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Machine Learning Analysis of Treatment Session Time Components

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INTRODUCTION

Treatment specific factors such as treatment modality, motion management, and in-room localization technique, directly impact the length of a treatment session. However, our understanding of the combined effect of these co-factors is often based on anecdotal observations of treatment deliveries and limited manual data collection for specific treatment processes.

Commercial radiation oncology information systems (ROIS) are not designed with the intent to facilitate collecting information detailing clinical process timelines and co-factors, and often lack the tools necessary to analyze this information for large numbers of treatments or patients.

Utilizing our clinical practice data analytics resource system (MROAR)[1], we evaluated session timeline details for treatments delivered over a 5-year period and investigated the impact of various co-factors on different parts of the treatment delivery process.

AIM

This study aims to utilize machine learning to determine the most important planning and delivery features that contribute to the overall treatment session, and treatment delivery time.

METHOD

We studied 10,968 radiotherapy treatment courses encompassing 14,542 treated plans, representing 160,844 radiotherapy treatment sessions occurring between 2014 and 2019. Treatment session timeline components were extracted, including imaging time, image analysis wait time, and treatment delivery time. The total treatment session time was defined as the summation of these components, displayed in Figure 1 below. Initial patient setup time in the treatment room was not included, as it is not directly captured by the ROIS for single plan treatment sessions.

Figure 1: Treatment session timeline components for multiple-plan treatment session. Imaging time: Time from first image capture to completion of the last image for a given plan. Image analysis wait time: Time between completion of the last image to initiation of first beam on. Treatment time: Time from initiation of first beam delivery to completion of all beams in a plan. Setup time: This is the time to adjust patient from one isocenter to the next. This component was not studied.

Random Forest regression models were developed using Scikit-Learn[2]. Parameters examined included: number of images (CBCT, KV, MV), number of beams, planning technique, treatment site, motion management strategy, use of high dose rate flattening filter free (FFF) vs standard beams, use of non-coplanar beams, and stereotactic body radiation therapy (SBRT) vs non-SBRT. Timeline distributions were analyzed to quantify and visualize the impact of these parameters.

A subset of the data (1,157 plans, and 4,633 treatment sessions) including SBRT treatments for sites where motion management (breath-hold vs. free-breathing) was utilized, was further analyzed to determine the combined effect of motion management strategy and dose rate on the treatment delivery time, and total session time.

RESULTS

Analysis of the entire dataset identified the number of CBCTs, fraction number, SBRT treatment, and the number of beams as the features that most impact treatment session time. Limiting the dataset to treatments for sites where motion management was required, identified SBRT and breath-hold treatments as features of high importance, whereas utilization of high dose rate FFF beams was not found to have a significant impact on treatment session time (Figure 2).

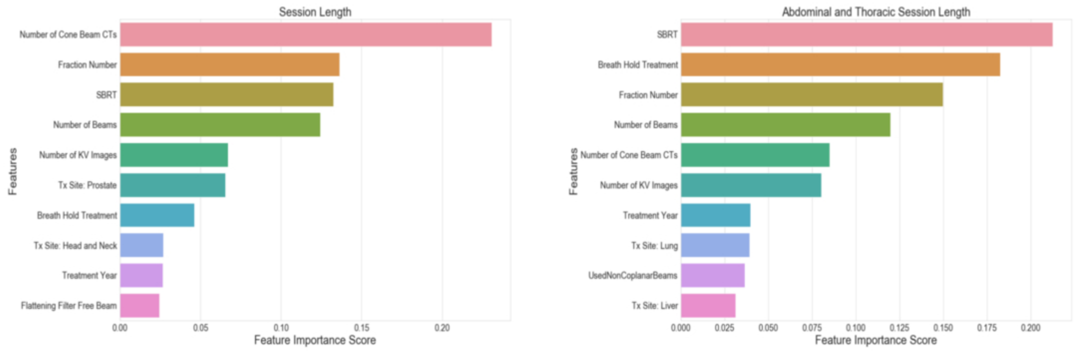
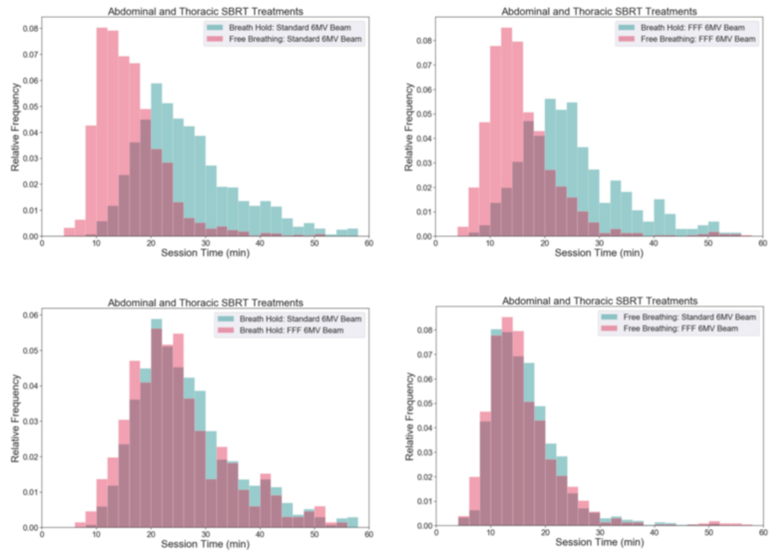


Figure 2: The ten most important features affecting session time for the all treatment types (left) and abdominal and thoracic subset (right).

