A COMPUTED TOMOGRAPHY QUALITY IMPROVEMENT INITIATIVE TO INCREASE PATIENT CENTERING ACCURACY BY UTILIZING A TECHNOLOGIST-FOCUSED PERFORMANCE REVIEW METHOD

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ABSTRACT

Introduction

Proper patient alignment in Computed Tomography (CT) is imperative to the optimization of image quality and radiation dose. Our facility previously implemented a Quality Improvement (QI) project that improved patient centering accuracy via an educational presentation. This research focuses on a more personalized approach to improving CT technologist centering performance using a technologist-focused performance review method.

Methods

Tracking individual CT technologist centering performance is accomplished via an informatics system which determines the degree of patient misalignment for each scan performed. Individualized centering performance reports were created using this data and provided to the CT supervisor for one-on-one discussions with the CT technologist. The performance reports displayed percentages of exams that were adequately aligned versus misaligned, provided data for grossly misaligned exams and case examples for careful review of centering techniques. The efficacy of this discussion was analyzed and compared to technologist performance at other institutions.

Results

Prior to this QI study, the data showed that our institution was performing at 75% alignment accuracy and was in the 57th percentile when compared to peer rankings. After implementing individual performance reviews with each technologist our institution achieved 80% alignment accuracy which corresponds to a 69th percentile ranking compared to other institutions. This represents a 5% increase in centering accuracy and an improvement in our peer ranking by 12%. Additionally, a two-tailed t-test

assuming equal variances showed that the decrease in distance from isocenter after performance reviews of .42 cm was highly significant ($p<0.0001$).

Conclusion

Improvements in vertical alignment have shown that our effort to increase centering accuracy was effective. The informatics system and individualized technologist centering report developed and employed were essential to our success. Most importantly, we have provided an avenue to ensure better image quality and dose management to our patients now and into the future.

1 INTRODUCTION

The importance of CT as a diagnostic modality has been clearly demonstrated by increased demand over the past two decades. The core reason for increased demand is the technological advances that have increased CT's diagnostic capability.[1,6,7,8] This capability has caused a significant decrease in exploratory surgeries, and the risk involved with them[1]. However, CT is an X-ray producing device that exposes patients to ionizing radiation and is not without risk. Therefore, an exam must be deemed clinically necessary by the physician to ensure the benefits are worth the risk of radiation exposure. In most cases the risk is small when compared to the benefit. Especially since CT has become the image modality of choice when superior spatial resolution is necessary; with the ability to resolve to within one millimeter.[1] Exams where CT's superior spatial resolution is absolutely necessary include, but are not limited to multiphase exams, vascular and cardiac exams, perfusion imaging, and screening exams of the heart, chest and colon.[9]

Although radiation dose in CT has been a subject of concern in recent years the scientific community is equally concerned with CT image quality. Patient misalignment in CT has the potential to affect both dose and image quality.[5,13, 15, 16, 19, 20] Image quality is directly impacted by the amount of noise or mottle present in an image. Various studies have shown that noise in CT images can mask lesions and have prompted evaluation of the effect of patient misalignment in CT.[10,11,12,13] Subsequent analysis has shown that misalignment as small as five centimeters can increase the amount of noise present by 15 percent or more.[15, 16]

The goal of diagnostic imaging is to optimize radiation dose and image quality.[5, 9, 13, 20] Since 1994 CTs have employed Tube Current Modulation (TCM) to control the amount of exposure along different axes of the patient, depending on differing levels of photon attenuation along the long and angular axes of the body.[9, 13, 14, 15, 16, 17, 20] Various studies have shown that the CT scanner's TCM operation is affected by patient misalignment.[5, 8, 9, 13, 14, 15, 16, 17, 20]

In addition, studies have shown that misalignment impacts the performance of the bowtie filtration utilized in CT, both in terms of radiation dose and image quality.[5, 19, 20] Because misalignment affects both image quality and dose in various ways (both in the quantity of photons and their distribution throughout the scanned body region) it is imperative that quality control is ensured. However, due to the relatively recent realization of the impacts of misalignment, methods are still being developed to handle this problem. One valuable tool in tracking centering performance is the use of radiology-based informatics systems. Although it is likely that others have utilized these systems to improve CT Centering, the results of those efforts, to the author's knowledge, have not been published.

