

Long-Term AAA Sac Pressure Monitoring

A useful, harmless, and important adjunct to postprocedural surveillance.

BY TAKAO OHKI, MD, PhD

"All patients with endovascular aneurysm repair must undergo lifelong periodic imaging to evaluate the stent graft."
—AneuRx Directions for Use.



Due to the continued risk of aneurysm rupture, the need for lifelong surveillance after endovascular aneurysm repair (EVAR) has become a fact of life. Although there are many options available to the vascular surgeon to assess the status of the stent graft, each of the standard imaging modalities has significant drawbacks and problems.

COMPUTED TOMOGRAPHY

Computed tomography (CT) imaging, the established "gold standard," is rapid, reproducible, widely available, and capable of producing high-resolution images. However, patients are exposed to the risks associated with ionizing radiation and are susceptible to contrast-related complications, including impairment of renal function.¹ In addition, a single scan with intravenous (IV) contrast usually costs \$1,500. Table 1 shows the estimated dosage of ionizing radiation a patient receives per examination. It is noteworthy that a single abdominal/pelvic CT scan without contrast is equivalent to 100 chest x-rays. This dose will be more than doubled if IV contrast is used and if delayed images are obtained.

Furthermore, the inconvenience of CT results in reduced patient compliance. Many of my patients do not mind coming to see me in the office, but they absolutely hate getting CT scans. Patients have to get the required blood tests prior to each CT scan, get stuck with a needle several times for IV injection, and spend half a day in the diagnostic center, etc. Finally, studies have demonstrated that simple measurement of maximum sac diameter on CT is not reliable and, in addition, there are published reports of rupture in aneurysms that have shown initial sac reduction.²

TABLE 1. ESTIMATED DOSAGE OF IONIZING RADIATION

Estimated Radiation Dose

• Chest x-ray	0.05 (1x)*
• Mammogram	0.8 (16x)
• Head CT	2 (40x)
• Abdominal-pelvis	10 (200x)
• Full body	25 (500x)
• Hiroshima A-bomb (mean)	20 (400x)

*Doses shown in mSv (millisieverts). Numbers in parentheses show the relative ratio compared to chest x-ray.

MAGNETIC RESONANCE IMAGING

Magnetic resonance (MR) scanning is inherently safer than CT because it does not use ionizing radiation and does not require nephrotoxic contrast agents. It may also have a higher sensitivity than CT for detection of small endoleaks, and it can accurately identify graft migration and excluded aneurysm sac volume. Yet it must be recognized that MR is more expensive and much more time consuming than CT. It is also not as widely available. Patients with metallic implants or pacemakers are unable to undergo MR, which precludes certain stent grafts composed of stainless steel such as the Zenith device (Cook Incorporated, Bloomington, IN).

DUPLEX ULTRASOUND

Color duplex ultrasound has been proposed as an alternative to CT due to its low cost, simplicity, and excellent patient safety. However, technical and logistical problems, such as long study times, the need for the patient to fast prior to the examination, and the need for experienced technologists (of which there is a severe shortage) limit the uniformity and practicality of color duplex as a surveillance modality. Furthermore, clinical evaluations of duplex ultrasound have shown a definitive

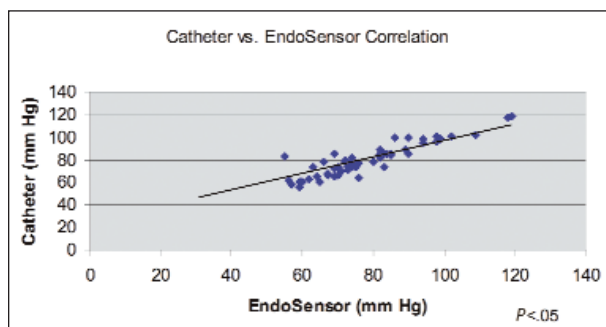


Figure 1. Sensor accuracy proven in the Apex trial.

lack of accuracy. In one study, aneurysm sac measurements were off by >5 mm in 30% of tests.³

WIRELESS PRESSURE SENSORS

Considering the fact that reducing sac pressure is the primary goal of AAA therapy, a surveillance method that specifically monitors the pressure within the aneurysm sac has logical appeal. Measuring sac pressure, demonstrating a reduction in sac pressure, and monitoring the trend can provide direct evidence of both procedural success and long-term stent graft stability, and has been proven in clinical studies.^{4,5} To this end, wireless implantable pressure sensors (EndoSure Sensor, CardioMEMS, Inc., Atlanta, GA; Remon Medical, Tel Aviv, Israel) have been developed. These sensors allow simple, safe, lifelong, accurate, and relatively low-cost measurements of intrasac pressure after EVAR.

