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Scientific Article

Prompt Pain Relief From Bone Metastases: The Virtual Simulation Program

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Purpose: Rapid pain relief for patients with bone metastases can be a challenge due to the lengthy and complex radiation therapy workflow. The purpose of this study was to evaluate the time (in days) between initial radiation oncology consultation and start of palliative radiation treatment after implementing an alternative virtual simulation palliative workflow.

Methods and Materials: Patients meeting strict criteria were selected for virtual simulation, which included only those with painful bone metastases who were recommended palliative radiation therapy using standard anterior-posterior/posterior-anterior or opposed lateral fields. A recent (within 30 days) diagnostic computed tomography (CT) scan clearly visualizing the target volume was required for treatment planning. For comparison, a reference group of 40 consecutive patients with bone metastases who underwent in-person CT simulation before virtual simulation implementation was reviewed.

Results: Forty-five patients were treated for painful bone metastases as part of the virtual simulation program from May 2021 to October 2022. Regarding travel distance, 23 patients lived locally (<50 miles from the treatment center) and 22 patients were distant (≥50 miles from the treatment center). Average time from consultation to treatment for all patients undergoing virtual simulation was 3.7 days, compared with 7.5 days for patients undergoing in-person CT simulation (3.8 days sooner, on average; $P \leq .001$). Before full implementation of the virtual simulation program, 5 eligible patients participated in a virtual simulation pilot from April 2021 to May 2021, in which each patient was contoured and planned on both a pre-existing diagnostic CT scan and a standard CT simulation scan. For virtual simulation-based plans, the average V90, V95, and V99 were 99.99%, 99.87%, and 96.70%. No significant planning target volume (PTV) coverage difference was found on subsequent in-person CT simulation scans.

Conclusions: The virtual simulation program decreased the time from consultation to start of treatment by more than 50% for patients recommended palliative radiation therapy for painful bone metastases. This benefit was most significant for outpatients traveling ≥50 miles for treatment. Virtual simulation-based planning can be considered for patients anxious to proceed with radiation therapy quickly or in underserved settings with limited transportation options to regional treatment centers.

Introduction

Advances in combined modality oncologic therapy continue to push the boundaries of expected survival for advanced-stage malignancies. Consequently, the prevalence of cancer survivors with active bone metastases is expected

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to rise.[1] Palliative radiation therapy is a cornerstone of treatment for symptomatic bone metastases because it provides pain relief for most patients. However, onset of relief typically does not occur until 1 to 2 weeks after treatment; therefore, expedited radiation delivery is warranted.[2-3] Unfortunately, the radiation planning process is complex, and treatments can be significantly delayed to complete each required step. This forces patients to endure cancer-related pain for elongated intervals of time while they await treatment. Because of this, timeliness of radiation oncology evaluation and treatment is considered a top priority for patients and referring physicians.[4]

Decreasing the time from initial referral to completion of radiation treatment has been primarily targeted by expanding the number of staff members dedicated to palliative treatments.[5] Fairchild et al[6] implemented a rapid-access palliative radiation therapy program, which provided a "one-stop" bone metastases multidisciplinary clinic. The aim of this clinic was to decrease barriers to palliative radiation therapy for patients who were referred from outside institutions. Barriers included travel distance, inconvenience of multiple appointments, and overall wait time for consultation.[6] Similarly, Job et al created the role of a palliative advanced practice radiation therapist who was dedicated specifically to palliative referrals. Use of this advanced practice therapist significantly decreased the time from referral to radiation treatment.[7]

Time from referral to completion of palliative radiation therapy can also be decreased by expediting steps within the planning workflow without changing the number of dedicated palliative staff. This is typically accomplished by temporarily pooling department resources to provide "same-day consultation, planning, and treatment" in an add-on fashion. This is effective from a timeliness perspective; however, greater workload per staff member may contribute to increased stress, burnout, and treatment error rates.[8,9]

The number of patients requiring urgent palliative-intent radiation continues to rise; therefore, alternative solutions will be required to mitigate treatment wait times and staff workload. One promising solution involves forgoing a computed tomography (CT) simulation scan and using a pre-existing diagnostic CT scan for palliative radiation planning instead. The nomenclature of this technique has varied, with terms such as diagnostic CT enabled planning, CT simulation-free planning, and diagnostic scan-based planning all being used in recent literature.[10-12] Patients are often unfamiliar with differences between diagnostic and simulation-based CT scans. However, since the COVID-19 pandemic, the term virtual being synonymous with not in-person has become quite familiar for patients with regard to follow-up appointments. Therefore, at our institution, we elected to term this a virtual simulation for ease of patient understanding and to establish a common and simple language among the staff.

