The Strut-Adjusted Volume Implant (SAVI; Cianna Medical, Aliso Viejo, CA) is designed to maximize the capacity to modulate dose allowing target tissue coverage with simultaneous normal tissue sparing. There are four sizes of SAVI catheters: 6-1 mini, 6-1, 8-1, and 10-1 with 7, 7, 9, and 11 catheters, respectively. Multiple sizes allow insertion in virtually any clinical situation including the most challenging, such as a tumor bed sandwiched between the chest wall (CW) and skin, cardiac proximity, thin breast tissue in the medial chest, or in the setting of breast augmentation. As the device opens in a continuous motion, it allows enormous possibilities to fit both length and width of cavities. The central catheter is approximately 7 mm longer to allow the dose to project forward from the tip of the catheter. In the event of an irregular cavity, the strut design allows the addition of other catheters to improve dosimetry, and the open architecture allows drainage of serous fluid in an attempt to prevent persistent seroma formation. In the published literature, more than 33% of women treated with the SAVI would not have been eligible for MammoSite (Hologic, Inc., Bedford, MA) balloon brachytherapy (skin <7 mm) and 5% for any balloon brachytherapy (skin <3 mm) (1, 2). In clinical scenarios where both the skin and the CW distances were <7 mm, the dosimetry was still outstanding with a V90 (target volume covered by 90% of the prescription dose) of 93%, V150 of 19.9 cc, and V200 of 10.6 cc (volume of target tissue covered by 150% and 200% of the prescription dose, respectively) with a skin dose average of 272 cGy per fraction and lung dose of 205 cGy/fraction (1). Published reports with other balloon-based catheters demonstrate that small skin bridges can be managed, but no catheter has demonstrated the ability to spare both skin and CW as well. This report by Arthur et al. (3) demonstrates that with skin bridges <7 mm and distance to rib <5 mm, the median doses were 120.6% (410 cGy) and 142% (482.8 cGy) of the prescription dose, respectively. Because the SAVI catheters are not displaced from the tissue by a balloon, modulation can be more finely tuned, with a trade-off that the V200 and V150 are higher than in the balloon devices.

The SAVI is clearly neither a balloon device nor an interstitial implant, lacking some of the flexibility that makes interstitial the gold standard, but also not needing the requisite skill and experience demanded by the interstitial technique. Guidelines were developed empirically for the MammoSite (Hologic, Bedford, MA), and mandating balloon to skin distance of ≥5 mm was considered safe and have kept the toxicity acceptably low. However, although we know that the V150 and V200 guidelines established by MammoSite are safe, it does not mean that doses that exceed this in the absence of a balloon to displace the catheters from the normal tissue are unsafe. Nearly 2-year data on the SAVI catheter show acceptable toxicity with Grade 1 telangiectasias, hyperpigmentation, Grade 2 fibrosis, asymptomatic seromas, and asymptomatic fat necrosis rates of 1.9%, 9.8%, 1.9%, 2%, and 1.9%, respectively. Recurrence rate in this same population is acceptable at 1% as well (1).

Published studies have also considered that because brachytherapy software has not traditionally taken into account heterogeneity corrections possibly the air inside the struts misrepresents the dose in current brachytherapy dose modeling. Both published reports and evaluation with the Varian Acuros software (Varian Medical Systems, Palo Alto, CA) demonstrate at the prescription point that the dose may vary by approximately 5%, which would give a dose of 357 at the 100% isodose line if the dose is limited to 100% of the prescription dose (4). This predicts very acceptable skin doses, which rarely exceed 100% of the prescription dose, and the calculation does not take into account the lack of back scatter at the skin surface, likely making skin doses somewhat lower.

Which device gives optimal planning target volume coverage?

Dosimetric goals in the National Surgical Adjuvant Breast and Bowel Project B-39 trial are to cover at least 90% of
the target volume with ≥90% of the dose ($D_{90} \geq 90\%$), but often, depending on the patient anatomy relative to the cavity position and size, these guidelines can be exceeded. With the Contura catheter (Bard Medical, Covington, GA), it is recommended that $V_{95}$ exceed 95%, and in recently published data $V_{95}$ was 96% (3). On the initial publication of the report on 102 patients treated with SAVI, with 21 months of followup, the $V_{95}$ was not calculated but the $V_{90}$ was 96% (1). When evaluating these data, it is notable that the population of patients who had a skin bridge less than 7 mm had a median maximum skin dose of 290 cGy (85%) with a $V_{95}$ of 95%, and with both CW and skin <7 mm, the skin and rib doses were 272 cGy (80%) and 264 cGy (78%), respectively, with a $V_{90}$ of 93%. In comparison, SAVI recommends keeping the skin dose ≤100%, whereas the Contura relaxes this constraint to 125%. Because coverage, skin, and CW dose are a balance, certainly relaxing the skin maximum will allow increases in coverage, and a decision on the importance of each is a clinical decision for the treating physician. There is certainly nothing about the design of the SAVI that would limit equivalent coverage, and in fact, the design gives enormous flexibility to modulate dose to patient anatomy and tumor bed characteristics. This flexibility may allow treatment in less than ideal situations, such as a close margin. With interstitial brachytherapy, commonly practiced in Europe, the “free margin” technique is used. In this technique, all margins are reported individually, and those margins that are close have dose projected further compared with margins that are considered adequate. With single-entry catheters, this technique would be challenging, if not impossible. However, accepted for publication and presented as a poster at the American Brachytherapy Society in 2011 is the exploration of asymmetric margins with the SAVI in the case of asymmetric margin widths on the lumpectomy specimen (5, 6).