OHSU previously implemented a Quality Improvement (QI) initiative that improved patient centering accuracy via an educational presentation.[4] The current study focuses on a more personalized approach to improving CT technologist centering performance. A radiology-based informatics system was used to generate individualized reports for use in counseling sessions between the CT supervisor and technologist that focused solely on centering performance. The purpose of this research is to investigate the extent to which this personalized approach impacted CT technologist centering performance, to improve and continue to ensure excellent patient care, and to document and provide examples of QI processes that others could implement to improve CT centering at their institutions.

2 BACKGROUND

2.1 CT BASIC OPERATION

CT is a unique imaging modality. Although it is an x-ray producing device it differs from conventional radiography in many novel ways. In CT, the x-ray tube rotates around the patient, vice being stationary. Both the CT tube and detector rotate together inside a gantry, while the patient is translated through the beam while lying on a moving table.

The x-rays generated penetrate a cross section of the patient's body and the attenuation profile is collected by the detector array. The CT's algorithm uses the attenuation data collected to reconstruct a volume of data which can be divided up into slices representing cross-sections of the patient.

Image reconstruction can be done in a variety of ways including beam back projections taken along the arc of the scanned region of interest and iterative reconstruction.[1]

Image quality is affected by various parameters of the CT scanner, often called techniques. These include the tube potential (kVp), tube current (mA), and the tube current time product (mAs). The tube potential affects both the quantity of photons produced due to increased bremsstrahlung efficiency and the quality of the photon energy spectrum and thus the effective beam energy. The quantity of photons is also determined by the tube current as well as the current time product. If all other parameters are held constant, radiation exposure and image noise can be affected by manipulating the current. Increasing the tube current increases the radiation dose but decreases the noise, which is partially determined by the amount of photons that reach the CT detector[1]. Conversely, decreasing the current leads to a noisier image, but utilizes less radiation. Although decreasing the amount of radiation may seem desirable, radiation exposure and image noise are conflicting factors. Focusing on one without the other may adversely affect dose or image quality. Additionally, images with lower noise and increased radiation may not provide any increased diagnostic value. CT scanners are therefore, programmed to optimize image quality at a predetermined level of current that uses just enough dose to produce an image of adequate diagnostic quality.[5, 9, 13, 20]

2.1.1 CENTERING AXES

As previously stated, the CT scanner consists of a rotating gantry that moves around the table where the patient is positioned. The gantry is contained in a large housing that protects the patient from mechanical injury due to the rotating machinery. All modern CTs use "slip-ring" technology to allow conduction of the electrical image data and rapid rotation of the gantry without cable interference. The table or "couch" can be lowered for patient ease of getting onto the table and also can be moved in and out of the bore (along the z-axes). CT Technologists control the table position with the use of laser lights for position reference markers. The cranial caudal axis of the patient is parallel to the z-axis of the CT scanner. And the scanner field of view (FOV) is a circle in the x-y plane. In most CT scanners, isocenter is the center of rotation of the CT gantry, and is also the center of the reconstructed image.[1]

In the absence of patient attenuation, the highest dose delivered would be at the center of the patient if they were centered correctly in the bore because the CT scanner is designed to deliver the highest dose to isocenter.[5,15,20] As previously stated, this is done at a predetermined level to ensure image quality by the TCM, whose operation is analogous of Automatic Exposure Control (AEC) in conventional x-ray.[13] However, if the patient is misaligned the dose distribution will change and thus image quality is degraded because the TCM algorithm generally uses a scout image to estimate the attenuation properties of the patient being examined.[5, 9, 15, 20]

2.1.2 SCOUT IMAGES AND MAGNIFICATION

A scout image has various other names (also called a Scan Projection Radiograph or SPR, CT radiograph, scout view, topogram, scanogram, or localizer) with some being copyrighted to specific vendors.[1] It is a preliminary two-dimensional scan that is acquired with a fixed tube angle while the patient table moves through the gantry. The image can be taken anterior-posterior (AP), posterior-anterior (PA), or laterally. The scout is used by the technologist to plan the CT scan parameters, determine alignment and is also used by the TCM algorithm to determine the body composition for photon attenuation properties.

