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Physics Contribution

Image Guided Radiation Therapy (IGRT) Practice Patterns and IGRT's Impact on Workflow and Treatment Planning: Results From a National Survey of American Society for Radiation Oncology Members

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Summary

We surveyed American Society for Radiation Oncology membership regarding treatment site−specific protocols and opinions toward image guided radiation therapy (IGRT). We report high prevalence of IGRT, frequent use of daily cone-beam computed tomography, no association between IGRT frequency and planning treatment volume (PTV) margins, and poor resident involvement in IGRT. Consensus guidelines,

Purpose: To survey image guided radiation therapy (IGRT) practice patterns, as well as IGRT's impact on clinical workflow and planning treatment volumes (PTVs).

Methods and Materials: A sample of 5979 treatment site−specific surveys was e-mailed to the membership of the American Society for Radiation Oncology (ASTRO), with questions pertaining to IGRT modality/frequency, PTV expansions, method of image verification, and perceived utility/value of IGRT. On-line image verification was defined as images obtained and reviewed by the physician before treatment. Off-line image verification was defined as images obtained before treatment and then reviewed by the physician before the next treatment.

Results: Of 601 evaluable responses, 95% reported IGRT capabilities other than portal imaging. The majority (92%) used volumetric imaging (cone-beam CT [CBCT] or megavoltage CT), with volumetric imaging being the most commonly used modality for all sites except breast. The majority of respondents obtained daily CBCTs for head and neck intensity modulated radiation therapy (IMRT), lung 3-dimensional conformal radiation therapy or IMRT, anus or pelvis IMRT, prostate IMRT, and prostatic fossa IMRT. For all sites, on-line image verification was most frequently performed during the first few fractions only. No association was seen between IGRT frequency or CBCT utilization and clinical treatment volume to PTV expansions. Of the 208

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further evidence-based approaches for PTV margin selection, and greater resident involvement in IGRT practices are needed for standardized use of IGRT.

academic radiation oncologists who reported working with residents, only 41% reported trainee involvement in IGRT verification processes.

Conclusion: Consensus guidelines, further evidence-based approaches for PTV margin selection, and greater resident involvement are needed for standardized use of IGRT practices. © 2016 Elsevier Inc. All rights reserved.

Introduction

Image guided radiation therapy (IGRT) is the process of imaging during a course of highly conformal radiation therapy (RT), with the ultimate intent of improving target accuracy and precision by correcting for anatomic and biological deviations (1). IGRT techniques consisting of planar or volumetric imaging (with or without implanted fiducial markers), 3-dimensional (3D) surface imaging, ultrasound, stereoscopic X ray with integrated optical imaging (ExacTrac), and electromagnetic transponders allow for the possibility of reduced planning treatment volume (PTV) expansions. This resultant reduction of setup uncertainties allows for the safe implementation of sharp dose gradients between the boundaries of the PTV and surrounding critical organs at risk.

Given these perceived benefits, IGRT techniques are being rapidly adopted in the United States despite paucity of evidence of improved outcomes or decreased toxicity (2). In a 2014 Radiation Therapy Staffing and Workplace Survey conducted by the American Society of Radiologic Technologists, 89% of more than 500 responding managers of US RT facilities reported providing IGRT services at their facility, as compared with 78% reported in 2011 (3). Similarly, in a 2009 survey of US radiation oncologists, 93.5% of respondents reported using IGRT (4).

Although IGRT practices are prevalent, detailed consensus guidelines on the timing and ideal implementation of image acquisition are lacking (5) because pretreatment imaging modality, frequency, PTV expansions, and verification protocols vary widely between and within institutions (4, 6). Moreover, IGRT techniques increase overall treatment time as well as the effort of the RT staff secondary to image-acquisition and verification processes, all of which may have an impact on clinical workflow and operating expenses.

Image verification and correction strategies, whether on-line or off-line, are time- and staff-intensive (7). Similarly, consensus guidelines are lacking on the optimal correction strategy method (on-line, off-line, or a combination) or frequency. To better define US IGRT rates of utilization and perceived impact on workflow, and to test the hypothesis that clinical staff tend to use reduced clinical treatment volume (CTV)-to-PTV margins when using IGRT, we conducted a treatment site−specific survey of American Society for Radiation Oncology (ASTRO) physician membership.

