Techniques in Vascular and Interventional Radiology

Ablation Planning Software for Optimizing Treatment: Challenges, Techniques, and Applications

Gray R. Lyons, MD, PhD, and Bradley B. Pua, MD, FSIR

Percutaneous ablation can deliver effective anticancer therapy with minimal side effects; however, undertreatment can lead to disease recurrence and overtreatment can lead to unnecessary complications. Ablation planning software can support the procedure during the planning, treatment, and follow-up phases. In this review, 2 examples of microwave ablation software are described with attention to how the software can influence procedural choices. In the future, ablation software will entail larger source datasets and more refined algorithms to better model the in vivo ablation zone. Moreover, ablation simulation has the potential to augment clinical care beyond the interventional suite, such as procedural demonstration for patients, clinical consultation with referring providers, documentation for the medical record, and educational simulation for trainees.
Tech Vasc Interventional Rad 22:21-25

KEYWORDS Ablation planning, Ablation confirmation, microwave ablation, cryoablation

Ablation Procedure and Technical Challenges

Image-guided tumor ablation entails direct application of chemical or energy-based therapy to eradicate or debulk a solid tumor. Thermal ablation modalities include radiofrequency and microwave ablation, which destroy tissue through heat deposition, and cryoablation, which causes cytotoxicity through freezing and thawing.[1] The advantages of percutaneous ablation over resection include precise tumor targeting with image guidance, minimal damage to nontarget tissue, short patient recovery period, and the economic savings of a minimally invasive approach. Moreover, in many patients who are not surgical candidates, ablation is an attractive therapeutic option for local disease control.

The ablation procedure generally entails the following components: focused imaging to localize the tumor target, procedural planning to optimize the approach, insertion of 1 or more modality-specific applicators directed to the target, deposition of therapy with intraprocedural imaging, removal of the applicator, and postprocedural imaging.[2] Successful ablation is predicated on precise targeting of the tumor and creation of an ablation zone that encompasses the entire neoplasm with adequate margins. An insufficient ablation zone can lead to residual and recurrent disease; however, excessive ablation can lead to unnecessary tissue damage and complications. Planning the ablation zone is often the most challenging technical factor for the operator.

To create an optimized ablation zone, it is imperative to know the extent of the ablation margin created by each applicator. Some modalities are amenable to intraprocedural feedback on ablation area: in thermal ablation, thermocouples can be placed to measure the temperature at a certain site, and in cryoablation, the low-density ice ball can be imaged live during the procedure.[3] But these are incomplete surrogates for the actual zone of ablation, as thermocouples only measure a single point in space, and the cryoablation ice ball does not correspond to the lethal isotherm.

Ideally, the operator would know the expected ablation size during the planning phase, before therapy is delivered. There are many resources available to predict the ablation

Department of Radiology, Division of Interventional Radiology, NewYork-Presbyterian Hospital/Weill Cornell Medicine, New York, NY.
The authors report that they have no competing financial interests to disclose.
Address reprint requests to Bradley B. Pua, MD, FSIR, Department of Radiology, Division of Interventional Radiology, NewYork-Presbyterian Hospital/Weill Cornell Medicine, 525 East 68th St, New York, NY 10065. E-mail: brp9018@med.cornell.edu

1089-2516/14/$-see front matter
https://doi.org/10.1053/j.tvir.2018.10.005

zone, and data have been generated from theoretical modeling,[4] in vitro gel phantom testing,[5] ex vivo tissue testing,[6] pathologic analysis of ablation zones,[7] and follow-up imaging of ablated tumors.[8] Reports have differed as to the applicability of these approaches to clinical ablation, with some studies finding significantly different ablation zone sizes,[8] while others found consistency between experimental and clinical ablation zone size.[9,10] Cryoablation is more susceptible to heat sink effect from nearby blood vessels or aerated lung,[11,12] which makes predictive modeling difficult.[13]

With so many parameters to consider when planning an ablation, it is impractical for the operator to consult all available sources for each procedure. Typically, one might reference the manufacturer published ablation map in a one-size-fits-all manner, but this can lead to suboptimal ablations, especially in complex cases. The problem of applying known ablation data to individual cases in an intuitive, visual format has been an impetus for developing ablation planning software. Ultimately, this can help clinicians identify tumor tissue at risk for undertreatment and healthy tissue at risk for overtreatment. These software packages have the potential to transform the ablation planning phase and improve operator confidence in delivering ablative therapy.

