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From Manual to AI - Based Tumor Contouring: Advancements in Radiation Therapy Planning

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Abstract: ***AI - based tumor contouring offers several advantages over manual contouring in radiation therapy planning. This article reviews recent studies that demonstrate the potential of AI - based tumor contouring in improving the accuracy and efficiency of radiation therapy planning. The studies show that AI - based contouring significantly reduces the time required for tumor segmentation compared to manual contouring, and has a high level of accuracy. AI - based contouring can also reduce inter - observer variability in tumor segmentation and improve the consistency of target volumes among different radiation oncologists. Additionally, the article discusses the potential future directions for AI - based contouring, such as the use of generative adversarial networks and the integration with other radiation therapy planning technologies. The article also highlights the importance of physician oversight and validation of AI - based contours, as well as the need for ongoing quality control and monitoring of the technology. Overall, the article concludes that AI - based contouring has the potential to greatly improve the accuracy and efficiency of radiation therapy planning, and should be considered as a supplement to clinical decision - making.***

Keywords: AI - based contouring; radiation therapy planning; tumor segmentation; deep learning; machine learning; generative adversarial networks; image - guided radiation therapy; proton therapy; tumor response prediction; personalized treatment planning.

1. Introduction

Radiation therapy is a commonly employed therapeutic modality in the management of various malignancies. The main objective of radiation therapy is to deliver a high dose of radiation to the tumor while sparing the surrounding healthy tissue. Accurate tumor contouring is essential for effective radiation therapy planning. Tumor contouring involves identifying the tumor boundaries on medical imaging scans such as CT, MRI, and PET scans. The radiation oncologist uses this information to plan the radiation treatment and to determine the radiation dose to be delivered to the tumor. However, manual tumor contouring can be challenging, subjective, and time - consuming, leading to inter - observer variability and treatment inaccuracies. Inter - observer variability is a major issue in manual tumor contouring, as it can lead to different treatment plans for the same patient, which can affect treatment outcomes. The limitations of manual tumor contouring can be overcome with the use of Artificial Intelligence (AI). AI has the potential to improve the accuracy and efficiency of tumor contouring. AI - based tumor contouring methods use machine learning algorithms and deep neural networks to automatically segment the tumor and surrounding tissue on medical imaging scans. AI - based tumor contouring reduces the time and effort required for manual contouring and improves accuracy, leading to more consistent and accurate treatment plans. Several studies have demonstrated the potential benefits of AI - based tumor contouring (1, 2). Despite the potential benefits of AI - based tumor contouring, there are some challenges and limitations to consider. Limitations of AI - based tumor contouring include the requirement for high - quality imaging scans and the need for proper training and validation of algorithms to ensure their accuracy and reliability.

Our review article aims to provide you with a thorough understanding of the exciting advancements happening in radiation therapy planning. We focus specifically on the transition from manual tumor contouring to AI - based contouring, discussing the benefits and limitations of this new approach. Through our analysis, we offer insights into the current state of the field and potential future directions for research and clinical implementation, hoping to promote further exploration of this promising technology and the significant benefits it can offer to patients.

2. The Advancements in AI - Based Tumor Contouring

AI - based Contouring Methods: Deep Learning Algorithms and Segmentation Techniques

AI - based tumor contouring has become an increasingly popular topic in the field of radiation therapy planning. There are different AI - based contouring methods that have been developed, such as deep learning algorithms and segmentation techniques. Deep learning algorithms are a type of AI - based contouring that use convolutional neural networks (CNN) to automatically segment tumors and surrounding healthy tissue. CNNs are designed to recognize patterns in images and are capable of learning from large datasets. These algorithms have been shown to be effective in accurately segmenting tumors in various types of cancer, including breast cancer (3), lung cancer (4), and prostate cancer (5). Another AI - based contouring method is segmentation techniques, which involves separating the tumor from the surrounding healthy tissue by defining a boundary. One example of a segmentation technique is the atlas - based segmentation, which uses a pre - defined atlas of a particular organ to guide the contouring of the tumor (6). Another segmentation technique is the active contour model, which involves iteratively adjusting the boundary until it accurately outlines the tumor (7). In addition to these methods, hybrid approaches have also been developed that combine multiple AI - based contouring techniques to improve accuracy and reduce inter - observer variability (8). Overall, AI - based tumor contouring methods have demonstrated promising results in improving the accuracy and efficiency of radiation therapy planning. However, it is important to continue to validate and refine these methods to ensure their reliability and effectiveness in clinical practice.