The EndoSure sensor has no battery and is powered externally. It is composed of flexible plates bearing inductor windings inside a hermetically sealed reference cavity. A change in the pressure surrounding the sensor will change the distance of the plates, thereby altering the capacitance and resonant frequency of the sensor.⁶ The change in resonant frequency can be monitored by external electronics that convert the frequency measurements into real-time pressure waveforms that are displayed on an external monitor. The sensors are extremely stable, operate over the full physiologic range of pressures, and have a resolution of 1 mm Hg.



Figure 2. Angiogram before EVAR (A). Completion angiography (early phase) shows an endoleak of unknown origin (B). Completion angiography (late phase) (C). The inferior mesenteric artery is shown and suggests a type II endoleak.

Safety and Efficacy

The safety and efficacy of the EndoSure sensor was evaluated in the APEX trial (Acute Pressure Measurement to Confirm Aneurysm Sac Exclusion), a prospective, multicenter clinical study.⁶ The trial results confirmed the safety of the sensor implantation procedure, as well as the feasibility of wireless pressure monitoring. Sac pressure measurements matched those recorded with a catheter, and the sensor demonstrated the ability to detect type I and III endoleaks during EVAR with excellent accuracy (Figure 1). Pressure

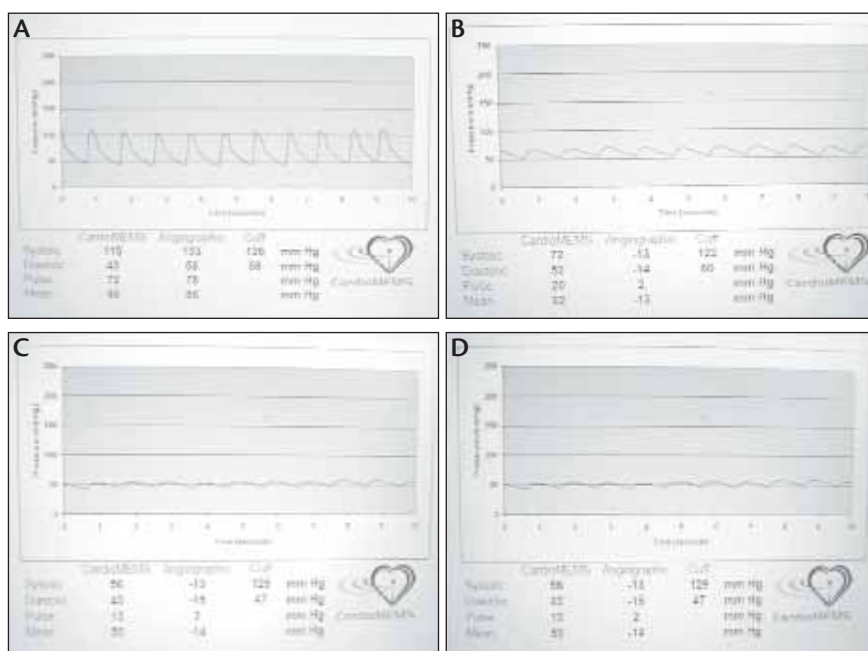


Figure 3. Waveform before EVAR (A). Waveform with an endoleak of unknown origin (B). Dampened waveform while inflating a balloon in the right common iliac artery (C). Waveform after right distal limb extension (D).

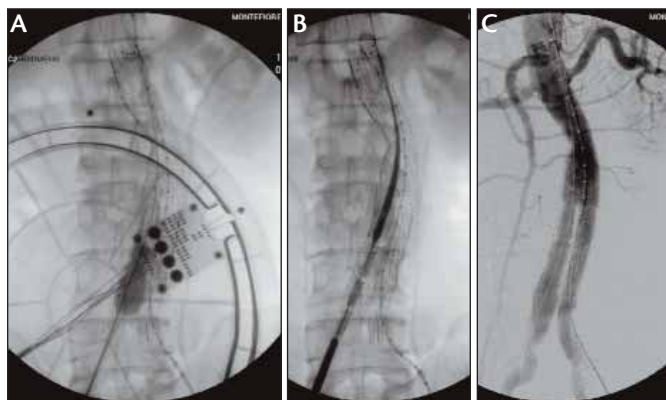


Figure 4. Pre-EVAR angiogram (A), completion angiogram (early phase) shows an endoleak of unknown origin (B), completion angiogram (late phase) (C). The inferior mesenteric artery is shown and suggests a type II endoleak.