This study aimed to quantify the effect on total time from consultation to start of palliative radiation treatment for patients in the virtual simulation (VS) program compared with those undergoing a standard in-person CT simulation. Assessment of our pre-existing palliative workflow, dosimetric validation results, and effects on staff satisfaction are also described.

Methods

Standard palliative workflow assessment

In early 2021, a survey to assess the pre-existing palliative treatment workflow (Fig. 1) was distributed to all key

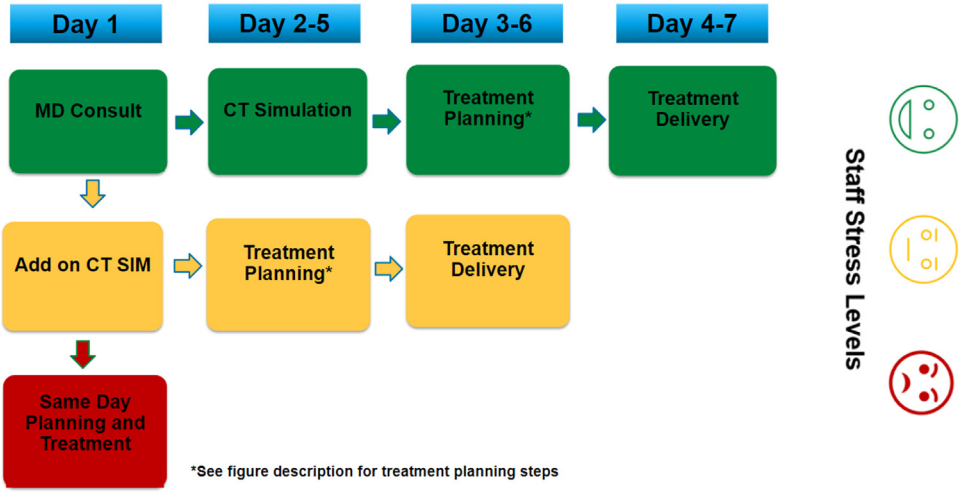

Figure 1 Standard palliative treatment workflow relative to time (in days) and staff stress levels. *Treatment planning includes initiation of treatment planning (simulation image upload into planning software), physician contouring, draft prescription, dosimetry beam placement, physician review, and physics quality assurance.

stakeholders, including radiation oncologists, advanced practice providers, radiation therapists, medical physicists, and dosimetrists. The survey directly gauged levels of staff satisfaction, stress, and efficiency related to the palliative workflow. Additionally, stakeholders were asked to identify causes of palliative radiation treatment delays and possible interventions.

Virtual simulation eligibility and workflow

An alternative radiation planning workflow was designed, which used a pre-existing diagnostic CT scan in lieu of acquiring an in-person CT simulation scan. Proceeding with the alternative "virtual simulation" workflow required strict patient selection. Only patients undergoing palliative-intent treatment to bone metastases of the thorax, abdomen, pelvis, or proximal extremity were eligible. Each patient required a recent diagnostic CT scan (within 30 days) with all patient anatomy near the target volume clearly visible. Patients did not require custom immobilization; however, the diagnostic CT scan position had to be confidently reproducible. Patients with a previous overlapping irradiated area or a nearby implanted device were excluded.

Once an eligible patient was selected, the treating physician would place a prior authorization order within the electronic medical record and would also notify the department of VS intent instead of placing a standard CT simulation order. This notification includes inpatient or outpatient status, site(s) to be treated, start date, whether the patient had a pacemaker or defibrillator, and the diagnostic CT to be used for planning (including the date and series number of the scan). Initiation of treatment planning begins with dosimetry uploading the instructed diagnostic CT scan to the physician's treatment planning software of choice. Physician contouring of a gross tumor volume and submission of a draft prescription then occurs, similarly to the standard workflow. To minimize any uncertainties with the use of a diagnostic CT, complex planning techniques were avoided; therefore, only anterior-posterior (AP), posterior-anterior (PA), and/or lateral beam arrangements were acceptable. Any beam arrangements with entrance through anatomy that may be difficult to reproduce were also avoided. The treatment couch used for treatment delivery was included in the dose calculation, and the diagnostic CT couch was excluded from the dose calculation. Isocenters were placed in the center of the gross tumor volume, a generous margin (>5 mm) was used, and minimal multileaf collimator blocking could be used. Megavoltage portal films and cone beam CT were required for every treatment setup. The treating therapists were provided a full-skin rendering of the patient position from the diagnostic CT to aid in initial positioning, and treatment delivery could only commence with the physical presence and approval of the treating physician.