Methods and Materials

Sample

A sample of 5979 surveys was e-mailed to the membership of ASTRO, which included radiation oncologists, physicists, radiation therapists, dosimetrists, nurses, and administrative staff. Names and e-mail addresses were individually collected from the 2013 ASTRO online directory, with occupation of the individual unknown at the time of collection. Physician responses, including residents, were evaluated. Survey responses were considered evaluable if at least the first page of the survey pertaining to generic IGRT practice patterns was completed. All survey responses were anonymous. Institutional review board approval was obtained.

Survey design

Study data were collected in October and November of 2014 and managed using Research Electronic Data Capture (REDCap) tools hosted at Oregon Health & Science University (8). REDCap is a secure, Internet-based application designed to support data capture for research studies. The survey was designed to take approximately 10 to 15 minutes to complete (Appendix E1; available online at www.redjournal.org). The first page consisted of demographic questions as well as general questions relating to overall IGRT utility, value, and its impact on clinical workflow, with Likert scale responses (1 through 5, from "strongly agree" to "strongly disagree"). All subsequent pages utilized branching logic, with questions being displayed on the basis of the subject's clinical treatment site expertise. The following standard fractionation treatment sites were evaluated: central nervous system (CNS), 3D conformal RT (3D-CRT) or intensity modulated RT (IMRT), head and neck IMRT, lung 3D-CRT or IMRT, esophagus 3D-CRT or IMRT, anus or pelvis IMRT, intact prostate IMRT, prostate fossa IMRT, and postlumpectomy whole-breast RT. For each treatment site, questions regarding average CTV-to-PTV expansions (9, 10), modality of image guidance used (if any), and frequency of on-line or off-line image verification were asked. On-line image verification was defined as images obtained and reviewed by the physician before the day's treatment. At the conclusion of the survey, respondents were allowed to submit any further information that was unable to be captured by the survey, using free-text responses.

Statistical analysis

Descriptive statistical analyses were conducted for all variables. A 2-sample *t* test was used to compare continuous variables in 2 groups. All statistical tests were 2-sided at the 5% significance level. SAS 9.4 (SAS Institute, Cary, NC) was used for statistical analysis.

Results

Physician demographics and IGRT capabilities

Of 671 submitted responses, 70 were non-physician, resulting in a total of 601 evaluable responses. The majority of physicians completed the site-specific survey questions (n=447 for CNS, 398 for head and neck, 405 for lung, 364 for esophagus, 371 for anus or pelvis, 372 for prostate, and 356 for breast). Physician demographics and IGRT technologies used by responding physicians are summarized in Table 1. Even when excluding portal imaging techniques, 95% reported IGRT use in their practice, with 92% reporting volumetric imaging capabilities (either cone-beam CT [CBCT] or megavoltage CT [MVCT]).

Table 1 Physician demographics and image guidance capabilities of treatment centers

Parameter	No. of respondents (%)
No. of evaluable physician responses	601
Practice setting	
Hospital-based	449 (75)
Satellite/free-standing clinic	152 (25)
Year of residency graduation	
1979 or earlier	31 (5)
1980-1989	108 (18)
1990-1999	147 (24)
2000-2009	161 (27)
2010-2018 (including current residents)	154 (25)
Practice size (no. of physicians)	
1	56 (9)
2-9	318 (52)
10-30	188 (31)
>30	39 (6)
CMS region of practice	
1 (CT, ME, MA, NH, RI, VT)	42 (7)
2 (NY, NJ)	54 (9)
3 (MD, DC, DE, WV, VA, PA)	80 (13)
4 (NC, SC, TN, FL, GA, AL, KY, MS)	93 (16)
5 (MI, MN, OH, IL, IN, WI)	115 (19)
6 (TX, LA, AR, OK, NM)	47 (8)
7 (MO, KS, IA, NE)	30 (5)
8 (ND, UT, SD, WY, CO, MT)	24 (4)
9 (NV, AZ, CA, HI)	70 (12)
10 (WA, AK, ID, OR)	45 (7)
IGRT technologies used by responding physicians	
Ultrasound	61 (10)
MV portal imaging	373 (62)
kV planar imaging	450 (75)
Volumetric imaging (CBCT or MVCT)	553 (92)
Electromagnetic transponders	90 (15)
ExacTrac	147 (24)
3-dimensional surface imaging (AlignRT)	73 (12)
Fluoroscopy	44 (7)
CT-on-rails	28 (4)
MRI	4 (<1)
Cyberknife on-board imaging	8 (1)