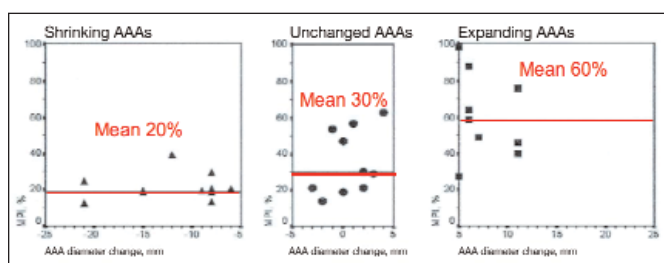


Figure 5. Sac pressure correlates with sac growth.⁵

sensing was helpful in confirming effective exclusion of the sac and also in identifying the significance of the endoleak and its source (Figures 2 through 4).⁵

Cost-Efficiency and Ease

Wireless intrasac pressure measurements have significant appeal for both physicians and patients. The system is simple and inexpensive to use. The pressure readings are easy to obtain; in fact, they can be performed by the patient at the office or at home. In the vast majority of cases, the measurement can be performed within 2 to 3 minutes. The patient will receive a printout of the waveform as well as the sac systolic, diastolic, and mean pressure.

Patient Compliance

This added interaction has actually increased patient compliance with long-term surveillance. Many of my patients wish to come back to the office more often than not to measure pressure, which was not the case when CT scan studies were taken each time the patient returned to the office. If the patient cannot or will not comply, what is the value of such a surveillance program? Because pressure measurements are completely harmless, the physician may

assess sac stability more often than is possible with CT if there is ongoing concern regarding the impact of a discovered or questionable leak on sac size and intrasac pressure. In addition, in patients who have renal insufficiency at the time of EVAR, or subsequently develop it, a wireless sensor may provide the only practical technique for adequately determining stent graft status. This is especially a concern with younger patients undergoing endovascular stent grafting because they will experience a much higher exposure to both radiation and contrast agents during their lifetimes (Table 1). As a point of reference, it has been estimated that one out of every 100 people exposed to 100 mSv of radiation (five abdominal CTs) over a lifetime probably would develop solid cancer or leukemia, and that half of those cases would be fatal.

Potential Objections

Two often-raised potential objections to chronic sac pressure measurements are the lack of rigorous long-term studies and questions related to transmission of pressure through organized thrombus or the issue often termed as *compartmentalization*.

Although long-term studies of sensor performance are still ongoing, other investigators have studied the possible relationship between pressure and sac characteristics and have demonstrated that sac pressure correlates to sac growth

when measured 2 years postprocedure using translumbar puncture techniques.⁵ In this important study by Diaz et al, the sac pressure was measured invasively via a translumbar sac puncture. The mean sac pressure correlated very well with enlargement/shrinkage of the sacs. In those whose AAA grew after the EVAR procedure, the sac pressure was significantly higher compared to those that shrunk (Figure 5).

We have been measuring sac pressure on a long-term basis with the EndoSure sensor and have also encoun-

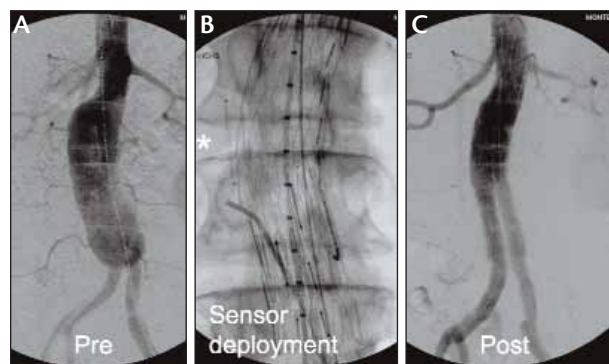


Figure 6. Angiography shows the sensor deployed outside the endograft but inside the sac.