Both Edmundson et al. and Dickler et al. (7, 8) published data exploring the amount of tissue treated by the MammoSite balloon device. According to their reports, the balloon stretches the tissue, and when relaxed the treated target tissue amounts to the equivalent of approximately 1.5 cm of measured tissue. Looking toward the future, with the increase in available methods for accelerated partial breast irradiation, it will likely make more sense to convert to a volume of target in cubic centimeters or percentage of breast, rather than a linear measurement. Examination of the published treated planning target volumes for evaluation (PTV-eval when the cavity is subtracted) demonstrates that the SAVI 8-1 and 10-1 treat an equivalent amount of tissue (8-1 with an average of 83.3 cc with a range of 20.6–138.9 cc and the 10-1 with an average of 125.9 cc with a range of 53.5–212.9 cc) (9) as the balloon devices (MammoSite average 95 cc with a range of 74–120 cc and Contura 83.8 cc with a range of 42–143 cc) (3, 8). Logic would then dictate that a similar amount of tissue gets therapeutic irradiation with the SAVI devices as with the balloon devices. The 6-1 and 6-1 mini treat smaller volumes but were designed for distinct clinical situations where the breast is small or the cavity is sandwiched between the skin and CW.

Device that is most flexible with regard to patient selection

Designed to allow maximum flexibility, the SAVI device conforms the target dose to virtually any cavity, even those with narrow skin and CW bridges, or both simultaneously. The juxtaposition of the strut to the tissue is what allows this conformality and is further strengthened by the variety of sizes and smooth expansion of the struts that maximizes conformance. In addition, the open architecture will allow placement of additional needles, if necessary, for asymmetric cavities, and fluid or hematoma will reside within the catheters thereby not interfering with conformance. Basically, the only criteria that determine the suitability for placement of the device are the pathologic criteria of the tumor. Of the first 102 patients treated in a multi-institutional setting, 27% were not eligible for a single-lumen balloon (skin bridge <7 mm) and 5% for any balloon brachytherapy (skin bridge <3 mm). Dosimetry in this study was outstanding with a $V_{95}$ of 95.2% overall and 93% in those patients with skin and CW bridges <7 mm. $V_{150}$ and $V_{200}$ were 25.8 and 12.7 cc with skin bridges <7 mm and of 19.9 and 10.6 cc, respectively, if both the CW and skin were less than 7 mm. In both situations, the median maximum skin dose was 280 cGy with narrow skin bridges and 272 cGy in narrow skin and CW bridges (1). Because neither normal tissue proximity nor breast size is an issue, the SAVI allows more women to choose accelerated partial breast irradiation.

Device predicted to have the least side effects

Predictions can be incorrect, as shown by the predictions of a computer crash at the start of the Year 2000 and innumerable end of the world and political predictions. Unfortunately, the true incidence of toxicity will only be found with close followup and reporting of these patients. When the single-lumen MammoSite was first introduced, dosimetric guidelines were produced extrapolating from interstitial data and based empirically on expert opinion. The $V_{150}$ and $V_{200}$ cutoffs appear to be safe, but the need for tumor bed—skin bridges of ≥7 mm was advised after reports surfaced of excessive skin toxicity if the dose exceeded 145% of the prescription dose. The Contura and MammoSite have now advised that 125% be the dose limit for the skin, and no recommendation is available for rib, despite reports of rib fractures. Lung and heart data are not currently available to establish these guidelines. The flexibility of the SAVI device allows the skin dose, even with skin bridges <3 mm, to rarely exceed 100% of the prescription dose. Time will tell if this constraint is the most advisable, but SAVI users will likely continue to keep
the skin as low as possible while maintaining good target coverage because it is easily achievable. MammoSite guidelines recommended that the $V_{150}$ be below 50 cc as reports from interstitial data indicated that $V_{150}$ may be a parameter associated with toxicity (10). Five-year non-randomized MammoSite data indicate acceptable toxicity with this constraint with a fat necrosis, infection, and symptomatic seroma rate of 2.3%, 9.5%, and 13%, respectively. Good-to-excellent cosmesis at 24 and 48 months using the Harvard scale was 94% and 90.6%, respectively (11). Benitez et al. (12) published a 5-year update on the MammoSite with telangiectasia, retraction, infection, and symptomatic seroma rates of 39.5%, 20.9%, 9.3%, and 12%, respectively. Twenty-one month rates of Grade 1 telangiectasias, hyperpigmentation, Grade 2 fibrosis, asymptomatic seromas, and asymptomatic fat necrosis were 2%, 1.9%, 9.8%, 1.9%, 2%, and 1.9%, respectively, with the SAVI (1). Recommendations were also to keep $V_{200} < 20$ cc, and again acceptable toxicity has been seen with the available followup data. Because the struts on the SAVI catheter are directly against the tissue, even a rudimentary knowledge of radiation physics demonstrates that the $V_{200}$ will be higher than when the struts are displaced from tissue, as in the balloon catheters. SAVI is not exactly like interstitial in that there are only 7–11 struts available for radioactive source placement, as opposed to 15–20 catheters. Recommendations are to keep $V_{200} \leq 20$ cc and that is readily achievable, especially with the 6-1 mini, 6-1, and 8-1 catheters. Despite being higher than the MammoSite guidelines, preliminary reports on the SAVI do not demonstrate increased toxicity, and simply because the 10-cc guidelines have been demonstrated to be safe does not mean that 20 cc is by definition unsafe (1).