Ablation Planning Software Techniques

Ablation planning is only as relevant as the technology it is supporting. Microwave ablation is particularly amenable to automated planning due to the relatively consistent ablation zone.[9,10,14] Compared to other modalities, microwave is less susceptible to tissue-specific and heat sink effects, which allow for more reliable planning. This section will review 2 commercially available ablation software packages for microwave ablation by the manufacturers Ethicon (NeuWave) and Medtronic (Emprint).

The NeuWave ablation planning software provides features for lesion identification, antennae targeting, and ablation confirmation following therapy. The software can tether directly to PACS (Picture Archiving System) to download procedural imaging directly, also with the unique ability to upload postprocedural data directly back into PACS for archiving. Figure 1 demonstrates an illustrative case where targeting was aided through software. In this case, the tumor was only visible following intravenous contrast injection; however, the lesion was tagged using ablation planning software, which allowed for confident antennae placement even after contrast washout (Fig. 1A-D). This has been validated in a larger series, which reported antenna repositioning in 18.6% of cases based on the ablation planning software feedback.[15]

One drawback to the NeuWave system is the inability to visualize directly the predicted ablation zone in the graphical user interface. In this case, the published ablation margins for a particular time and wattage setting were referenced and manually drawn to model the expected ablation zone (Fig. 1E). One must be careful in this stage to avoid patient motion or altering the target coordinates, as misregistration artifact will occur if the target is moved. Even though this manual approach is cumbersome, it is still worthwhile to overlay the predicted ablation zone onto the target lesion image, thus providing delineation of the expected margins and alerting the operator to any coverage deficiencies.

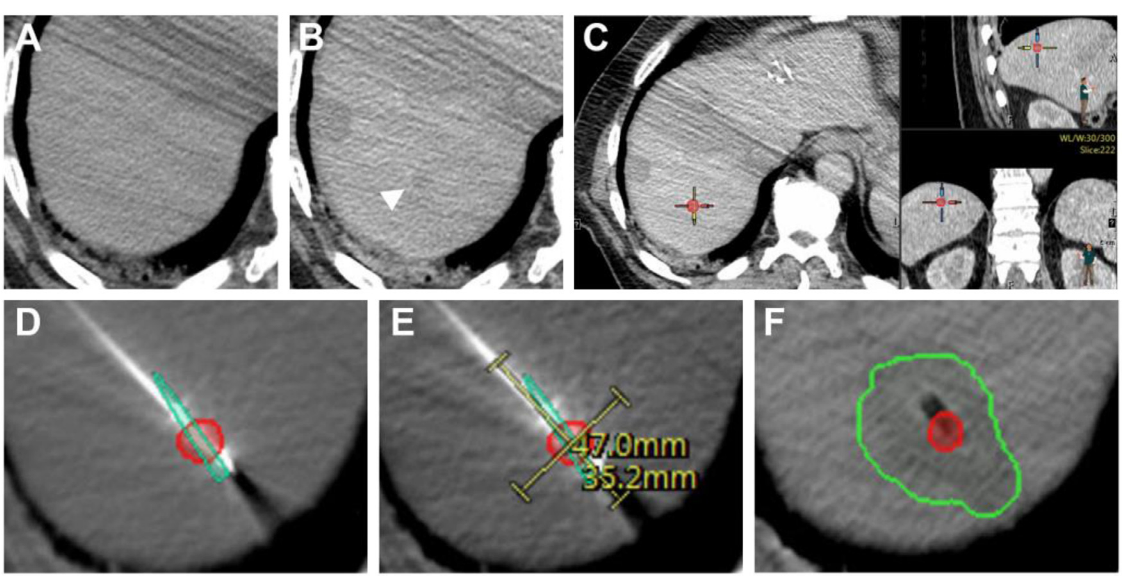

Figure 1 Percutaneous microwave ablation in a 74-year-old patient with rectal cancer and segment 7 liver metastasis. Target could not be visualized with noncontrast technique (A), so IV contrast was administered to identify the lesion (B, arrowhead). NeuWave simulation software was used to mark the lesion in 3 dimensions (C, red sphere), and this mark was propagated with CT fluoroscopy during antennae placement (D). The manufacturer published ablation zone axes were manually drawn in the software (E) to confirm adequate margins. Postablation imaging demonstrates parenchymal contraction, a low-attenuation ablation zone, and gas in the ablation epicenter (F). The green ablation zone outline is created by the simulation software using edge-detection algorithm and hand corrected by the operator. Case courtesy of Dr W. Alago, Memorial Sloan Kettering Cancer Center. (Color version of figure is available online.)