Some vendors use only one scout image in either the AP or PA directions, but some also use an additional lateral scan in conjunction. The attenuation of a patient is estimated as water-equivalent cylinders or ellipsoids at different table locations.[20]

Once the scout image is taken, guidelines or boundaries are placed at the beginning and ending place of the desired scan length by the technologist and the techniques (mAs, kVp), type of scan (helical or axial), direction of scan, pitch, detector configuration, reconstruction kernels(s), and TCM are set.[20]

Misalignment along the vertical access becomes a problem due to minification and magnification effects that occur because the CT system's TCM generally estimates the amount of current necessary based on the scout image. Therefore, the scan would either underestimate or overestimate the size and associated attenuation values respectively based on the estimated values set in the TCM.[5, 20, 22]

2.2 DOSE REDUCTION STRATEGIES AND IMAGE CONSISTENCY

2.2.1 BOWTIE FILTERS

A bowtie filter is a beam shaping device that is thinner at the center than the edges. This shape tailors the dose distribution in a way that fits most patients' cross-sections. The bowtie filter received its name because it resembles a common bowtie in appearance. Most CT scans are either of the head or the torso. The torso is typically broken up into the chest, abdomen, and pelvis, which represent over three quarters of all CT procedures.[1, 9] All of these body parts have an approximate elliptical shape in common. The bowtie filter takes advantage of this shape by reducing the intensity of the incident x-ray beam at the periphery of the x-ray field. The thicker portion of the filter is at the edges where less photon penetration is necessary to reach the detector relative to the center of the body that is thicker and requires more photons to penetrate it. The bowtie filter thereby equalizes the amount of x-rays reaching the CT detector by reshaping the beam and flattening the photon fluence reaching the detector array by placing a thicker portion of the filter in the way of the photons at the periphery.[1, 5, 19] The photon fluence is the amount of photons incident on a surface in a given time period divided by the area of incidence.

Reshaping the distribution of photons across the image field is what allows the bowtie filter to affect image quality. The more uniform the field the better the image quality. If the bowtie filter were absent more photons would be present at the periphery of the CT detector relative to the center and a lack of image uniformity would result, negatively impacting image quality.[5]

A factor that affects the performance of the bowtie filter is the alignment of the patient within the scanner. For example, if the patient is positioned to low within the scanner (which is usually the case) the planned photon distribution is distorted about the axial cross-section. The planned photon distribution is thereby effectively moved above the intended location. The planned distribution is inherently set by the CT's design parameters and the assumption that the patient is properly centered within the axial cross-section of the scanner. The bowtie filter's fixed position relative to the CT's isocenter is a part of these design parameters.

If the patient is too low in the scanner the distribution of photons at the edges, which is already purposefully lower than the center, will now end up in an area of the body's cross-section of naturally higher attenuation than originally intended. Thus the lower portion of the imaged cross-section will result in photon "starvation," which is accompanied by a streaking artifact. In summary, if the dose distribution is shifted away from its intended position at isocenter, the amount of the photons needed to produce a quality image at the edges is decreased to the point of producing an artifact.[5]

Marsh et al determined, based on the results of their study and previous studies, that the breast dose index during a standard thoracic exam can increase by as much as 20% due to misalignment within the scanner.[5] This can be attributed to the effects of misalignment on the bowtie filter's proper or intended performance. In this case, the intended dose distribution shifted similarly to the description above, but on the opposite side of the image. This resulted in a higher photon flux (and dose to the breasts) than intended.