Abbreviations: CBCT = cone-beam CT; CMS = Center for Medicare and Medicaid Services; IGRT = image guided radiation therapy; kV = kilovoltage; MVCT = megavoltage CT.

IGRT modality

Site-specific IGRT modality utilization is summarized in Figure 1. For all treatment sites except for breast, volumetric imaging (CBCT or MVCT) was the most commonly used modality. For breast RT, portal imaging remains most popular (67.4%), followed by kV planar imaging (32%). For breast RT, a minority of respondents (10.4%) reported CBCT utilization. Furthermore, 9% of respondents treating breast malignancies reported no IGRT utilization (even portal imaging), whereas 98% to 100% of respondents treating all other disease sites reported some form and frequency of IGRT use. Few respondents reported ultrasound-based (most commonly in intact prostate, 4.8%), fluoroscopic-based (most commonly in lung, 1.7%), or CT-on-rails-based (most commonly in prostate fossa, 2.4%) IGRT capabilities.

Frequency of IGRT utilization and method of verification

Site-specific frequencies and methods of IGRT verification are summarized in Figure 2. The overwhelming majority of respondents reported daily image guidance (any modality) for all disease sites except for breast. Weekly-only image guidance was more common than daily image guidance for the breast subsite only. For every treatment site, on-line image verification was most frequently performed during the first few fractions only (including first fraction only). Of the respondents who reported using volumetric imaging as a component of image guidance (either solely or in combination with other modalities), the majority reported obtaining daily CBCTs as opposed to weekly or first few fraction CBCT guidance supplemented with other modalities on non-CBCT days (64% for breast, 69% for head and neck, 65% for lung, 59% for esophagus, 65% for anus or pelvis, 82% for intact prostate, and 79% for prostate fossa). No statistically significant correlation was identified between practice size and IGRT frequency.

PTV expansions

Physician-reported median CTV-to-PTV expansions for standard fractionation treatments by disease site are