Lastly, how the cavity is drawn in the SAVI can make a significant difference in the calculation of $V_{200}$. Because the dwell positions are in the struts, if the cavity is drawn inside the struts, including them in the target tissue and PTV-eval the $V_{200}$ may be falsely elevated. Given the four sizes and differences in PTV-eval volumes treated as discussed previously, it may make more sense to correlate toxicity with the percentage of PTV-eval receiving 150%, 200%, or 300% of the prescription dose. Of course, it will take experience and time to correlate these and see if refinement of guidelines should be considered. In that regard, time will demonstrate the truth.

Another difference to be addressed is the air cavity that lies inside the SAVI. Commercial brachytherapy planning systems do not correct inhomogeneities in tissues treating all tissues as water, much like external beam plans several years ago. To take inhomogeneities into account, Monte Carlo calculations are used, and today there is a commercial system that approximates the Monte Carlo system using a grid-based Boltzmann solver (solves the linear Boltzmann transport equation). Because the SAVI is filled with air, as opposed to water as in the balloon devices, questions arose as to the actual dose delivered when the inhomogeneities were taken into account. This has been evaluated using the Monte Carlo calculation, and the commercial system and magnitude of dose difference depends on the size of the device, amount and position of air and fluid within the device, arrangement of the sources, and dwell times. However, the differences between the delivered and planned doses at 1 cm range from 3% to 9%, with an average of 5% (4). Although a slightly higher dose at depth is not an issue, the question is raised on how this affects skin dose. Skin dose is also affected if within the dose range, but because there is less backscatter from the air outside the body, this dose is relatively less. Regardless, if every effort is made to keep skin dose $\leq 115\%$ of the prescription dose, studies would indicate that skin toxicity even in the worst case scenario is unlikely to be excessive.

Finally, issues are raised regarding the dose homogeneity index (DHI). DHI is calculated by the following formula: $DHI = (1 - \frac{V_{150}/V_{100}}{V_{90}/V_{50}})$. In interstitial therapy reporting the $V_{90\%}$, $V_{95\%}$, $V_{100\%}$, and $V_{200\%}$ was not a sufficient explanation of the dosimetric symmetry of the implant. One could have acceptable values for these volumes and percentages but still have an implant that was relatively and excessively hot or cold in some areas. DHI was a value designed to point out when the dose was not sufficiently homogeneous and when excessive dose was being given by few of the catheters. When the balloon devices were introduced, although the DHI was reported, it began to lose significance. Because the balloon displaces the source from the tissue, especially in the case of the original MammoSite with only one dwell position, evaluating the relative symmetry of the dose in the target volume was an exercise as variation across the tissue by virtue of the implant was not possible. Even with the multistrut devices within the balloon, the distance between the sources and tissue caused by the balloon made this value fairly meaningless. With the SAVI, there are struts, and source dwell positions, directly adjacent to target tissue. However, because the struts are centered inside the cavity and target, it is obvious that the dose will be higher centrally and rapidly decreases toward the prescription point. There are inherent inhomogeneities in the design; however, there are no data to support that having the dose higher in tissue most likely to harbor cancer cells adjacent to the tumor bed and struts is undesirable. There are also no toxicity data that indicated that DHI, a value important in the description of interstitial implants and clinically associated with toxicity, is applicable to either the balloon devices or the SAVI. Time will tell if this is important, but before that time insistence on its inclusion as an important end point is only speculation.

In summary, although the SAVI device is designed with clear differences from both interstitial and balloon devices, there is to date no indication that the changes to allow simplicity of use (single entry) with maximum dose modulation capability (dwell positions juxtaposed to tissue) have an inherent excess in risk of toxicity to the patient. It is
a device that is easy to use and facile in its design to allow use in sundry clinical situations to maximize the dose to the tissue at risk and minimize the dose to normal tissues.

References