COVER STORY

THE ROLE OF PRESSURE SENSORS

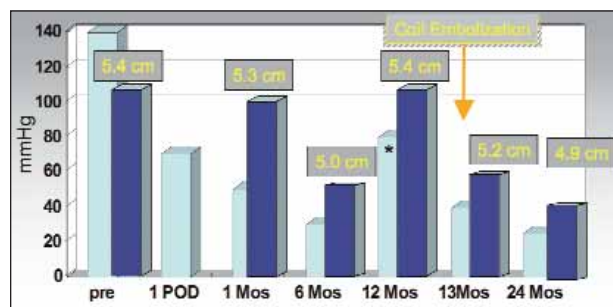


Figure 7. Trend in sac systolic pressure (light blue) and AAA size (CT scan, dark blue) after EVAR. The sac pressure declined over time until 6 months after the procedure. This correlated well with sac shrinkage (dark blue). However, at 12 months, the sac pressure increased to 78 mm Hg(*). This change in sac pressure triggered us to obtain a CT scan that showed significant enlargement of the sac (5 cm to 5.4 cm) and presence of a type II endoleak. Translumbar coil embolization was performed successfully. The sac pressure has declined, and the sac has shrunk following embolization up to 2 years.

tered anecdotal cases in which long-term pressure sensing has been extremely helpful (Figures 6 through 9). Another anecdotal case that was part of the Apex trial also showed value of chronic sensing. The patient had successful EVAR, and the sac pressure decreased significantly (sac/systemic systolic pressure ratio=0.31). However, during the follow-up period, the pressure ratio jumped to 0.57, and a subsequent CT scan showed a type III endoleak that was repaired successfully. Timely detection of an increase in sac pressure can lead to timely repair.

Whether the distance between the sensor and the source of the endoleak will affect the accuracy of the pressure reading has been an issue. Several laboratory research sheds light on this issue.⁷⁻⁹ These studies showed that pressure attenuation is present as it traveled through longer distances of thrombus. However, the change in the pressure, depending on how far the sensor was from the endoleak, has been relatively small. According to Xenos, the change in pressure was only $\pm 11\%$.⁸ This level of difference is not significant enough to hamper the value of pressure sensing. We also studied whether compartmentalization exists or not using an *ex vivo* circulatory model with various human AAA thrombus.⁹ Again, the sac pressure only changed by $\pm 10\%$, depending on the distance of the sensor from the endoleak. It is noteworthy that the sensor technology is not attempting to detect differences of 1 mm Hg to 2 mm Hg, but a significant change in the order of 30 mm Hg to 40 mm Hg, and thus the variance in pressure due to distance from the endoleak, and the nature of the thrombus will not diminish the value of the sensor (Figures 6 through 9).

Many believe that significant compartmentalization exists

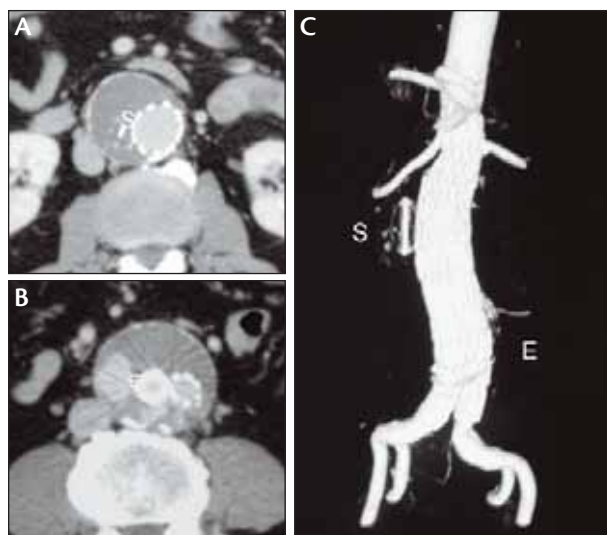


Figure 8. A CT scan was obtained after the sensor showed a sudden increase in sac pressure. The sensor (s) is shown residing inside the sac remote from the endoleak (A), 3 cm distal from the sensor, a type II endoleak (E) is seen (B), a 3D reconstruction shows the distance between the sensor and the type II endoleak (C).

within the sac. This belief is not supported by data, however. If compartmentalization is an actual phenomenon, it may be necessary to deploy more than one sensor. In the sac, pressure is transmitted through clot via two different forms, including (1) hydrostatic fluid pressure and (2) from direct contact with the thrombus. When the sensor is placed within a closed system (watertight), these two pressures are almost equal (within $\pm 10\%$). This is because the thrombus