Virtual simulation pilot

Before widespread implementation, a VS pilot program including 5 eligible patients was completed. Each patient was contoured and planned on both a pre-existing diagnostic CT scan and a standard CT simulation scan. During the pilot phase, each patient's actual treatment plan was delivered using the CT simulation scan per standard operating protocol. However, the additional diagnostic CT treatment plan was superimposed on the standard CT simulation treatment plan for dosimetric validation (Fig. 2). Validation was accomplished by comparing planning target volume (PTV) dose coverage (V90, V95, V99, and Maxiumum Dose) and Hounsfield units (HUs) of adjacent normal tissues (liver, lung, and bone), with V90 defined as the percentage of the PTV receiving at least 90% of the prescribed dose.

Virtual simulation time-based endpoints

After the pilot program, all eligible patients with painful bone metastases were offered the option of undergoing VS starting in May 2021. Patient characteristics including treatment site, dose, fractionation, outpatient-inpatient setting, and travel distance were

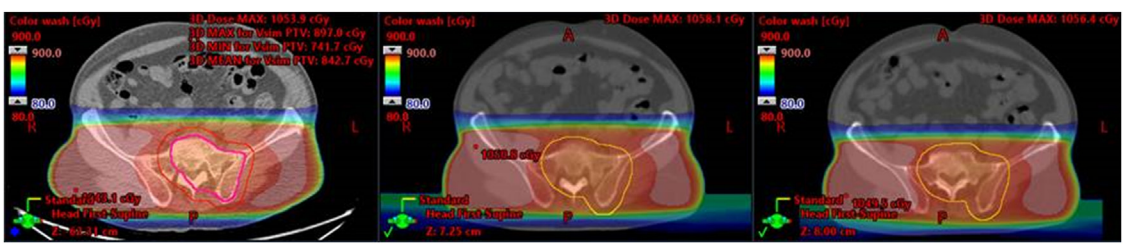

Figure 2 Pilot dosimetric validation demonstrating comparable target dose coverage. Left: virtual simulation; center: in-person computed tomography simulation; and right: virtual simulation plan superimposed on in-person computed tomography simulation image.

recorded for each patient. To assess the timeliness of treatment, all pertinent workflow step completion times were also recorded. This included time of radiation oncology consultation, initiation of treatment planning (upload of VS or in-person CT simulation images to planning software), contouring, draft prescription, beam placement, plan approval, treatment setup, treatment start, and treatment finish. To establish a baseline cohort, identical data were retrospectively collected from patients who would have been eligible for VS but were treated with standard in-person CT simulation in early 2021 (before VS implementation).

The primary endpoints were time from radiation oncology consultation to start of radiation treatment, time from initiation of treatment planning to start of radiation treatment, and duration of treatment. Other endpoints included subgroup analysis related to outpatient or inpatient setting and travel distance. Patient travel was considered local if <50 miles to the treatment center and distant if ≥50 miles. Descriptive statistics were used to summarize each data set. We planned a 2-sample t test assuming unequal variances, with an α of .05 to compare endpoints between VSs and standard in-person CT simulations. Differences were considered statistically significant if $P < .05$. Additionally, an identical stakeholder survey was distributed to assess levels of staff satisfaction with the VS workflow 6 months after implementation. Approval by the institutional review board was obtained (IRB number:23-000835).

Table 1 Patient characteristics among those palliatively treated for painful bone metastases

Characteristics	Patients, No. (%)	
	Virtual simulation (n = 45)	Standard in-person CT simulation (n = 40)
Sex		
Male	21 (47)	23 (58)
Female	24 (53)	17 (42)
Disease site	n = 52	n = 41
Spine	24 (46)	19 (46)
Pelvis	9 (17)	5 (12)
Chest	6 (12)	6 (15)
Shoulder	6 (12)	2 (5)
Hip	6 (12)	7 (17)
Femur	1 (1)	2 (5)
Multisite treatment	n = 7	n = 1
Dose/fractionation		
8 Gy/1 fraction	34 (76)	40 (100)
20 Gy/5 fractions	11 (24)	0 (0)
Treatment setting		
Outpatient	35 (78)	36 (90)
Inpatient	10 (22)	4 (10)
Travel distance		
Local	23 (51)	20 (50)
Distant*	22 (49)	20 (50)

Abbreviation: CT = computed tomography.
* More than 50 miles.