The strength of the NeuWave ablation software is the ablation confirmation feature, which uses an edge detection algorithm to identify the ablation area following treatment (Fig. 1F). Given that microwave ablation is known to cause tissue contraction, it can be difficult to confirm visually a technically successful ablation. NeuWave ablation confirmation includes a tissue contraction feature that shrinks the target marker following ablation to give a more accurate representation of the target lesion. When overlaid with the ablation zone margin depicted in the software, the operator is then better able to assess the effects of the ablation procedure. The utility of this feature has been demonstrated clinically, as 1 series found that inadequate ablation margins were identified in the software in 7% of cases, thus prompting additional ablation.[15]

The Emprint ablation planning software is a more recent addition to the ablation armamentarium and includes additional features not available in other systems (Emprint software version 1.4 is under FDA 510(k) review at the time of publication.). The software system allows for lesion identification, antennae targeting, and predictive ablation zone modeling. Moreover, the software begins by allowing the user to select organ-specific workflows, which adjusts ablation zone predictive modeling based on experimental device performance in different organs. Once the organ of choice is selected, images are accessed directly from PACS and the target is selected.

The most useful and innovative feature of the Emprint software is the ability to draw a region of interest around the target to delineate the desired ablation zone. Once the desired probe size and power are selected, the program then outputs the necessary ablation time required to achieve the desired ablation size. These parameters are drawn from a manufacturer dataset using in vivo healthy porcine specimens, which are more likely to mirror real-world human ablations compared to in vitro or ex vivo data.[8] With this tool, the operator is spared the inefficiency and uncertainty of searching reference value diagrams for an acceptable ablation zone. Rather, the ablation zone is visually selected, and the computational algorithm applies the correct parameters for the procedure.

The lung nodule ablation procedure depicted in Figure 2 demonstrates the utility of the Emprint predictive modeling tool. In this case, the initial treatment plan (Fig. 2B and C) called for 100 W and 10 minutes to achieve a robust zone of ablation. However, scrolling through the image stack demonstrated that these parameters would extend the ablation margin to the apical pleura and chest wall tissues, which could increase patient pain and complication risk (Fig. 2D). A smaller ablation area was selected using triplane reconstruction and 3-dimensional (3D) rendering of the antenna trajectory (Fig. 2E and F), which led to safe and successful lung nodule ablation without extension to the pleura. Note the similarity between the predicted ablation size and the actual ablation size manifest by a surrounding "halo" on postprocedural images (Fig. 2G).

Although the Emprint software does not provide ablation confirmation as the NeuWave device does, the prospective modeling and predictive value of the ablation selection tool are particularly valuable in optimizing treatment. Rather