2.3 TUBE CURRENT MODULATION UTILIZATION

As previously stated, Tube Current Modulation is a method of current control analogous to AEC in general x-ray.[13] TCM aims to adjust the current to ensure image consistency across all areas of the region of the body region being scanned, independent of changing attenuation values.[13, 20] Areas of the body with increased attenuation (high bone content) would require higher current, whereas areas of lower attenuation (air in the lungs) require lower current to maintain the same image quality.[5, 13]

TCM uses an image quality (IQ) reference parameter set by the user to define the desired level of image quality. The effect on dose when changing the reference parameter is vendor specific and care must be taken when setting and changing this parameter.[13] Increasing the image quality would result in less noise but also more dose. Decreasing the image quality would do the opposite. The image quality reference parameter is compared to a scout image that is conducted prior to each CT exam, as previously mentioned when discussing scout images and magnification.

Most modern CTs use either one or two localizer scans to compare to the IQ reference parameter.

However, some machines use online scanning, an active dose modulation method used to characterize attenuation data "on the fly." This is done by using data acquired in the previous half or whole revolution to modulate the tube current angularly, instead of utilizing a scout image.[5, 13, 20]

Whether using a scout or not, the tube current can be modulated based on the patient attenuation characteristics along the scan direction (e.g. along the z-axis), known as longitudinal modulation, or at different angles during each rotation to account for the patient attenuation characteristics for different projection angles, known as angular modulation. Some machines use a combination of the two but the exact workings of TCM vary significantly among vendors and specific functions are often listed using proprietary names and methodologies.[13]

Merzan et al. have compiled a list of modern scanners and a comprehensive list of how different vendor's TCMs operate and how scan parameters can influence the TCM. This list was developed to help CT users understand the TCM differences between vendors and can be seen below.[20]

	GE Revolution CT	Philips Brilliance iCT 256	Siemens SOMATOM® Force	Toshiba Aquilion One™
Name	SmartmA	DoseRight	CareDose4D	SureExposure 3D
Number of SPRs used	1	1	1 (2[a])	1 or 2, as specified
IQ reference parameter	NI	DRI	Quality ref.mAs	SD
Minimum/maximum tube current adjustable	Yes	Yes[b]	No	Yes
Online feedback	No	No	Yes	No
Aims at same noise level for all patients	Yes	No	No	Yes
Aims at constant noise throughout each scan	Yes	Yes	No	Yes

DRI, dose right index; IQ reference parameter, image quality reference parameter; NI, noise index; Quality ref.mAs, quality reference tube current-time product; SD, standard deviation; SPR, scanned projection radiograph.
[a]Combines SPRs if multiple available.
[b]Adjustable when creating the protocol only.

Figure 1: Merzan et al. Table 1. Specification of the automatic tube current modulation systems of the CT scanners investigated in the study. Reprinted from the British Journal of Radiology with blanket permission for Dissertation/Thesis use contained on their website.

2.4 EFFECTS OF CT MISALIGNMENT ON CT IMAGES

2.4.1 IMAGE QUALITY

The goal of image quality in CT is the same as in all other diagnostic imaging; to produce quality images that are free of artifacts and accurately represent the anatomy and/or physiology in a specific region of interest (ROI).[1,5] Minimizing artifacts in CT depends upon a variety of factors driven by the techniques of the scanner. Mostly, these factors have been well accounted for in relatively recent technological advances and are an automated process.[9] However, alignment in CT is primarily driven by the technologist.[1, 19] And as previously stated, misalignment can mask the presence of lesions due to the presence of noise in the image.[6, 7, 8, 10, 11, 12] The masking takes place because of changes in pixel values that determine the grayscale of the image.[1]

2.4.1.1 CT NUMBER ACCURACY

The difference in grayscale values in CT images is what gives the images their diagnostic worth and need to be consistent and reliable. The grayscale voxel values are measured in Hounsfield units (HUs) and are relative to the attenuation property of water.[1]

The HU is a comparison of a voxel's attenuation characteristics relative to those of water, as shown in the following equation which defines the HU[1].

$$\mathrm{HU} = 1000\left(\frac{\mu_{\mathrm{voxel}} - \mu_{\mathrm{water}}}{\mu_{\mathrm{water}}}\right) \qquad \text{Eqn. 1}$$

In equation one, μ is the linear attenuation coefficient for either a voxel of interest or of water[1].

