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Benefits and considerations in using a novel computed tomography system optimized for radiotherapy planning

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ABSTRACT

In this study, we evaluated a novel 16-bit computed tomography (CT) system optimized for radiotherapy planning. Over six months, using various protocols, we conducted 616 scans, with an average of four CT series per session imported into our treatment planning software (TPS). The direct density (DD) reconstruction enabled a single CT number calibration curve for multiple tube voltages. Metal artifacts could be effectively reduced. The 16-bit character permitted dose calculation in high-density regions, while TPS integration challenges remained. In conclusion, our findings emphasize the system's potential benefits and considerations in radiotherapy workflows.

1. Introduction

Modern image-guided radiotherapy techniques require a so-called planning computed tomography (CT) system. This necessary imaging is taken a few days before the first radiation session at a linear accelerator (LINAC). Hereby, the patient is placed in the desired treatment position using immobilization devices and lasers. The goal is to achieve reproducible and robust positioning for the entire course of treatment. Subsequently, the acquired images must meet the needs of two distinct end-users and treatment planning tasks. Radiation oncologists require high-quality images to accurately define the tumor volume and surrounding critical structures and organs-at-risk (OARs). Medical physicists use the CT number to relative electron density (RED) or mass density calibration curve of the planning CT to calculate 3D dose distributions in the preferred treatment planning software (TPS) [1].

In recent years, various software solutions, such as automatic contouring [2] and image quality enhancement algorithms [3], have been developed that are beneficial for radiotherapy processes. While some of these tools are now integrated into CT systems by manufacturers, others may require additional and site-specific steps to be incorporated into clinical workflows [4].

This article outlines the implementation of a novel planning CT system that incorporates a wide variety of such tools and evaluates the impact on our internal workflows during the first six months of usage. The aim of this study is to present and discuss relevant features within the context of our clinical CT configuration to justify potential workflow changes, while also addressing any general or current issues that may arise.

2. Materials and methods

Data for this study was extracted without any patient identifiers, ensuring that no personal identifiable information or protected health information was utilized. Given the retrospective and anonymized nature of the data, approval from an ethics committee was not required. This approach is in line with European legislation guidelines and adheres to the ethical principles laid out in the Helsinki Declaration of 1964 and its later amendments.

In May 2022, our clinic began utilizing the planning CT SOMATOM go.Open Pro, developed by Siemens Healthineers (Erlangen, Germany), which had been available since November 2019. This CT is characterized by the following core properties: Scannable range of 2 m, max table load of 307 kg, large bore of 85 cm with 60 cm true scan field of view, scan speed up to 20 cm/s and 128 reconstructed images per rotation. In addition, it has tools specifically tailored for radiotherapy, designed to speed up or even improve workflows. As the following five points are expected to have the highest influence on radiotherapy planning, they were investigated in more detail in our patient cohort (cf. Table 1).

For comprehensive details on the topics covered in sections 2.1 through 2.5, please refer to the supplementary material provided.

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Table 1
Feature workflow relationship.

Nr.	Feature	Affected Workflows
1	CarekV and DirectDensity	CT calibration curve, Import of CT reconstructions, Contouring, Dose calculation
2	Multiple reconstruction kernels	Import of CT reconstructions, Contouring
3	16-bit data	CT calibration curve
4	iMAR and Direct i4D	Contouring, Treatment plan creation, Dose calculation
5	Automatic contouring and virtual marker	Import of CT reconstructions, Contouring, Treatment plan creation

Overview of SOMATOM go.Open Pro features that impact the radiotherapy planning process.

2.1. Automatic contouring and virtual marker

A deep learning-based solution, DirectORGANS (v.2.0), was utilized for automatic contouring with customizable structure parameters. The CT system also featured positioning lasers for marking reference positions on patients, known as virtual markers. The structure set was then exported to the TPS alongside the CT images in DICOM format.

2.2. Image quality

The CT's image quality can be enhanced by four software solutions:

- SAFIRE, an iterative reconstruction algorithm [5,6].
- iMAR for metal artifact reduction [7–9].
- Direct-i4D to minimize movement artifacts in 4D-CT scans [10–12].
- CarekV and CareDose4D for optimizing tube voltage and current settings based on patient anatomy [13,14].

2.3. Direct density

Due to variable CT tube voltage with CarekV, Direct Density (DD) provides a reconstruction algorithm for images directly proportional to RED. This energy-independent approach allows for a single calibration curve across all tube voltages, though the calibration process is more intensive [15,16].

2.4. 16-bit data

Transitioning to the go.Open Pro provided 16-bit image data, an improvement from the previous 12-bit planning CT (SOMATOM Definition AS Open from Siemens). This increased CT number range enabled a more accurate dose calculation in high-density areas [17].

2.5. TPS-link

Our primary TPS is Varian Eclipse v.16.1, and this report emphasizes the interaction between go.Open Pro and Eclipse.