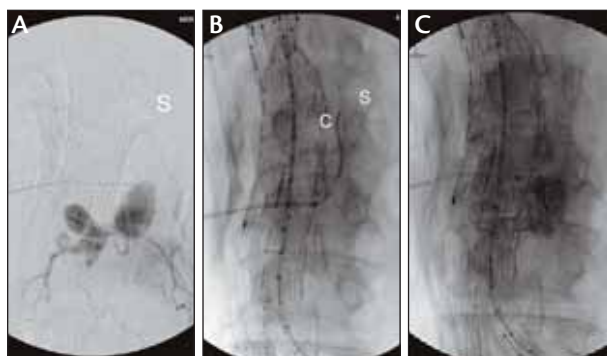


Figure 9. A translumbar angiogram shows a complex type II endoleak 3 cm away from the sensor (s) (A). A catheter (c) was placed in various areas of the sac, and the pressures were recorded. There was excellent correlation between the sensor pressure (72/75 mm Hg) and the catheter. The pressure measured with the catheter varied but remained within the range (from 70/73 to 80/80 mm Hg) (B). Fluoroscopic image shows multiple coils placed inside the nidus of the endoleak (C).

has enough porosity to allow fluid to move around, and fluid is an excellent vehicle to transmit pressure. After all, thrombus is not a watertight object. The sensor will detect the sac pressure accurately provided that the sac is a “closed circuit” and provided that it is filled with fluid or clot and not air (air dampens the pressure significantly).

The nature of the clot does have an effect on pressure transmission, however, as shown by several studies; this effect is within a 5% to 15% range and would therefore not diminish the value of pressure sensing.^{8,9} The negative effects on pressure transmission are greatest in more fibrous and more organized clot. In this regard, the type of thrombus that the sensor is surrounded by provides an excellent environment for pressure sensing. This is because the sensor is always placed in the space between the stent graft and the pre-existing mature thrombus (Figure 10), and because thrombus in the absence of continued blood flow does not mature or organize in the manner it will otherwise, the sensor as well as any endoleak will be surrounded with thrombus that is not as fibrous or organized.

Some of the misunderstanding regarding pressure reading and the issue of compartmentalization may have

come from the fact that investigators thus far have used needles placed inside the sac and have not differentiated whether the measurement was obtained when the needle was inside the organized clot or the more fibrous, pre-existing clot (Figure 10). Thus, even concern about the disputed concept of compartmentalization is not a limiting factor for wireless pressure sensing of the sac.

One additional and obvious objection would stem from the relative newness of the technology, that unlike stent grafts, long-term performance has not been demonstrated. Although this is true, both the Remon and the CardioMEMS wireless systems that have been evaluated have reported follow-up results at up to 2 years from the date of implant (Figure 11) and demonstrate that the device is fully functional and continues to be completely safe for the patient (unpublished data, July 2006).¹⁰ Because neither device requires an internal battery to operate, there is no reason for it to fail.

Certainly nobody would advocate reliance exclusively on pressure information. However, judicious use of selective imaging that limits exposure to ionizing radiation and nephrotoxic contrast agents combined with wireless pressure

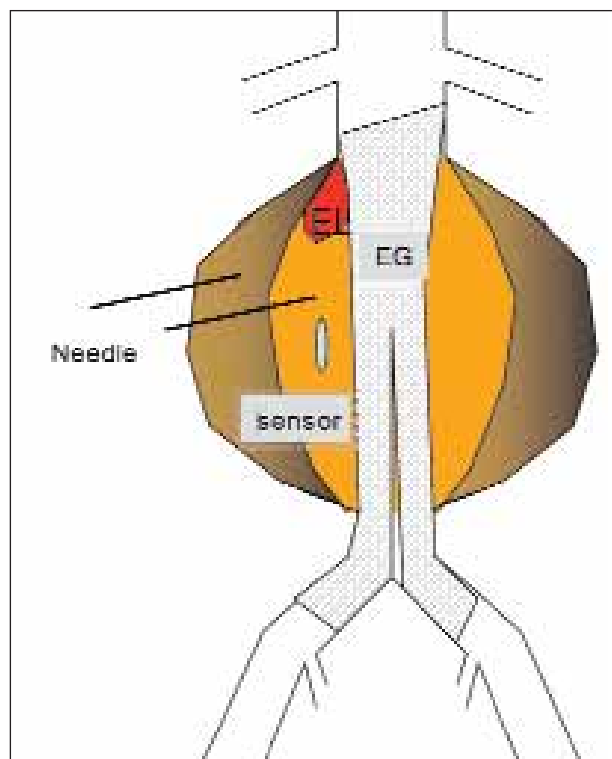


Figure 10. A schematic image of pressure measurement of the sac after EVAR. The translumbar needle could be placed in the pre-existing organized thrombus (dark brown area) where compartmentalization may be more of an issue, or within the less-organized thrombus (orange area) that formed after EVAR. This difference may account for some to believe the presence of compartmentalization. Conversely, the wireless sensor is always placed inside the less-organized thrombus, and the significance of compartmentalization is much less, if any. EG = endograft; EL = endoleak.