Szczykutowicz et al. have shown that misalignment of only as much as 10 centimeters can cause a statistically significant change of 20 HU in CT imaging, which has been noted in a different study as the clinical threshold to adequately diagnose kidney stones.[5, 23]Another quantity that misalignment affects is the image noise.

2.4.1.2 NOISE MEASUREMENTS

The amount of noise in an image is driven by the CT scanner electronics, detector quantum efficiency and the number of photons reaching the detector. The scanner electronics and detector efficiency are baseline quantities. Therefore, we are interested in the quantity of photons that reach the detector because we are able to control this factor.

This quantity is referred to as the signal to noise ratio (SNR). As the SNR increases, we have more photons relative to the baseline noise of the CT scanner and image quality improves.[1]

Noise is a statistically random process because radiation incident on the detector from a relative point source is a random process, and is modeled as a standard deviation of an ROI.[1, 5, 9, 24]

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}} \qquad \text{Eqn. 2}$$

In equation 2, σ is the standard deviation, N is the number of pixels in the measurement, $\bar{x}$ is the mean pixel intensity value and x_i is each individual pixel element[24].

ROIs correspond to a grouping of pixels, which are normally used to quantify noise in an image by comparing an ROI's standard deviation from the rest of the image. The standard deviation of an ROI versus the rest of the image's pixel values is determined by an algorithm in the scanner. Various studies have used the standard deviation of different ROIs to quantify the effect of misalignment in CT.[5,]

2.5 DOSE MEASUREMENT

Exact dose measurement in CT is a complicated process for a variety of reasons including, but not limited to, the rotating gantry and the challenge of measuring patient-specific organ doses.[9] Therefore, computing dose in CT is not a straightforward process. Dose in CT is currently being measured using a quantity (or some form of this quantity) known as the Computed Tomography Dose Index (CTDI).

2.5.1 COMPUTED TOMOGRAPHY DOSE INDEX (CTDI)

CTDI is as the name indicates, a dose index. It was not intended to be used as a direct measurement of patient dose, but to provide a means of comparing relative dose indices for similar clinical exams among different facilities.[1, 9, 23]. Various modifications and enhancements have occurred over the years and CTDI has become the foundation of dose estimation worldwide.[1] Different methods of CTDI measurement will be discussed below.

2.5.1.1 $CTDI_{100}$

$CTDI_{100}$ is a dose measurement made using a 100mm long cylindrical "pencil" chamber of an approximate diameter of 9mm. A "pencil" chamber is a type of ionization chamber which measures the amount of radiation exposure to a gas filled container or chamber. The measurement using the "pencil" chamber is taken at the center or peripheral hole of a polymethylmethacrylate (PMMA) cylindrical phantom. There are two different standard PMMA phantoms currently in use. One of 32 cm diameter, and another of 16cm diameter The ion chamber is inserted into the phantom and a CT scan is taken with the tube rotating, but without translating the table. The dose is measured along the z-axis and is defined by the following equation.[9]

$$CTDI_{100} = \frac{1}{nT} \int_{-50\,mm}^{+50\,mm} D(z)\,dz$$

Eqn. 3

In equation 3, n is the number of detector elements in the z-direction, T is the thickness of each dexel, or detector element, and D(z) is the dose measured by an ion chamber in the z-direction.

2.5.1.2 $CTDI_w$

$CTDI_w$ is a weighting method used to measure the average dose to the phantom because of the uneven dose distribution spoken of briefly when discussing bowtie filters and dose distribution. A more accurate representation of the average dose across the entire phantom is given by the following equation.

$$CTDI_w = (2/3) \times CTDI_{100,periphery} + (1/3) \times CTDI_{100,center}$$

As previously noted, $CTDI_{100}$ and thus $CTDI_w$ are taken with no table translation, and are therefore only representative of the 100mm long "pencil" chamber. This measurement is normalized to the phantom using a conversion factor. However, CT scans are not limited to the dimensions of a phantom and also are affected by the pitch.[1, 9]