In our clinic, 12 pre-defined CT protocols were used. Each protocol incorporated DirectORGANS, SAFIRE with a noise reduction strength of 3 out of 5, CarekV, CareDose4D, DD, and tissue-optimized kernels for soft tissue, bone, and air. Direct-i4D was employed for 4D-CTs. The aim of this configuration was to attain clinical enhancements beyond what was feasible with the previous CT.

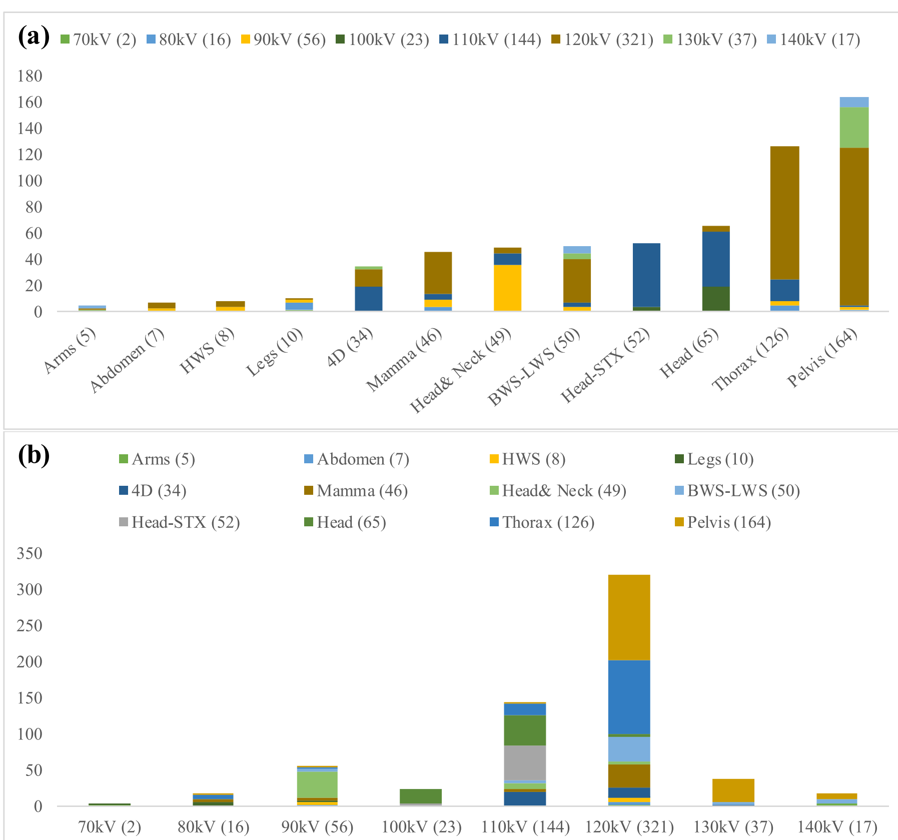

Fig. 1. Stacked bar charts of 616 planning CT scans from SOMATOM go.Open Pro taken in the first six months of clinical use. In (a) scans are grouped by CT protocol and stacked by tube voltage and in (b) vice versa. The quantity is indicated within parentheses. The used abbreviations and their meanings are as follows: BWS stands for thoracic spine, HWS stands for cervical spine, LWS stands for lumbar spine, and STX stands for stereotactic treatment.

3. Results

During the initial six-month period with the new planning CT system, a total of 616 CT scans were performed, resulting in treated plans. The distribution of these scans among different protocols and tube voltages is presented in Fig. 1. The majority of scans, accounting for 52.1 %, were conducted using a tube voltage of 120 kVp. Scans with a tube voltage of 110 kVp accounted for 23.4 %, while the remaining scans utilized various tube voltages, each constituting less than 10 % of the total. Among the protocols used, the pelvis protocol was the most frequently employed, comprising 26.6 % of the scans. This was followed by the thorax protocol, utilized in 20.5 % of the scans, and the head protocol, which accounted for 10.5 %. The remaining protocols were each used in less than 10 % of the scans.

The fact that several reconstructions (possible reconstructions: DD, tissue optimized kernels, CT with contrast agent, multi-phase CT scan) are stored in each CT protocol results in several CT series per scan, which are automatically sent to the TPS in DICOM format. Ultimately, an average of 4 CT series per session were imported into Eclipse (standard deviation: 2.9; range: 1–22). Of the 616 scans, the iMAR algorithm was employed in 32 % of cases due to the presence of visible metal artifacts within the scan region. This decision was based on one of two reasons: either manual evaluation of the topogram suggested the presence of metal artifacts, or a medical physicist encountered dosimetrically significant artifacts caused by metallic objects in the treatment planning process and iMAR had not been utilized previously.