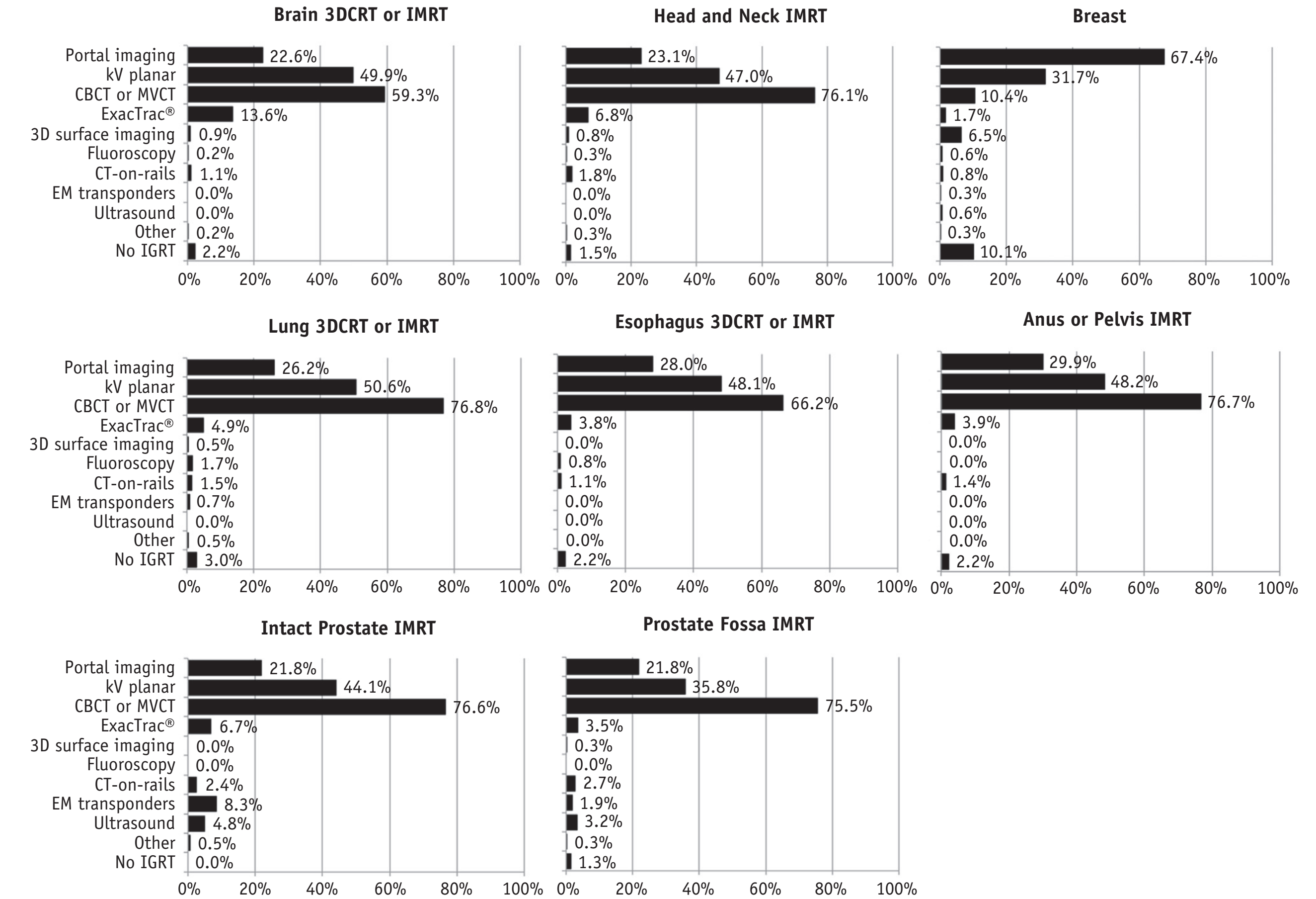

Fig. 1. Percentage of respondents utilizing specified pretreatment image modality for standard fractionation treatments, by disease site. For many disease sites, respondents reported using more than one modality of image guided radiation therapy (IGRT), explaining why cumulative percentages for each disease site is greater than 100%. *Abbreviations:* 3D-CRT = 3-dimensional conformal RT; CBCT = cone-beam CT; EM = electromagnetic; IMRT = intensity modulated RT; kV = kilovoltage; MVCT = megavoltage CT.

summarized in Table 2. The median lung PTV expansions at centers not using 4-dimensional CT (4D-CT) were significantly larger than centers using 4D-CT (10 mm without 4D-CT to 5 mm with 4D-CT). A similar trend was seen for esophagus (7 mm without 4D-CT to 5 mm with 4D-CT). The PTV expansions for lung without 4D-CT simulation exhibited the widest variability in responses (interquartile range, 7-13 mm), whereas prostate exhibited the greatest agreement (interquartile range, 5-6 mm).

Table 3 demonstrates mean CTV-to-PTV expansions by IGRT modality (planar vs volumetric) and frequency. No association was seen between IGRT frequency and PTV expansions ($P>.11$ for all comparisons). Table 4 demonstrates CTV-to-PTV expansions based on any utilization of CBCT, irrespective of frequency. For anus or pelvis only, a statistically significant reduction in mean PTV expansion was exhibited with the use of CBCT (any frequency, yes or no) (8.1 ± 4.4 mm without CBCT and 7.1 ± 3.7 mm with CBCT, $P=.03$; Table 4).

Clinical workflow and hypothetical questions

For centers with resident physicians, only 41% (n=85) of respondents have residents approve IGRT, and of those, 15% (n=27) reported no further attending-level verification after resident approval. The majority of physicians (54%) reported feeling comfortable with therapists doing IGRT without the physician at the console. Respondents were more inclined to disagree that IGRT techniques negatively impact overall clinic productivity (53%) and negatively impact the doctor/patient relationship owing to excessive interruptions (57%). Given the hypothetical scenario of IGRT reimbursement being the same as non-IGRT, an overwhelming majority of respondents (98%) would still use IGRT. Additionally, if IGRT was available and would not require any extra time, 34% would use it always for all sites. Specifically for pediatric patients, respondents were inclined to agree that the benefits of IGRT outweigh the risks of additional radiation exposure (85%).