Results

Patient characteristics

These data include all patients who received palliative radiation for painful bone metastases through the VS program from May 2021 through October 2022 (Table 1). During this time interval, a total of 45 VS treatments were completed. Treatment disease sites included the spine (n = 24), pelvis (n = 9), hip (n = 6), chest (n = 6), shoulder (n = 6), and proximal femur (n = 1). Fractionation schedules included 8 Gy in 1 fraction (n = 34) and 20 Gy in 5 fractions (n = 11). Most patients were treated in the outpatient setting (n = 35). Per travel distance, 23 patients were local, and 22 patients were distant.

Stakeholder palliative workflow assessment results

Regarding causes of palliative radiation treatment delay, the 4 main categories identified were radiation oncology staff limitations, medical equipment availability (CT simulators, linear accelerators), treatment planning time (contouring, beam placement, quality assurance), and patient limitations (transportation, performance status). Interventions for each cause of treatment delay were then ranked by stakeholders on a 5-point Likert scale to assess for both the effort required to implement an intervention and the potential positive effect on the palliative workflow that an intervention would have. An effect effort matrix was generated (Fig. 3) to help guide which interventions should be considered. This matrix divided causes of palliative treatment delay into 4 intervention categories: intervene now (high impact, low effort), challenging intervention (high impact, high effort), incremental intervention (low impact, low effort), and avoid intervention (low impact, high effort). Computed tomography simulator availability emerged as the most promising intervention candidate, and the decision to

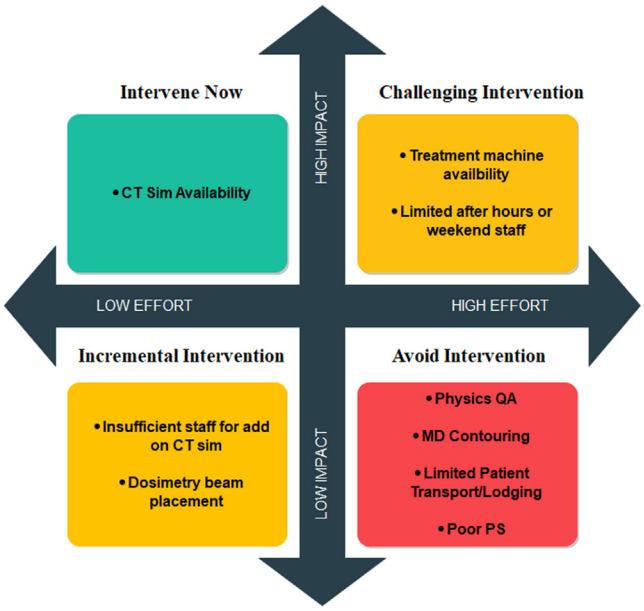

Figure 3 Impact effort matrix, which categorizes palliative workflow sources of delay by intervention potential.

proceed with an alternative CT simulation workflow was finalized.

Pilot dosimetric results

Five eligible patients participated in the VS pilot program from April 2021 to May 2021. For pre-existing diagnostic CT scan "virtual simulations," the average HUs of bone, liver, and lung were 390, 60, and −911, respectively. No significant HU difference was found with bone, liver, or lung on subsequent CT simulation scans. For VS-based plans, the average V90, V95, and V99 were 99.99%, 99.87%, and 96.70%, respectively. No significant PTV coverage difference was found on subsequent CT simulation scans. The average Dmax was 1.8% higher with VS planning. Dosimetric results are summarized in Table E1.

Time endpoint results

Average time from consultation to treatment for all VS patients was 3.7 days, compared with 7.5 days for all standard in-person CT simulation (CTS) patients ($P < .001$) (Fig. 4). Average time from consultation to treatment for