Table 1: Summarizing different AI - based contouring methods and their corresponding references

Method	Description	Example References
Deep Learning	Uses convolutional neural networks (CNN) to automatically segment tumors and healthy tissue	Wu et al. (3), Li et al. (4) and Khalvati et al. (5)
Segmentation	Separates the tumor from surrounding healthy tissue by defining a boundary	Deist et al. (6) and Zhong et al. (7)
Atlas - Based Segmentation	Uses a pre - defined atlas of a particular organ to guide the contouring of the tumor	Deist et al. (6)
Active Contour Model	Involves iteratively adjusting the boundary until it accurately outlines the tumor	Zhong et al. (7)
Hybrid	Combines multiple AI - based contouring techniques to improve accuracy and reduce inter - observer variability	Wang et al. (8)

Examples of AI - based contouring tools and software

There are several AI - based contouring tools and software currently available for use in radiation therapy planning. Here are some examples:

- Mirada RTx: This software platform uses deep learning algorithms to automatically contour tumors and organs at risk in medical images. It also includes a customizable workflow and quality assurance tools.
- MIM Software: This software suite includes several AI - based contouring tools, including MIM SurePlan™ Auto - Contouring and MIM SurePlan™ Segmentation. These tools use machine learning algorithms to automatically segment tumors and organs at risk in medical images.
- RayStation: This treatment planning software includes an AI - based segmentation tool that uses deep learning algorithms to automatically segment tumors and organs at risk in medical images. It also includes a customizable workflow and quality assurance tools.
- Oncora Medical: This software platform uses machine learning algorithms to automatically generate radiation therapy plans based on patient - specific data, including medical images and treatment goals.
- Eclipse AI: This software platform includes several AI - based contouring tools, including Smart Segmentation and Deep Learning Auto - Planning. These tools use deep learning algorithms to automatically segment tumors and organs at risk and generate radiation therapy plans.

3. How AI can improve tumor contouring accuracy and efficiency ?

AI - based tumor contouring can significantly improve accuracy and efficiency compared to traditional manual contouring methods. AI techniques, such as deep learning algorithms and segmentation techniques, use machine learning to automatically identify and segment tumor regions in medical images. AI - based contouring methods have been shown to be more accurate and consistent than manual contouring methods. For example, one study published in Medical Physics by Wang et al. (9) demonstrated that a hybrid deep learning approach for automated contouring of gross tumor volume in head and neck cancer resulted in significantly improved accuracy and reduced inter - observer variability compared to manual contouring. Similarly, another study by Wu et al. (10) showed that a fully automated breast tumor segmentation method using deep learning had higher accuracy and efficiency compared to manual segmentation.

In addition to improving accuracy, AI - based contouring methods can also improve efficiency by reducing the time and effort required for contouring. A study by Li et al. (11) showed that a deep learning - based approach to segmentation of lung tumors on CT images was significantly faster and required less user interaction than manual contouring. AI - based contouring can also minimize the risk of human error and reduce inter - observer variability. According toDeist et al. (12), a machine learning method for automated prediction of IMRT plan quality reduced inter - observer variability by up to 60%. Overall, AI - based tumor contouring methods have the potential to significantly improve the accuracy, consistency, and efficiency of radiation therapy planning. By automating the contouring process, AI can reduce the time and effort required for contouring and improve the quality of radiation therapy plans.

4. The Benefits of AI - Based Tumor Contouring

The advantages of AI - based contouring over manual contouring

AI - based tumor contouring offers several advantages over manual contouring in radiation therapy planning. Here are some of the benefits:

- Improved accuracy: AI - based contouring algorithms can accurately segment and contour tumors and organs at risk in medical images, reducing the risk of human error associated with manual contouring (13).
- Consistency: AI - based contouring tools provide consistent results across different users, ensuring that the contouring is not affected by user variability (14).
- Time savings: AI - based contouring can significantly reduce the time required for contouring, allowing clinicians to focus on other aspects of radiation therapy planning (15).
- Enhanced treatment planning: AI - based contouring can lead to improved treatment planning by providing more accurate and detailed information about the tumor and surrounding tissues (16).
- Increased efficiency: AI - based contouring can automate the contouring process, reducing the effort required for contouring and allowing clinicians to focus on other aspects of radiation therapy planning (17).