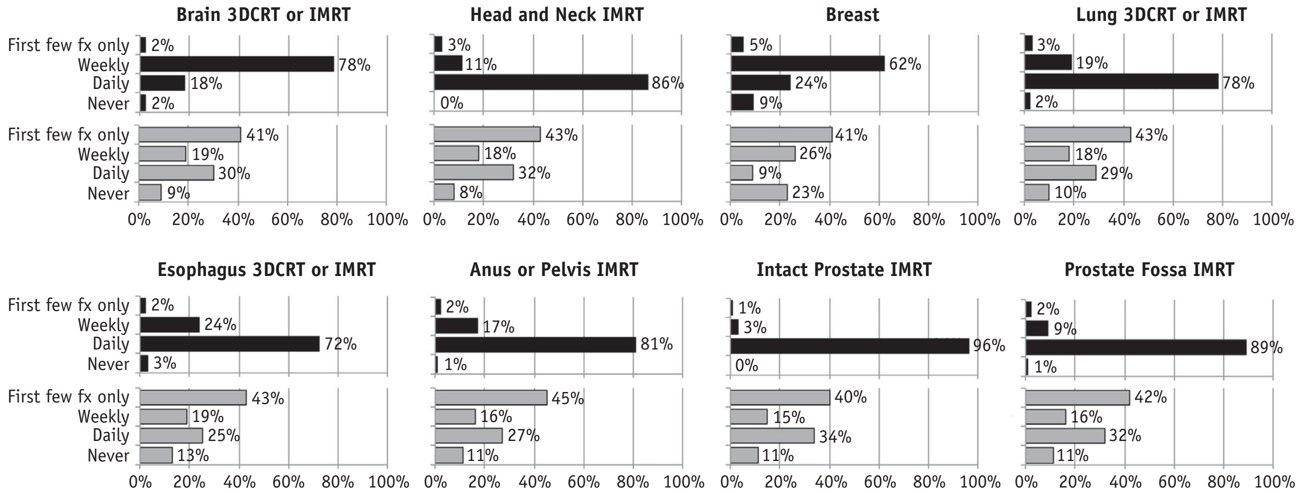

Fig. 2. Physician-reported image guided radiation therapy frequency (black) and on-line image verification frequency (gray) for standard fractionation treatments, by disease site. *Abbreviations:* 3D-CRT = 3-dimensional conformal radiation therapy; fx = fractions; IMRT = intensity modulated RT.

Free-text responses

Many physicians reported mainly off-line image verification, unless shifts implemented by therapy staff were greater than institutional tolerances (ranging from 3 mm to 10 mm) or there were uncertainties by therapy staff, at which time on-line verification was performed. One respondent commented, "We have a culture where therapists are comfortable calling us for any concern." Another physician reported that he/she does not check images on-line because, "I know what my therapists do, how they do it, and trust them."

Table 2 Standard fractionation CTV-to-PTV expansions, by treatment site

Treatment site	Median (mm)	IQR (mm)
Brain 3D-CRT or IMRT	5	3-5
Head and neck IMRT	5	3-5
Lung 3D-CRT or IMRT		
w/4D-CT simulation*	5	5-7
w/o 4D-CT simulation*	10	7-13
Esophagus 3D-CRT or IMRT		
w/4D-CT simulation*	5	5-10
w/o 4D-CT simulation*	7	5-10
Anus or pelvis IMRT	6	5-10
Intact prostate IMRT†	5	3.25-5
Prostatic fossa IMRT†	5	5-6

Abbreviations: 3D-CRT = 3-dimensional conformal radiation therapy; CNS = central nervous system; CTV = clinical treatment volume; IMRT = intensity modulated radiation therapy; IQR = interquartile range; PTV = planning treatment volume; SD = standard deviation.

* With (w/) or without (w/o) 4-dimensional computed tomography simulation (4D-CT).

† Posterior direction PTV expansion only.