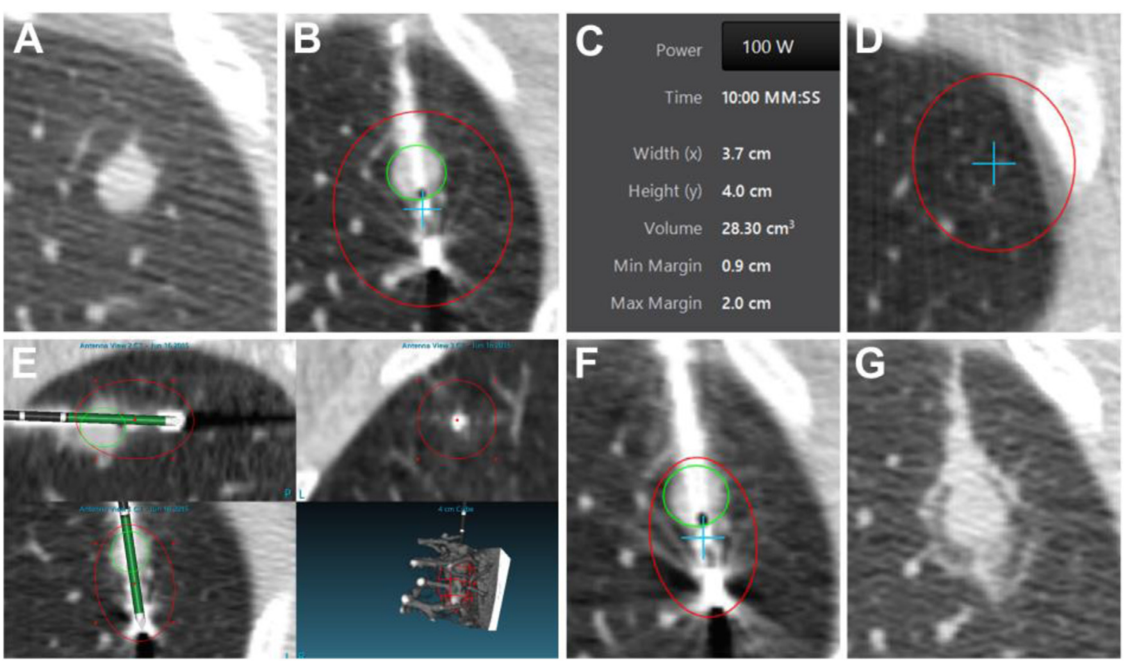

Figure 2 Percutaneous microwave ablation in a 41-year-old patient with adenoid cystic carcinoma of the oropharynx with pulmonary metastases. The nodule (A) was targeted with a microwave antenna and an initial ablation zone was selected in the Emprint software (B) with planned ablation parameters of 100 W for 10 minutes (C). Analysis of a cranial slice of the treatment volume (D) demonstrated extension of the treatment area to the pleura and chest wall. Repeat planning using triplane reconstruction and 3D modeling (E) demonstrate the ablation zone proximity to the chest wall and allowed the selection of a smaller treatment volume (F) to minimize nontarget tissue damage. The lesion was ablated at 75 W for 2 minutes, which yielded the predicted, satisfactory treatment area (G) without extension to the extrapulmonary tissues.

than extrapolating ablation parameters from a published monograph or analyzing the ablation area after treatment, this feature provides useful projections of ablation area and actionable information to select treatment parameters within the graphical user interface. This technology has been published in several case series reports; however, it should be noted that there is no statistically rigorous analysis to date to describe the clinical utility of this software.[16-18]

Ablation Planning and Solving the Treatment Problem

The ablation simulation tools described above are most feasible with microwave ablation, which has been shown to produce a relatively consistent and reliable ablation zone. But what about ablation procedures involving >1 microwave antennae, or procedures using cryoablation, where the ablation area depends on tissue type, heat sink effects, and synergy between multiple probes?

It has been over 10 years since Wood et al[19] published a review of technologies for ablation guidance in the "interventional suite of the future," and these advancements are now making their way into common practice. Ultimately, the goal is to decrease treatment failure and recurrence rates while also avoiding overtreatment and procedural complications. However, ablation zones can be hard to predict, due to variability in tissue types, physiology, operator mechanics, and ablation technology. This leads to the "treatment problem" of percutaneous ablation: consistently achieving a technically successful ablation without local recurrence (undertreatment) while minimizing healthy tissue damage (overtreatment) in every procedure.

The treatment problem will not have an easy solution, but ablation planning and simulation software will play an expanding role in the development of the modality. In the future, one can envision tissue-specific protocols and modeling of anatomical factors by the software using robust datasets drawn from many studies. This information will be integrated by the computer to determine the ablation zone with a high degree of confidence, including predicting aberrations from heat sink or patient motion.[20] Machine-learning algorithms could be used to parse millions of data points and create advanced planning maps based on structured predictions. Advanced ablation procedures, for example, a cryoablation of a metabolically heterogeneous volume using multiple cryoprobes, will be modeled and previsualized with contoured maps that conform to tissue and probe architecture.

Many groups are working to create the ablation procedure of the future, and ablation simulation is a focus of several vendors. In addition to the ablation software packages reviewed in detail above, it should be noted that there are many commercial products available, each with unique advantages and disadvantages. Some commonly used vendors include CAScination (www.cascination.com), EDDA (www.edda-tech.com), Endocare (endocare.com), Healthtronics (www.healthtronics.com), INTiO (www.intio.us), iSYS (www.interventional-systems.com), Perfint (www.perfinthealthcare.com), and others. The number of entrants into the ablation simulation marketplace is an indicator of the promise of this technology. When ablation simulation is combined with other emerging ablation technologies such as multimodality navigation systems,[21-23] 3D printing models,[24] and robotic procedural assistance,[25] the field will continue its slow march toward solving the ablation treatment problem.

Expanding the Scope of Ablation Simulation

While the technology of ablation planning software gradually improves, the existing simulation software can be applied outside of procedural planning to support the clinical mission. Potential uses of this technology include procedural demonstration for patients, clinical consultation with referring providers, documentation for the medical record, and educational simulation for trainees. In this section, the potential uses of ablation simulation software and the implications for patient care are reviewed.