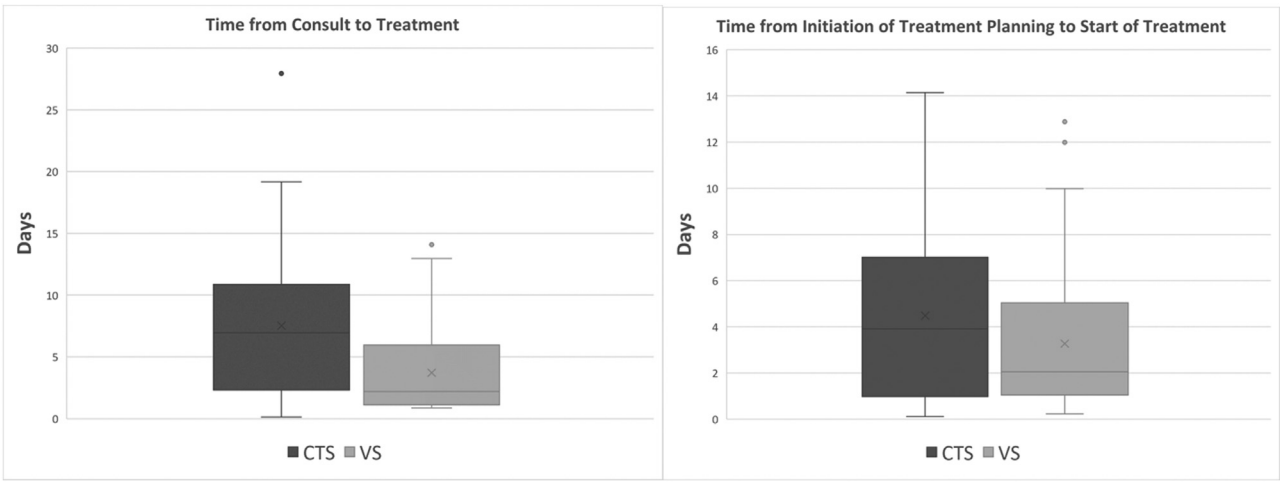

Figure 4 Time-based outcomes depicted on box plots comparing planning based on virtual simulation (VS) and in-person computed tomography simulation (CTS). Average time from consult to treatment for all VS patients was 3.7 days, compared with 7.5 days ($P < .001$) for all standard in-person CTS patients. Average time from initiation of treatment planning to start of treatment for all VS patients was 3.3 days, compared with 4.5 days ($P = .06$) for all CTS patients.

Table 2 Time endpoints comparing VS and in-person CTS

Time Endpoints	VS	CTS	*P* value
Time from consultation to treatment, average, d	3.7	7.5	<.001
Outpatient, all	4.3	7.4	.001
Outpatient, distant*	4.3	8.9	.003
Outpatient, local†	4.2	5.8	.12
Inpatient, all	1.8	8.5	.19
Time from initiation of treatment planning to start of treatment, average, d	3.3	4.5	.06
Outpatient, all	3.9	4.8	.12
Outpatient, distant*	3.9	5.7	.08
Outpatient, local†	3.8	3.9	.48
Inpatient, all	1.2	1.3	.47
Treatment duration, average, min	11.3	10.3	.27

Abbreviations: CTS = computed tomography simulation; VS = virtual simulation.
* More than 50 miles.
† Less than 50 miles.

all VS patients treated in the outpatient setting was 4.3 days, compared with 7.4 days for all CTS patients treated in the outpatient setting ($P = .001$). Average time from consultation to treatment for distant VS patients treated in the outpatient setting was 4.3 days, compared with 8.9 days for distant CTS patients treated in the outpatient setting ($P = .003$).

Average time from initiation of treatment planning (upload of virtual or in-person CT simulation images to planning software) to start of treatment for all VS patients was 3.3 days, compared with 4.5 days for all CTS patients ($P = .06$) (Fig. 4). On subgroup comparisons of VS and CTS patients for average time from initiation of treatment planning to treatment, differences were also not statistically significant. Average treatment duration for all VS patients was 11.3 minutes, compared with 10.3 minutes ($P = 0.27$) for all CTS patients. All time-related endpoint results are summarized in Table 2.

Staff satisfaction results

Key stakeholders (radiation oncologists, advanced practice providers, radiation therapists, medical physicists, and dosimetrists) were distributed 20 identical surveys before and 6 months after implementation of the VS workflow. Staff felt significantly less stressed ($P = .04$) and more satisfied ($P < .001$) treating painful bone metastases urgently 6 months after VS implementation (Table E2).