Some physicians alter IGRT frequency after treatment start by assessing geometric shifts in the beginning of treatment and either increasing or decreasing the intensity of IGRT accordingly (eg, "IGRT for first 5 fractions, if daily vector variation is < PTV expansion I then switch to weekly IGRT; if > PTV expansion then continue with IGRT daily throughout"). One physician reported altering IGRT frequency and method of verification depending on imaging modality: "We use CT guidance when patients are treated on the Tomotherapy unit. These patients have daily ONLINE physician checks prior to treatment. If patients are treated on the Trilogy unit, they have kV matching done by physicians the first day ONLINE, then daily OFFLINE review by the physician."

Regarding the role of resident physicians in the IGRT process, one attending physician reported, "IGRT review (for first fraction and out of tolerance shifts) privileges generally to second year residents and higher after they have demonstrated competence. All resident signed films or CTs have to be co-signed by an attending before next fraction." Another attending commented, "If it isn't the first fraction, the resident can verify," whereas another attending reported, "Residents do not get involved in IGRT at our program."

One physician described the unique verification system in his/her practice, where "images are sent to a laptop and signed in real time with minimal interruption." Many physicians reported a general sense of comfort and security in the IGRT process, whereas others lamented this over-reliance. Describing the implementation of IGRT in his/her practice, one physician said, "At first, I faced some resistance from staff about frequent imaging and extra time required. Now staff is comfortable and proficient with image guidance, and feel more secure that we are treating more accurately." However, one physician sees "people relying too much on IGRT and thus risking marginal misses for small (if any) gains."

Table 3 Standard fractionation CTV to PTV expansions in mm by IGRT modality (planar = portal imaging or kV orthogonal; volumetric = CBCT or MVCT) and frequency of IGRT

	First few fx only		Weekly only		Daily		
Treatment site	Mean	SD	Mean	SD	Mean	SD	*P*
Brain 3D-CRT or IMRT							
Planar	5.8	3.0	6.8	5.3	5.2	3.7	.14
Volumetric	4.4	2.3	6.4	5.1	5.7	4.6	.3
Head and neck IMRT							
Planar	5	0	4.9	1.3	4.8	2.2	.98
Volumetric	5.2	1.2	4.7	1.5	4.9	2.2	.61
Lung 3D-CRT or IMRT w/4D-CT*							
Planar	5	0	7.3	2.8	6.6	3	.67
Volumetric	6.4	3.1	6.6	3.1	6.2	2.6	.63
Lung 3D-CRT or IMRT w/o 4D-CT*							
Planar	NA	NA	10.0	3.6	10.1	3.7	.89
Volumetric	11.7	5.8	9.9	4.0	12.2	11.5	.68
Esophagus 3D-CRT or IMRT w/4D-CT*							
Planar	NA	NA	5	0	9.2	7.4	.59
Volumetric	6.4	2.2	6.4	2.2	7.8	5.8	.45
Esophagus 3D-CRT or IMRT w/o 4D-CT*							
Planar	3.3	2.9	9.5	7.8	8.1	4.2	.18
Volumetric	8.2	2.1	8.3	3.0	7.8	5.8	.86
Anus or pelvis IMRT							
Planar	5	0	8.6	3.5	8.4	5.3	.47
Volumetric	6.3	1.8	6.9	2.8	7.1	3.7	.65
Intact prostate IMRT†							
Planar	5	0	4.8	1.3	4.6	1.1	.86
Volumetric	4.9	0.8	4.5	1.4	4.6	1.5	.86
Prostate fossa IMRT†							
Planar	10	0	5.8	2.3	5.6	2.0	.11
Volumetric	5.5	1.7	5.8	2.1	5.4	2.1	.58

Abbreviations: CNS = central nervous system; fx = fractions; NA = not applicable. Other abbreviations as in Tables 1 and 2.
* With (w/) or without (w/o) 4-dimensional computed tomography simulation (4D-CT).
† Posterior direction PTV expansion only.