4. Discussion

Although we use the DD reconstruction for dose calculation for all patients, it should be noted that it is not optimal for contouring as the calibration curve is steeper than the standard reconstructions, which causes density values to be closer together and results in a loss of image-contrast. Therefore, we also send the three standard reconstructions for soft tissue, air, and bone to the TPS to ensure the best possible contouring accuracy. However, these options also have drawbacks. The fact that we now generally import four times the amount of data per planning CT into the TPS means that the server storage fills up faster, the importing process takes longer, and naming the image data is time consuming. The last two points can be automated using TPS scripts (in our case C# programs that communicate with Eclipse scripting application interface (ESAPI) [18]), but not every clinic has access to such resources or is utilizing them, so this should be kept in mind.

Another important issue is the integration of the DD data into the TPS. In general, only a single calibration curve will be automatically assigned to a specific CT system, which means that the DD calibration curve will also be assigned to the standard reconstructions, which carries the risk of the dose calculation being performed on the wrong reconstruction. While it is possible to deactivate automatic assignment, manual assignment is also not risk-free and requires an additional step. As there is currently no solution to this problem from TPS vendors or Siemens, we have developed two check programs that automatically check at two points in the planning process whether the right reconstruction for dose calculations has been used. We use the CT series description, embedded as DICOM tag in every CT image, as an indicator of the reconstruction algorithm used. The practice of utilizing DICOM tags for safety checks, as demonstrated by Nordström et al., is widely adopted [19].

Some TPS systems do not yet support the full 16-bit CT number range. For example, Eclipse v.16.1 does not allow CT numbers below −3000 HU and confines relative electron densities between 0.001 and 15. Even so, certain CT numbers have to be input, or the dose calculation will be unsuccessful, resulting in the calibration curve appearing as a flat line beyond the density limits. Fortunately, these ranges are typically not critical for patient treatments in radiotherapy. Nevertheless, we required manufacturer intervention to identify and navigate these constraints. Other vendors may face similar challenges.

By employing iMAR and Direct-i4D, artifacts were significantly minimized, simplifying contouring and improving the accuracy of dose calculation. Moreover, fewer and smaller artifacts need to be contoured and corrected with a realistic density to further enhance dose accuracy. A comparison can be made by evaluating the number of such assistive structures over a similar timeframe for our previous 12-bit CT scanner (SOMATOM Definition AS Open from Siemens), which lacked artifact reduction capabilities. A reduction of 71.6 % (88 cases in the 6 months before vs. 25 with go.Open Pro) was observed through data mining with ESAPI. Automatic contouring with DirectORGANS simplified and standardized the contouring process. Most structures could be adopted with minimal or no changes in the opinion of our regular contouring staff. We have now stored the structure templates in the CT protocols rather than in the TPS, which allows us to start the contouring process more quickly with all the necessary structures already in place and correctly colored and labeled according to our nomenclature. While not all of these structures are automatically contoured, this new workflow still saves time and effort. The improvement in efficiency resulting from automatic contouring is consistent with the findings of Bi et al. [20], Walker et al. [21] and Cha et al. [22]. Furthermore, the nomenclature has been significantly better maintained due to this simplification, which likely stems from the fact that there are fewer manual decisions being made, such as selecting the structure template.

By providing the user origin as a virtual marker from the CT and automatically contouring the patient's outer contour, the first two steps after CT import, which our medical physicists would normally have to do, are eliminated. Additionally, the need for physical markers on the patient that must later be disposed of is eliminated.

Surely there were limitations in this work. The go.Open Pro replaces a CT that was over 10 years old at the time of decommissioning, which is expected to result in progress in hardware and software that may impact established workflows. Comparing it with similar CT devices from other manufacturers, such as the BigBoreRT from Philips, which offers some similar specifications and features, would lead to better contextualization of the results. The performance of automatic contouring could be quantitatively evaluated in terms of time and quality by comparing it with manual contouring or other software solutions, following the approach of Bi et al. [20]. Demonstrating unambiguous improvement in image quality and minimizing imaging dose can only be achieved through repeated phantom measurements, as it has been consistently demonstrated in previous studies [5,15,16]. This level of assessment is not feasible with patients.

In summary, the implementation of a novel CT system optimized for radiotherapy planning has brought both benefits and considerations to our clinic's workflow. The automatic contouring and virtual marker features have simplified and standardized the contouring process, while the image quality improvements through iMAR and Direct-i4D have reduced artifacts and enhanced the accuracy of dose calculations. However, the use of specialized reconstructions algorithms and DD required additional considerations, such as the steeper calibration curve and the need to import larger amounts of data. To address these issues, we have implemented our own software solutions to ensure proper reconstruction usage and efficient data management. In conclusion, the integration of a planning CT equipped with customized software solutions for radiotherapy has proven to be a valuable asset to our clinical workflows.

CRediT authorship contribution statement

Maximilian Grohmann: Conceptualization, Writing – original draft, Writing – review & editing, Visualization, Software. **Cordula Petersen:** Data curation, Investigation, Supervision, Conceptualization. **Manuel Todorovic:** Data curation, Investigation, Supervision, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.phro.2023.100510.

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