measurements would allow careful evaluation of sac status and could lessen, rather than increase, the need for intervention. In addition to using the information obtained from the sensor, one should obtain periodic abdominal radiographs with predetermined protocols so that one can reliably compare one image to the other and detect early signs of stent migration and fracture. The poor reputation regarding abdominal radiographs in detecting stent migration mainly comes from the lack of such standardized protocol. We have spent a great deal of effort in developing protocols to make CT scans reliable but have failed to do so for abdominal x-rays. One abdominal radiograph utilizes only 1/200 of the ionizing radiation of a CT scan and does not require contrast injection, and therefore, it will not only be much easier for the patient, it will cause much less harm. In the future, we envision a protocol such as the one shown in Table 2.

There is no question that implantation of a secondary

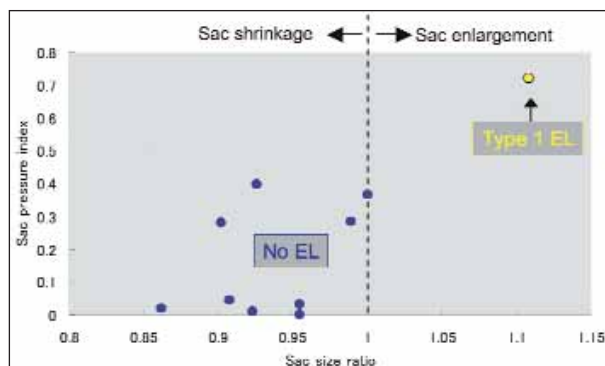


Figure 11. The correlation between pressure index and sac size ratio, 12-month follow-up data from Montefiore. The sac pressure index is SacS/SysS ratio where SacS is sac systolic pressure and SysS is systemic systolic blood pressure. The sac size ratio is the ratio between the maximal sac size obtained from the 1 month postoperative CT scan versus the 12-month CT scan. All of the patients who did not have an endoleak (n=9, blue dot) shrunk or stabilized their sac size and had <0.4 SacS/SysS ratio. Conversely, one patient who had persistent type I endoleak (yellow dot) had high SacS/SysS ratio and also an enlarged AAA.

device during EVAR will add cost to the total operation. Fortunately, the current DRG is meant to cover the total procedure cost and not individual items. It is not uncommon for the vascular surgeon to elect to add stent graft segments to extend the length of the device and deal with intraoperative endoleaks. The added expense of these items is not considered, as they are a necessary and fundamental requirement to ensure a successful outcome. The pressure sensor should be regarded in the same light. In addition, if the patient is ultimately spared multiple contrast CT examinations or urgent repair for a ruptured AAA, the added cost of the device is more than justified.

CONCLUSION

Noninvasive sac pressure monitoring using implantable sensors has the potential to present a safe, reliable, cost-

TABLE 2. FUTURE EVAR SURVEILLANCE PROTOCOL

- Monthly-biannual wireless pressure sensing (depending on the likelihood of failure based on AAA anatomy and type of endograft used).
- Abdominal radiography every 6-12 months to detect graft migration, component separation, and stent fractures. This radiography should be performed under strict protocol to minimize parallax and artifacts.
- CT and/or angiogram only if abnormality detected by pressure sensor or abdominal radiogram.

effective alternative for post-EVAR stent graft surveillance that is compatible with all types of imaging and provides the physician with multiple options not available with other methods, such as the ability to monitor from the home and perform measurements at greater frequency without harm to the patient or added cost and complexity. I personally believe that not only is the development of an intrasac transducer necessary, but it is a desirable adjunct to EVAR, and an adjunct that might possibly eliminate some of the complex imaging protocols that are presently necessary over long-term follow-up.

I am not proposing that the sensor is the answer to all postprocedural surveillance issues, but that it is an important adjunct that may lessen the burden of a full-blown imaging protocol. If one does not agree with the sensor approach, then, I would like to ask this question, "Is the alternative option of lifelong CT scanning so perfect and so satisfactory?" ■

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