sites in fully anticoagulated patients following coronary interventions. *Circulation* 1994;90:1-621.
 48. Carere RG, Webb JG, Ahmed T, Dodek AA. Initial experience using Prostar: a new device for percutaneous suture-mediated closure of arterial puncture sites. *Cathet Cardiovasc Diagn* 1996;37:367-372.
 49. Kulick DL, Rediker DE. Use of the Perclose device in the brachial artery after coronary intervention. *Cathet Cardiovasc Interv* 1999;46:111-112.
 50. Winter K, Khalighi K, Claussen CD, Duda SH. Percutaneous arterial closure in severely scarred groins: a technical note. *Cathet Cardiovasc Diagn* 1998;45:315-317.
 51. Schulze RP, Haerer W, Ludwig B. A new percutaneous vascular surgical device after PTCA and stenting. *Circulation* 1997;96:1-137.
 52. Schwartz DE, Pinkerton CA, Vetter JW, Knopf WD, Fitzpatrick M, Ho KKL. Acute results of the STAND-I percutaneous vascular surgical device trial. *Circulation* 1997;96:1-137.
 53. Gerckens U, Cattelaens N, Müller R, Lampe EG, Grube E. Percutaneous suture repair of the femoral artery after percutaneous diagnostic cardiac catheterization or coronary angioplasty. *Dtsch Med Wschr* 1996;121: 1487-1491.
 54. Gerckens U, Cattelaens N, Müller R, Lampe EG, Grube E. Percutaneous vascular suture of femoral access sites after diagnostic and interventional catheterization procedures—safety and effectivity of a new suture-based closure device. *Herz* 1998;23:27-34.
 55. Sievert H, Becker T, Wander T et al. Early ambulation after PTCA in anticoagulated patients with the Prostar-Perclose percutaneous suture device and the Angio-Seal device—a randomized trial. *J Am Coll Cardiol* 1999; 33:35A.
 56. Loubeyre C, Karam C, Fajadet J et al. Prospective use of a percutaneous vascular closure device in patients undergoing PTCA and stenting. *J Am Coll Cardiol* 1997;29:278-A.
 57. Morice MC, Lefevre T. Immediate post PTCA percutaneous suture of femoral arteries with the Perclose device: results of high volume users. *J Am Coll Cardiol* 1998;31:101A.
 58. Baim DS, Pinkerton CA, Schatz RA, Vetter JW, Fitzpatrick M, Ho KKL. Acute results of the STAND-II percutaneous vascular surgical device trial. *Circulation* 1997; 96:1-442.
 59. Aubry P, Benamer H, Boudvillain O et al. Immediate post PTCA sheath removal without using closure device. *Circulation* 1998;98:1-88.
 60. Feldman T. Percutaneous vascular closure: plugs, stitches, and glue. *Cathet Cardiovasc Diagn* 1998;45: 89.
 61. Lunney L, Karim K, Little T. VasoSeal hemostasis following coronary interventions with abciximab. *Cathet Cardiovasc Diagn* 1998;44:405-406.
 62. Turi, ZG. Plugging the artery with a suspension: a cautious appraisal. *Cathet Cardiovasc Diagn* 1998;45: 90-91.