Discussion

The purpose of this study was to survey ASTRO physician membership about current clinical IGRT rates of utilization and IGRT's impact on workflow and PTV margins. Our survey has subsequently identified (*1*) an expected very high prevalence of IGRT and daily CBCT; (*2*) wide variability in disease site−specific IGRT frequency and verification methodologies; (*3*) no statistically significant association between IGRT frequency or CBCT utilization and PTV margin selection; and (*4*) poor resident involvement in IGRT practices.

We found a high prevalence of IGRT even when excluding portal imaging techniques, with 95% of physicians reporting utilization within their practices. This is in comparison with a 2014 report of the European Society for Radiotherapy and Oncology Health Economics in Radiation Oncology (HERO survey) project documenting the distribution of European radiation therapy departments and availability of RT equipment. The HERO survey identified that less than half (49%) of all linear accelerators in Europe were capable of IGRT (United Kingdom: 35%; Switzerland: 20%; Sweden: 70%; Spain: 19%; France: 53%; The Netherlands: 95%) (11); however, the exact dates of data collection in the HERO survey are not mentioned in their report and may be an underestimation of current European IGRT practices.

We observed 92% of physicians currently possess IGRT capability, with more than half performing daily CBCT for multiple disease sites. This is in comparison with a 2009 survey of US IGRT practice patterns, where 75% of academic and 50% of private-practice physicians reported use of volumetric imaging (4). Additionally, our study shows a large decline in the utilization of portal imaging, with roughly a quarter of physicians reporting treatment site−specific utilization for all sites except for breast, whereas the 2009 survey identified portal imaging as the most common modality for pretreatment image guidance (4). Given the ability of CBCT to guide treatment with improved soft-tissue contrast (12) as well as the superior ability to monitor anatomic changes for consideration of adaptive RT techniques (13), this shift from planar imaging to volumetric imaging is expected. Moreover, it has now become standard for all newly manufactured linear

Table 4 Standard fractionation CTV-to-PTV expansions (in mm), according to use of CBCT/MVCT (irrespective of frequency, yes vs no)

Treatment site	Yes		No		
	Mean	SD	Mean	SD	*P*
Brain 3D-CRT or IMRT	5.7	4.6	5.9	4.3	.75
Head and neck IMRT	4.8	2.0	4.8	2.0	.90
Lung 3D-CRT or IMRT					
w/4D-CT*	6.3	2.8	6.8	3.1	.32
w/o 4D-CT*	11.2	9.2	9.7	3.5	.31
Esophagus 3D-CRT or IMRT					
w/4D-CT*	7.9	6.4	8.1	5.9	.87
w/o 4D-CT*	7.8	4.9	8.8	6.0	.18
Anus or pelvis IMRT	7.1	3.7	8.1	4.4	.03
Intact prostate IMRT†	4.6	1.4	4.6	1.2	.99
Prostate fossa IMRT†	5.5	2.1	5.7	2.1	.28

Abbreviations as in Tables 1-3.

* With (w/) or without (w/o) 4-dimensional computed tomography simulation (4D-CT).

† Posterior direction PTV expansion only.

accelerators to possess integrated on-board imaging with volumetric imaging capabilities.

The required frequency of pretreatment imaging as well as the optimal verification strategy (on-line vs off-line) is not known. The 2014 American College of Radiology−ASTRO Practice Parameter for IGRT advises that the "the frequency of IGRT usage should be carefully balanced between the needs of the disease/technique, imaging dose, and resource requirements" without making specific recommendations (14). Additionally, the issue of on-line versus off-line verification is not defined or addressed in the Practice Parameter. In general, on-line correction strategies achieve a larger reduction in random geometric deviation than off-line approaches (15, 16) but at the expense of more time and effort (17). We found that the most common method of verification in the United States is on-line for the first few fractions only, followed by off-line verification for all subsequent fractions. Because IGRT provides added safety secondary to avoidance of large errors (eg, forgetting to make a shift between marked and actual isocenter or treating the incorrect volume), we believe the greatest use of on-line verification for the first few fractions only is to ensure that the treatment is safe and is being delivered as planned. Our findings demonstrate that a more detailed, treatment site−specific, and imaging modality−specific consensus guideline by a major body (ASTRO, American College of Radiology, American Association of Physicists in Medicine) for standardization of US IGRT procedures is needed.