Discussion

During the past 2 decades, the field of radiation oncology has shifted toward increasingly sophisticated medical imaging and conformal treatment techniques. Advancements such as intensity modulated radiation therapy, proton beam therapy, and magnetic resonance imaging–guided radiation therapy all share this theme. Additionally, they all share the goals of improved disease control and mitigation of side effects.[13,14] Unfortunately, the increased complexity of these techniques is also associated with elongated treatment planning intervals and prior authorization delays, often lasting 1 to 2 weeks before start of radiation therapy.[15,16] This tradeoff is generally still beneficial for definitive-intent treatments; however, for patients receiving palliative therapy, goals of care are shifted. Quality-of-life improvement through rapid and durable symptom relief often becomes prioritized by patients over maximizing treatment precision.[17]

Likewise, we implemented the VS program with the central goal of expediting the time to treatment for patients with painful bone metastases. Our results demonstrated a reduction of more than 50% in the time from initial consultation to treatment with use of VS compared with CTS. The cause of this magnitude of benefit is likely multifactorial and may be secondary to supply-demand constraints that are institution-dependent. For example, our institution has just 1 operating CT simulator, but it also has high volume with >100 patients on treatment per week. Longer-term follow-up and VS implementation at other sites will be required for further understanding. Additionally, nearly 80% of this cohort was treated in the outpatient setting; therefore, these results are most applicable for clinic patients. Interestingly, outpatients traveling greater distances for treatment benefited significantly more than those who were local. This could suggest that the burden of an additional in-person CT simulation visit may be a large enough barrier for these patients to significantly delay treatment. Patients in rural areas with limited access to regional cancer centers may maximally benefit from this.[18]

The time from initiation of treatment planning to start of treatment was not significantly different with VS compared with CTS. No significant time difference was found during the interim workflow steps of contouring, draft prescription, dosimetry beam placement, physician review, or physicist quality assurance. The wait time from initiation of treatment planning to start of treatment was >3 days for both VS and CTS patients, which was primarily related to turnaround time of radiation plans. This wait time may be expedited for VS patients by preplanning before consultation and should be considered in future palliative treatment workflows. However, standard in-person CTS patients would be unable to benefit from preplanning as described, and an increase in frequency of same-day consultation and reservation of simulation slots may be necessary to decrease wait times. Furthermore, no

significant difference was identified between VS and CTS regarding treatment duration (includes both treatment setup and on beam time); however, VS did take 9% longer on average. Treatment setup time was expected to be longer with VS; however, the requirement that a physician must be present for all VS patient treatments may have partially offset this. Notably, Schiff et al[19] recently analyzed a cohort of 30 patients forgoing a CT simulation and found that the time from order approval to plan generation was significantly shorter and the total treatment time was significantly longer compared with CTS patients. However, similarly to our study, they found no significant difference when comparing time from order approval to first treatment.[19] While workflow and patient characteristic differences may not allow for direct comparison, it will be informative for separate institutions to continue analyzing time-related endpoints long term. The actively accruing diagnostic CT planned (DART) trial will be especially helpful for these endpoints, because it aims to assess the total time spent at cancer center per patient.[20]

Dosimetric validation of pre-existing diagnostic CT-based planning has been investigated at several treatment centers.[21] Compared with standard CTS, Wong et al[10] found 95% PTV dose coverage within 3% and minimal HU variation for 150 patients. Metastases in the pelvis, abdomen, thorax, and lumbar spine were most reproducible in that cohort.[10] Glober et al found a median D95 of 96% for a group of 25 patients planned with a pre-existing diagnostic CT.[11] Our VS pilot produced similar results with no significant difference found between normal-tissue HUs, PTV coverage, or Dmax compared with standard CTS. Additionally, Schuler et al[12] assessed more than 80 patients at 4 weeks after palliative treatment for painful metastases, planned using a pre-existing diagnostic CT. The authors found that pain response was equivalent to published evidence on patients treated with standard CTS-based planning.[12]

Before VS implementation, our primary goal was to decrease time to treatment; however, a counterbalance measure was set to avoid decreasing staff satisfaction. This could have inadvertently occurred by worsening another step in the palliative workflow, such as increasing treatment setup time. Comparison of staff satisfaction survey results before and 6 months after implementation suggest that overall staff satisfaction was improved. Nevertheless, close communication with all stakeholders will be vital as the VS program continues to expand. Future studies should consider evaluating patient satisfaction as well regarding comparisons between standard in-person CTS and VS workflows.

Conclusions

The VS program decreased the time from consultation to start of treatment by over 50% for patients requiring urgent palliative radiation therapy for painful bone metastases. This benefit was most significant for outpatients traveling ≥50 miles for treatment. Virtual simulation-based planning should be especially considered for patients in underserved settings with limited access to regional treatment centers. The VS workflow did not negatively affect staff satisfaction.

Disclosures

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.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.adro.2023.101361.

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