2.5.1.3 VOLUME CTDI

$CTDI_{VOL}$ is a standardized way of measuring CT Dose across various scanners. It is a value that is measured in the factory over a range of several kV values and other techniques (such as mAs and pitch) for each particular scanner and stored into the CT's memory. $CTDI_{VOL}$ is generally displayed on the scanner prior to the scan after the scan parameters are entered into the machine by the CT technologist or can also be displayed automatically according to the protocol entered or TCM settings. The $CTDI_{VOL}$ is given by the following equation.[1, 9]

$$CTDI_{VOL} = \frac{CTDI_w}{pitch} \qquad \text{Eqn. 4}$$

In equation 4, the pitch is how far the table translates (in mm) per full rotation of the gantry, divided by the beam width. Utilizing the pitch allows the weighted CTDI to be converted to a $CTDI_{VOL}$.

2.5.2 SIZE SPECIFIC DOSE ESTIMATE (SSDE)

The limitations of CTDI is that it is a dose index, as previously stated, and was not meant as a patient dose estimator. Even with the adaptations that have been made in developing the $CTDI_{VOL}$ it is based on measurements made in a cylindrical phantom and the measurements taken tend to underestimate the dose for most patients because the 32-centimeter phantom is equated to an adult with a 47-inch waistline[1].

The tendency of $CTDI_{VOL}$ to underestimate dose for smaller patients, and to overestimate dose for larger patients necessitated the introduction of the Size Specific Dose Estimate (SSDE). SSDE size corrects the $CTDI_{VOL}$ to different effective diameters of patients. The American Association of Physicist's in Medicine (AAPM) Report 204 contains a thorough analysis and methodology for more accurate size-corrected doses from $CTDI_{VOL}$ that are independent of scanner manufacturer. However, care must be taken that correction factors used are specific to the appropriate phantom (e.g. either the 16 or 32 cm phantom).[1]

2.5.3 PATIENT MISALIGNMENT EFFECTS ON CT DOSE

As previously discussed, dose changes can occur due to magnification and minification effects when the scout image is taken. This results in misoperation of the CT scanner's TCM. When magnification is present, the patient appears larger than their actual size. The effect of minification is the opposite and underestimates the patient's size. These effects have been studied and documented in numerous studies.[5, 20, 22] Specifically, Matsubara, et al. conducted a phantom study on the effects of vertical misalignment in CT on two different scanners. One was a 64-MDCT scanner (Toshiba Aquilion 64, Toshiba Medical Systems), and the other a 16-MDCT (LightSpeed Ultra 16 with Xtream, GE Healthcare). This study found that the mAs varied by 75-141% compared with gantry isocenter in the 16-MDCT scanner and 78-124% in the 64-MDCT scanner from five centimeters above and five centimeters below gantry isocenter. Matsubara, et al. noted that the reason why the range in mAs was greater in the 16-MDCT than the 64-MDCT was due to the fact that misalignment is more pronounced the closer the x-ray tube is to the gantry isocenter (the 16-MDCT tube being closer to isocenter than the 64-MDCT). This is thought to occur due to an increase in the magnification (or minification) rate with shorter distances between the tube and isocenter. However, the effect on image quality due to noise showed a narrower range in the 16-MDCT due to the reconstruction algorithm and other factors.[20] Therefore, determining the effects of misalignment on each scanner requires a complex analysis of various factors. However, as previously discussed, the tube current time product changes shown above are a direct indicator of how many photons are generated, and thus the amount of dose. The importance of this increase in dose is also known to impact image quality; both in terms of image uniformity due to the dose distribution and "noise streaking" that can occur due to "photon starvation."[5]