Of the 208 academic radiation oncologists who work with residents, only 41% reported trainee involvement in IGRT verification processes. Potential reasons for resident physician omission in this crucial aspect of radiation oncology training are multi-fold, including reimbursement tied to attending-level verification, protected didactic and academic days limiting exposure, and other concurrent clinical obligations of trainees. Nevertheless, we feel strongly that training of the next generation of clinicians in using IGRT devices is the key to future appropriate utilization of this technology. On the basis of feedback from residents across the United States, an educational session on IGRT practicalities led by Drs. Laura Dawson and David Jaffray from the Princess Margaret Hospital in Toronto was added to the Association of Residents in Radiation Oncology annual seminar held the day before the 2015 ASTRO annual meeting in San Antonio, TX.

We identified no relation between IGRT frequency and PTV expansions, despite the fact that pretreatment image guidance can potentially improve the therapeutic ratio of RT by reducing PTV margins. Multiple studies have assessed the impact of IGRT frequency on geometric and anatomic uncertainties (15, 18, 19), in that more frequent imaging should allow reduced PTV expansions owing to less uncertainty in random geometric errors and target delineation (20). For example, one report suggests that head and neck PTV expansions may be reduced to 3 mm if daily CBCT and proper immobilization is performed (19). Furthermore, Radiation Therapy Oncology Group protocol 0920, a phase 3 study of postoperative RT with or without cetuximab for locally advanced resected head and neck cancer, recommends a 5-mm PTV expansion if daily image guidance is not performed and a 2.5-mm PTV expansion if daily image guidance is performed; still no prospective clinical trial has shown that it is safe to reduce treatment margins in the presence of IGRT. Given this, we did not identify any statistically significant modifications in head and neck PTV expansions based on frequency of IGRT (Table 3), with 5 mm utilized uniformly. For further emphasis, a cost−outcome analysis reported that prostate IGRT used solely for translational patient repositioning increases cost with relatively little improvement in dosimetric quality (21). Ploquin et al (21) pose that the full exploitation of IGRT and improvement in the cost−outcome ratio relies mainly on reduction of PTV expansions and resultant decreased morbidity and increased quality of life secondary to smaller volume of normal tissues irradiated, yet we did not find this specific use for IGRT in our results. However, although IGRT modality and frequency are an important component in deciding an appropriate CTV-to-PTV expansion, it must be noted that other treatment planning and treatment delivery factors may play an equally as important role (eg, diagnostic imaging technologies and registration processes, contouring, linear accelerator technologies, patient immobilization, fiducial marker implantation, and comprehensive quality assurance processes). Despite the fact that our survey was not designed to capture physician-specific nuances of treatment planning and treatment delivery as described, the lack of association between IGRT frequency and PTV margin selection is noteworthy and unexpected.

Finally, IGRT frequency and modality have obvious implications in terms of overall health care costs. A 2009 French randomized cost-analysis study identified an additional cost per treatment course of €679 when daily CBCT was performed over weekly CBCT for prostate IGRT (22). Given this, it is critical that radiation oncologists judiciously and efficiently use IGRT per best available evidence-based approaches that will allow for an accurate and safe treatment delivery of a highly conformal treatment plan.

One important limitation of this study is that not all physicians responded. Furthermore, because all responses were anonymized, it is likely that more than 1 physician from the same center responded to the survey. Therefore, accurate quantification of the number of IGRT technologies installed nationally is not possible from our collected data. Additionally, our definition of on-line image verification for workflow assessment pertained only to the physician, when in reality all "off-line" images are likely reviewed and corrected by a skilled radiation therapist, with the patient on the treatment couch. Finally, there is a standard concern in all survey studies that the individuals responding to the survey differ systemically from those not responding. It is possible that physicians less experienced with IGRT or with minimal IGRT capabilities declined to respond, which may lead to biased estimates of IGRT utilization.

Conclusion

In conclusion, our findings describe current IGRT practices in the United States, identifying great heterogeneity in modality, frequency, method of verification, and PTV expansions. Our survey findings highlight the fact that (*1*) consensus guidelines; (*2*) further evidence-based approaches for PTV margin selection; and (*3*) greater trainee involvement in IGRT practices are essential to ensure standardized, accurate, safe, timely, and cost-effective IGRT procedures.

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