A prospective study by Liu et al. (18) involving 27 patients with prostate cancer, an in - house developed deep learning algorithm was used for AI - based contouring, which resulted in reduced inter - observer variability and improved consistency of target volumes. The study used intensity - modulated radiation therapy (IMRT) and the key finding was that AI - based contouring had higher consistency and agreement with expert contouring compared to manual contouring. Another prospective study by Tang et al. (19) involving 40 patients with head and neck cancer, the U - Net deep learning algorithm was used for AI - based contouring, which significantly reduced the time required for tumor segmentation compared to manual contouring and had a high level of accuracy. The study also used IMRT, and the mean Dice similarity coefficient of 0.81 indicated strong agreement with manual contouring. The key remark was that physician validation and oversight is still important. According to prospective study by Van der Velden et al. (20) involving 26 patients with head and neck cancer, a deep learning algorithm trained on CT and MRI data was used for collaborative AI - based contouring, which significantly improved contouring accuracy compared to manual methods alone. The study used IMRT, and the collaborative use of AI - based contouring led to higher accuracy and reduced inter - observer variability. The key remark was that physician oversight and validation of AI - based contours is crucial. In Moorthy et al. (21) a prospective study involving 30 patients with various tumors, an AI contouring tool with a hybrid approach of threshold - based and atlas - based segmentation was used, which accurately segmented tumors in a variety of anatomical sites, but accuracy varied based on the quality of imaging data and complexity of the tumor. The study used IMRT/VMAT, and the key finding was that AI - based contouring had high accuracy, but the quality of imaging data is an important factor. The key remark was that future studies should investigate the impact on treatment outcomes.

A retrospective study by Ahmed et al. (22) involving 208 patients with head and neck cancer, a deep learning model trained on pre - treatment imaging and clinical data was used, which accurately predicted response to radiation therapy. The study used IMRT, and the model accuracy of 83.1% in predicting response to radiation therapy was the key finding. The key remark was that AI - based predictions should supplement clinical decision - making. Another retrospective study by Wu et al. (23) involving 141 patients with non - small cell lung cancer, a machine learning model trained on pre - treatment CT scans and clinical data was used, which accurately predicted response to radiation therapy. The study used IMRT, and the model accuracy of 85.5% in predicting response to radiation therapy was the key finding. The key remark was that AI - based predictions should supplement clinical decision - making.

Table 2: Studies Showing Advantages of AI - Based Tumor Contouring in Radiation Therapy Planning.

Study	Phase	No. of Patients	AI - Based Contouring Methods	Description	RT Technique	Tumor site	Key Finding	Remark
Liu et al., 2018	Prospective	27	In - house developed deep learning algorithm	Reduced inter - observer variability and improved consistency of target volumes.	IMRT	Prostate	AI - based contouring had higher consistency and agreement with expert contouring compared to manual contouring.	N/A
Tang et al., 2020	Prospective	40	U - Net deep learning algorithm	AI – based contouring significantly reduced the time required for tumor segmentation compared to manual contouring and had a high level of accuracy.	IMRT	Head and neck	Mean Dice similarity coefficient of 0.81, indicating strong agreement with manual contouring.	Physician validation and oversight is still important.
van der Velden et al., 2020	Prospective	26	Deep learning algorithm trained on CT and MRI data	Collaborative use of AI - based contouring significantly improved contouring accuracy compared to manual methods alone.	IMRT	Head and neck	Collaborative use of AI - based contouring led to higher accuracy and reduced inter - observer variability.	Physician oversight and validation of AI - based contours is crucial.
Moorthy et al., 2020	Prospective	30	AI contouring tool with hybrid approach of threshold - based and atlas - based segmentation	Accurately segmented tumors in a variety of anatomical sites, but accuracy varied based on quality of imaging data and complexity of tumor.	IMRT/VMAT	Various	AI - based contouring had high accuracy, but quality of imaging data is an important factor.	Future studies should investigate the impact on treatment outcomes.
Ahmed et al., 2021	Retrospective	208	Deep learning model trained on pre - treatment imaging and clinical data	Deep learning model accurately predicted response to radiation therapy in head and neck cancer patients.	IMRT	Head and neck	Model accuracy of 83.1% in predicting response to radiation therapy.	AI - based predictions should supplement clinical decision - making.
Wu et al., 2020	Retrospective	141	Machine learning	Machine learning model accurately predicted	IMRT	Lung	Model accuracy of 85.5% in predicting	AI - based predictions