Treatment session time and treatment delivery times were 17.5 ± 8.8 minutes and 7.7 ± 5.8 minutes for SBRT treatments, and 8.0 ± 5.5 minutes and 3.7 ± 2.3 minutes for non-SBRT treatments. There were no significant differences in session time for patients treated with standard dose rate vs high dose rate flattening filter free 6MV beams. First fraction vs subsequent fraction session times were 21.8 ± 10.1 vs 15.8 ± 7.5 minutes for SBRT and 13.6 ± 10.2 vs 7.6 ± 4.7 minutes for non-SBRT treatments due to additional imaging. Session time for abdominal and thoracic SBRT treatments was 26.3 ± 9.2 minutes with breath-hold, compared to 16.1 ± 6.5 minutes with free-breathing. Our cross-validation model predicted session times within 3.5 minutes. Treatment session time and timeline components are summarized in the table below for single-isocenter, abdominal and thoracic SBRT patients.

Timeline Feature	Breath-Hold						Free-Breathing					
	Mean		80th Percentile		20th Percentile		Mean		80th Percentile		20th Percentile	
	6FFF	6X	6FFF	6X	6FFF	6X	6FFF	6X	6FFF	6X	6FFF	6X
Session Time (min)	24.93 ± 9.19	26.80 ± 9.19	32.47	33.92	17.39	19.25	16.08 ± 6.58	16.20 ± 6.10	19.66	20.30	11.45	11.20
Treatment Time (min)	12.39 ± 6.30	15.95 ± 6.38	16.98	20.27	6.73	10.60	5.49 ± 3.51	7.70 ± 4.20	6.89	11.30	3.17	4.50
Imaging Time (min)	3.28 ± 5.17	3.17 ± 5.57	6.65	7.52	0.00	0.00	3.50 ± 5.33	1.29 ± 3.92	6.70	0.0	0.00	0.00
Image Analysis Wait Time (min)	9.25 ± 3.17	7.67 ± 3.18	11.40	10.05	6.90	5.37	7.09 ± 3.32	7.22 ± 3.15	9.39	9.43	4.89	4.95

Treatment session times for both breath-hold and free-breathing SBRT treatments using standard and high dose rate FFF 6MV beams, were evaluated and summarized in the plots on the right (Figure 3). Treatments delivered under breath-hold showed longer overall treatment session times compared with free-breathing treatments, regardless of the type of beam used in planning (top left: standard 6MV, top right: 6FFF). Regardless of breathing management technique, no significant difference was observed between standard 6MV and 6FFF for the overall session time (bottom left: breath-hold, bottom right: free-breathing).



For abdominal and thoracic SBRT treatments, Figure 4 shows treatment delivery length (beam-on time) distributions for breath-hold standard 6MV, breath-hold 6FFF, free-breathing standard 6MV, and free-breathing 6FFF plans. The results show a clear separation between free-breathing and breath-hold treatments, and a much smaller difference between high dose rate (6FFF) and standard beams. This agrees with the patterns observed in overall treatment session time. Impact of other individual co-factors, such as the number of CBCTs, on the overall treatment session time was also found to be significant (Figure 5), with implications on imaging requirements for patients treated with multiple plans in a single fraction.

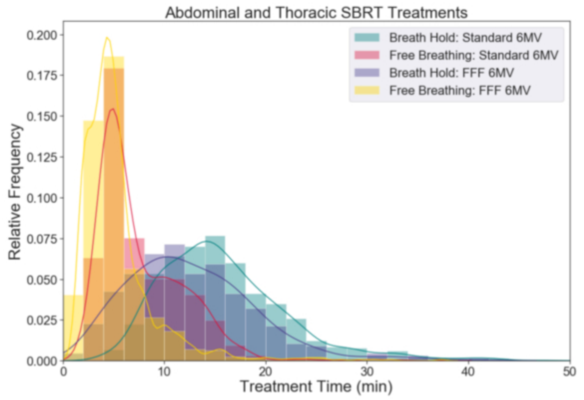


Figure 4: Distribution of treatment delivery (beam-on) time for various combinations of motion management and beam type.

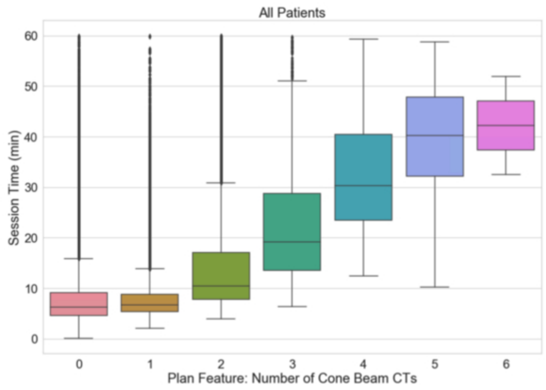


Figure 5: Impact of number of Cone Beam CTs on the overall session time.

CONCLUSIONS

This study confirmed the anticipated impact of some treatment planning and delivery cofactors on treatment delivery (beam-on) time, as well as the overall treatment session time, while highlighting the marginal impact of other cofactors such as the use of high high dose rate flattening filter free beams.

This study also allowed us to quantify the treatment session timeline components for various combinations of planning and delivery techniques, and show how they affect the overall utilization of clinical resources. This is important as we increase the utilization of SBRT for clinical indications traditionally treated with relatively simple setups and planning, such as single fraction bone metastases.

REFERENCES

1. Mayo, et al. The big data effort in radiation oncology: Data mining or data farming? *Adv Radiat Oncol.* 2016;1:260-271.
2. Pedregosa et al. Scikit-learn: Machine Learning in Python. *JMLR.* 2011;12:2825-2830.

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