Patients may benefit directly from consultation involving ablation simulation software. It has previously been shown that review of radiographic imaging during patient consultation improves understanding and satisfaction.[26] Additionally, preoperative computer modeling in aesthetic surgical procedures has been shown to increase patient satisfaction with outcomes.[27] Taken together, it is reasonable to assume that the ability to visualize the medical imaging along with a simulated procedure map will increase patient understanding and agency during the consent process, as well as increasing patient satisfaction following the procedure. As interventional radiology progresses as a clinical discipline, ablation simulation may provide a useful tool to improve the patient experience.

Other providers—from referring primary care clinicians to members of a tumor board—also may find utility in ablation simulation software. It has been previously shown that computational 3D modeling of head and neck tumors improved staging accuracy by an otolaryngologist on panendoscopy.[28] In the same way, demonstration of ablation treatment simulation using 3D modeling and animated treatment path may improve understanding and confidence in the treatment plan among the treatment team. As interventional radiologists seek to expand the scope of their practice, ablation simulation has the potential to improve engagement with physician colleagues in the tumor board and beyond.

Ablation simulation and planning images can be easily imported into PACS, and this data will then be part of the electronic medical record. As with all components of the medical record, this has quality improvement, legal, and billing considerations that may influence practice. For example, if a tumor ablation procedure was planned with simulation software, adverse outcomes could be better assessed retrospectively in the quality improvement process with opportunity for improvement in future cases. Moreover, supportive information regarding medical decision making would be available for discovery should legal issues arise. Although ablation simulation is currently not directly compensated in most situations, archiving ablation simulation data could lead to outcomes research demonstrating the product value—a necessary prerequisite to changes in billing policies. Continued implementation of ablation simulation and incorporation of this data in the medical record has the potential to affect quality improvement, legal, and billing aspects of clinical practice.

Finally, ablation simulation has the potential to augment the educational experience for trainees. The benefits of simulation-based training in interventional radiology are reviewed by Miller et al in this issue and will not be covered here. But it should be emphasized that ablation planning software is more than just simulation—it is a prelude to a physical procedure. In this respect, the potential educational benefits of computer simulation followed by clinical implementation are considerable. As the future of image-guided intervention education will increasingly rely on simulation, ablation planning software will provide a useful tool to train the next generation of interventional radiologists.

Conclusion

Ablation planning software is a promising technology that can improve technical success in the ablation procedure, as well as support the clinical mission through planning, navigation, and visualization of ablation therapy. The value of ablation simulation is limited by the quality of reliable source data, and additional studies will be needed to better characterize and model complex ablation procedures.

Acknowledgments

The authors wish to thank Dr W. Alago at Memorial Sloan Kettering Cancer Center for sharing procedural images and the product teams from Ethicon and Medtronic for conducting demonstrations of their ablation software.