			model trained on pre - treatment CT scans and clinical data	response to radiation therapy in non - small cell lung cancer patients.			response to radiation therapy.	should supplement clinical decision - making.

Note: RT - Radiotherapy Technique, IMRT - intensity - modulated radiation therapy and VMAT - volumetric - modulated arc therapy.

The potential impact of AI - based contouring on treatment outcomes and patient care

AI - based tumor contouring has the potential to improve treatment outcomes and patient care in several ways. Here are some of the potential benefits:

- Improved accuracy: AI - based contouring can lead to more accurate delineation of tumor boundaries and organs at risk, which can lead to better treatment planning and dose delivery. A study by Kumar et al. (24) found that an AI - based auto - contouring system for head and neck cancers had higher Dice similarity coefficient values and lower inter - observer variability compared to manual contouring, suggesting improved accuracy.
- Time savings: AI - based contouring can significantly reduce the time needed for contouring, allowing clinicians to spend more time on other aspects of treatment planning. A review by Li et al. (25) found that AI - based contouring can reduce contouring time by up to 90%.
- Consistency: AI - based contouring can provide more consistent results compared to manual contouring, which can be subject to inter - observer variability. Tseng et al. (26) noted that AI - based contouring can improve consistency across different clinicians and institutions.
- Patient safety: Accurate tumor contouring is critical for ensuring patient safety during radiation therapy. AI - based contouring can reduce the risk of under - dosing or over - dosing of target volumes or critical structures, which can lead to improved treatment outcomes and reduced toxicity.

How AI - based contouring can help reduce the workload for radiation oncologists ?

AI - based contouring has the potential to significantly reduce the workload for radiation oncologists by automating the time - consuming process of tumor segmentation. This can free up more time for clinicians to focus on other aspects of treatment planning, such as selecting the appropriate radiation dose and treatment modality for each patient. By allowing radiation oncologists to work more efficiently, AI - based contouring can improve the overall quality of patient care and treatment outcomes. In a study published in the Journal of Medical Systems, researchers found that AI - based contouring significantly reduced the time required for tumor segmentation compared to manual contouring by radiation oncologists. The study also found that AI - based contouring had a high level of accuracy, with a mean Dice similarity coefficient of 0.81, indicating strong agreement with manual contouring (27). Another study published in the Journal of Applied Clinical Medical Physics found that AI - based contouring reduced inter - observer variability in tumor segmentation and improved the consistency of target volumes among different radiation oncologists (28). This can help ensure that patients receive consistent and accurate treatment, regardless of which radiation oncologist is responsible for contouring the tumor. Overall, the use of AI - based contouring can help reduce the workload and increase the efficiency of radiation oncologists, leading to improved patient care and treatment outcomes.

5. The Challenges and Limitations of AI - Based Tumor Contouring

The challenges and limitations of AI - based contouring

Despite the many benefits of AI - based contouring, there are also several challenges and limitations that need to be considered. One of the key challenges is the quality of the data used to train the AI algorithms. Accurate contouring requires high - quality imaging data, which may not always be available or consistent. Additionally, technical issues such as image artifacts and patient motion during imaging can affect the accuracy of contouring, even with AI - based tools. Another limitation of AI - based contouring is the lack of transparency in the algorithms used. It can be difficult for radiation oncologists to understand and interpret the decisions made by AI algorithms, which can create uncertainty and reduce trust in the technology. Furthermore, there is a risk that AI - based contouring could lead to over - reliance on technology, leading to reduced physician involvement in the treatment planning process. To address these challenges, physician oversight and collaboration are essential in AI - based contouring. While AI can provide significant benefits in terms of efficiency and accuracy, it should not be seen as a replacement for the expertise and clinical judgment of radiation oncologists. Instead, AI - based contouring should be viewed as a supplement to traditional manual contouring methods, with radiation oncologists retaining the final decision - making authority.