References

1. Hinshaw JL, Lubner MG, Ziemlewicz TJ, et al: Percutaneous tumor ablation tools: Microwave, radiofrequency, or cryoablation—what should you use and why? Radiographics 34:1344-1362, 2014
2. Ahmed M, Solbiati L, Brace CL, et al: Image-guided tumor ablation: Standardization of terminology and reporting criteria—a 10-year update. Radiology 273:241-260, 2014
3. Erinjeri JP, Clark TW: Cryoablation: Mechanism of action and devices. J Vasc Interv Radiol 21:S187-S191, 2010
4. Boas FE, Srimathveeravalli G, Durack JC, et al: Development of a searchable database of cryoablation simulations for use in treatment planning. Cardiovasc Intervent Radiol 40:761-768, 2017
5. Liu Z, Ahmed M, Weinstein Y, et al: Characterization of the RF ablation-induced 'oven effect': The importance of background tissue thermal conductivity on tissue heating. Int J Hyperthermia 22:327-342, 2006
6. Cavagnaro M, Amabile C, Cassarino S, et al: Influence of the target tissue size on the shape of ex vivo microwave ablation zones. Int J Hyperthermia 31:48-57, 2015
7. Jaskolka JD, Kachura JR, Hwang DM, et al: Pathologic assessment of radiofrequency ablation of pulmonary metastases. J Vasc Interv Radiol 21:1689-1696, 2010
8. Winokur RS, Du JY, Pua BB, et al: Characterization of in vivo ablation zones following percutaneous microwave ablation of the liver with two commercially available devices: Are manufacturer published reference values useful? J Vasc Interv Radiol 25:1939-46.e1, 2014
9. De Cobelli F, Marra P, Ratti F, et al: Microwave ablation of liver malignancies: Comparison of effects and early outcomes of percutaneous and intraoperative approaches with different liver conditions: New advances in interventional oncology: State of the art. Med Oncol 34:49, 2017
10. Vogl TJ, Basten LM, Nour-Eldin NA, et al: Evaluation of microwave ablation of liver malignancy with enabled constant spatial energy control to achieve a predictable spherical ablation zone. Int J Hyperthermia 34:1-9, 2017
11. Yashiro H, Nakatsuka S, Inoue M, et al: Factors affecting local progression after percutaneous cryoablation of lung tumors. J Vasc Interv Radiol 24:813-821, 2013
12. Nakatsuka S, Yashiro H, Inoue M, et al: On freeze-thaw sequence of vital organ of assuming the cryoablation for malignant lung tumors by using cryoprobe as heat source. Cryobiology 61:317-326, 2010
13. Hashimoto K, Izumi Y, Yamauchi Y, et al: Prediction of the critical thermal zone during pulmonary cryoablation on computed tomography from correlated experimental and clinical findings. J Thorac Cardiovasc Surg 145:832-838, 2013
14. Ierardi AM, Mangano A, Floridi C, et al: A new system of microwave ablation at 2450 MHz: Preliminary experience. Updates Surg 67:39-45, 2015
15. Laeseke PF, Ziemlewicz TJ, Shane A, et al: Impact of ablation guidance and confirmation software on percutaneous microwave ablation of liver tumors. In: Presented at Radiological Society of North America; 2017, 2017 Chicago, IL. Abstract available at: https://rsna2017.rsna.org/program/index.cfm Accessed March 5, 2018
16. Berber E: The first clinical application of planning software for laparoscopic microwave thermosphere ablation of malignant liver tumours. HPB (Oxford) 17:632-636, 2015
17. Hoffman T, Kalia A, McLennan G, et al: Can planning software be used to confirm complete thermal coverage during percutaneous microwave ablations? In: Presented at World Congress of Interventional Oncology; 2015, 2015 New York, NY. Abstract available at: http://www.sio-central.org/page/previous-year-s-programs Accessed March 5, 2018
18. Zaidi N, Okoh A, Yigitbas H, et al: Laparoscopic microwave thermosphere ablation of malignant liver tumors: An analysis of 53 cases. J Surg Oncol 113:130-134, 2016
19. Wood BJ, Locklin JK, Viswanathan A, et al: Technologies for guidance of radiofrequency ablation in the multimodality interventional suite of the future. J Vasc Interv Radiol 18:9-24, 2007
20. Rieder C, Kroger T, Schumann C, et al: GPU-based real-time approximation of the ablation zone for radiofrequency ablation. IEEE Trans Vis Comput Graph 17:1812-1821, 2011
21. Kim E, Ward TJ, Patel RS, et al: CT-guided liver biopsy with electromagnetic tracking: Results from a single-center prospective randomized controlled trial. AJR Am J Roentgenol 203:W715-W723, 2014
22. Esser M, Schneeweiss S, Nikolaou K, et al: Complexity of ultrasound and CT fusion examinations: Are they feasible in the daily routine? AJR Am J Roentgenol 207:1-6, 2016
23. Beyer LP, Wiggermann P: Planning and guidance: New tools to enhance the human skills in interventional oncology. Diagn Interv Imaging 98:583-588, 2017
24. Guenette JP, Himes N, Giannopoulos AA, et al: Computer-based vertebral tumor cryoablation planning and procedure simulation involving two cases using MRI-visible 3D printing and advanced visualization. AJR Am J Roentgenol 207:1128-1131, 2016
25. Koethe Y, Xu S, Velusamy G, et al: Accuracy and efficacy of percutaneous biopsy and ablation using robotic assistance under computed tomography guidance: A phantom study. Eur Radiol 24:723-730, 2014
26. Nasser FS, Ritsema DF, Cheney S, et al: Reviewing radiographic images with patients: Results of a trial on patient preferences, understanding, and satisfaction. J Endourol 24:2083-2091, 2010
27. Donfrancesco A, Montemurro P, Heden P: Three-dimensional simulated images in breast augmentation surgery: An investigation of patients' satisfaction and the correlation between prediction and actual outcome. Plast Reconstr Surg 132:810-822, 2013
28. Pankau T, Wichmann G, Neumuth T, et al: 3D model-based documentation with the Tumor Therapy Manager (TTM) improves TNM staging of head and neck tumor patients. Int J Comput Assist Radiol Surg 10:1617-1624, 2015