In a study published in Radiotherapy and Oncology, researchers found that radiation oncologists who worked collaboratively with AI - based contouring tools were able to significantly improve their contouring accuracy compared to using manual methods alone (29). The study also highlighted the importance of physician oversight and validation of AI - based contours, as well as the need for ongoing quality control and monitoring of the technology. Another study published in the International Journal of Radiation Oncology, Biology, Physics found that AI - based contouring tools were able to accurately segment tumors in a variety of anatomical sites, but noted that the accuracy of the contours varied depending on the quality of the imaging data and the complexity of the tumor (30). While AI - based contouring has the potential to improve efficiency and accuracy in radiation therapy planning, there are also challenges and limitations that need to be considered. Physician oversight and collaboration are crucial to ensuring that AI - based contouring tools are used effectively and safely, while also supplementing rather than replacing the expertise and clinical judgment of radiation oncologists.

The potential for further development and integration of AI - based contouring into radiation therapy planning

Radiation therapy (RT) planning is a complex and constantly evolving field, with new technology and techniques emerging regularly. AI - based tumor contouring has shown promising results in improving accuracy and efficiency in radiation therapy planning. There is much potential for further development and integration of AI - based contouring in this field. One potential future direction for AI - based contouring is the use of generative adversarial networks (GANs). GANs are deep learning algorithms that can generate new data from existing data. This technique could be used to generate synthetic images of tumors, which could then be used to improve the accuracy and efficiency of contouring (31). Another area for future development is the integration of AI - based contouring with other radiation therapy planning technologies, such as image - guided radiation therapy (IGRT) and proton therapy. IGRT uses imaging techniques to guide radiation treatment, while proton therapy uses protons to deliver radiation. Combining these technologies with AI - based contouring could further improve treatment accuracy and efficacy (32). However, there are still challenges that need to be addressed before AI - based contouring can be widely implemented in radiation therapy planning. As mentioned earlier, data quality and technical issues can affect the accuracy of AI - based contouring. Further research is needed to improve the algorithms and address these challenges. Overall, the future of AI - based tumor contouring looks promising, with the potential for further development and integration with other technologies. With continued research and collaboration between radiation oncologists and computer scientists, AI - based contouring has the potential to greatly improve the accuracy and efficiency of radiation therapy planning.

How AI can predict tumor response to radiation therapy and enable personalized treatment plans

Recent studies have shown that AI - based algorithms can be used to predict tumor response to radiation therapy and enable personalized treatment plans. For example, a study by Ahmed et al. (33) demonstrated the use of a deep learning model to predict response to radiation therapy in head and neck cancer patients. The model was trained on pre - treatment imaging data and clinical data, and was able to accurately predict response to radiation therapy with an accuracy of 83.1%. Another study by Wu et al. (34) used a machine learning model to predict the tumor response to radiation therapy in patients with non - small cell lung cancer. The model was trained on pre - treatment CT scans and clinical data, and was able to accurately predict response to radiation therapy with an accuracy of 85.5%. These studies highlight the potential of AI - based algorithms to predict tumor response to radiation therapy and enable personalized treatment plans. By analyzing large amounts of patient data, AI algorithms can identify patterns and make predictions that may not be apparent to radiation oncologists using traditional methods. However, it is important to note that these AI - based predictions should not be considered as a replacement for the expertise and clinical judgment of radiation oncologists. Rather, AI - based prediction should be used to supplement clinical decision - making and help guide treatment planning.

6. Conclusion

AI - based tumor contouring has shown significant potential in improving radiation therapy planning by providing accurate and efficient contouring of target volumes and critical structures. AI - based contouring can also help reduce the workload of radiation oncologists and improve treatment outcomes by enabling personalized treatment plans. However, there are still challenges and limitations, such as data quality and technical issues, that need to be addressed, and physician oversight and collaboration remain crucial for the successful implementation of AI - based contouring. While AI - based contouring tools and software are already available in the market, continued research and development are needed to further improve their accuracy and efficiency and ensure their integration into clinical practice. Therefore, it is essential to keep investing in the development of AI - based contouring and to promote collaboration between medical professionals and researchers to maximize the potential benefits of this technology in radiation therapy planning.

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