The dose quantities displayed by CT scanners, $CTDI_{VOL}$ and SSDE are also impacted by misalignment. As previously noted, CTDI was not originally meant as a patient dose metric and many iterations of CTDI have been developed to best enable it to be used as a more accurate dose estimator.[1,9] The challenges previously mentioned are only exacerbated by misalignment with both of these quantities. This is the case with SSDE because it is essentially a size-corrected $CTDI_{VOL}$. The size correction would be affected by magnification and minification effects in the scout image as the patient is displaced away from isocenter and would either over or underestimate the dose respectively. $CTDI_{VOL}$ already underestimates dose for larger patients, as previously stated, but becomes more indeterminate with misalignment because the scanner's displayed value is set according to a look-up table that is preprogrammed into the scanner by the vendor. The values in the look-up table are dependent on techniques or settings of the scanner and the expected dose measurement conducted with the phantom centered in the scanner.[5] Thus the scanner would be using a look-up value based upon a scout image that was inaccurate. The previous study mentioned by Matsubara, et al. alluded to the limitations of using the scanner's displayed values in conducting their study vice measuring their own doses using an ion chamber, for example.[20]

In a phantom study conducted by Marsh et al. dose measurements were taken at different heights using an ion chamber. They noted that measured and reported values of $CTDI_{VOL}$ varied among scanners as the heights within the scanner changed. But differences between the scanner-reported and measured $CTDI_{VOL}$ did not change in a substantial way. The method in that study to ensure accurate measurements regardless of mispositioning was to normalize the phantom widths measured using localizers by dividing by the phantom width measured on the corresponding axial images (for each height away from isocenter). They determined where the beginning and ending width measurements were located on the axial images by an algorithm calculated in Matlab for measurement consistency. However, the article noted that in one particular scanner, although the $CTDI_{VOL}$ didn't change much with mispositioning, the SSDE did change. It stated that the discrepancy between $CTDI_{VOL}$ and SSDE when reviewing CT dose indices for Quality Control purposes, can be accounted for by miscentering.[22]

This article demonstrated the complication of obtaining accurate dose measurements and the compounding effects of miscentering. Other articles have shown that characterizing the effects of noise uniformity, streaking artifacts and CT number changes is also a complex process. All of these articles in the scientific literature have established the need for adequate centering. For these reasons and more, OHSU has endeavored to improve centering accuracy.

2.6 PREVIOUS OHSU QUALITY IMPROVEMENTS USING IMALOGIX™

OHSU uses a radiology-based software system called Imalogix™ to track various metrics associated with diagnostic imaging. Imalogix™ was born out of the desire to properly manage dose and has evolved into a platform where various analytics are performed to aid in improved patient care, technologist performance, and proactive decision making by physicians, physicists and managers.

The need for radiology-based informatics systems, such as Imalogix™, has been driven by technological advances, increased throughput and the impracticality of manual data keeping with the large amount of data that is tracked.

A variety of scan parameters are automatically uploaded into the system for each scanner used. Each scan is time and date stamped along with a patient identification number. All scan parameters are also tracked, including vertical and lateral alignment data. These data can be downloaded into a comma-separated value (CSV) file for review and manual data manipulation and analysis.

Imalogix™ supports various institutions in their data analysis needs and provides a summary overview of institutional centering performance on the homepage, when logging in. This snapshot provides an instant look at how one's institution is doing as a percentage of scans that have been accurately centered (defined as within three cm of isocenter) and a comparison to other organizations tracked by Imalogix™. A screen shot of this summary can be seen below.

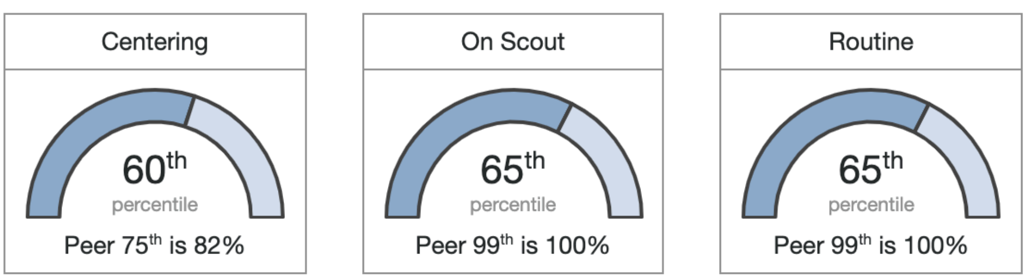


Figure 2: Imalogix graphical display of statistics with accuracy and peer ranking.

The method used for determining isocenter offset employed by Imalogix is similar to the method described previously where scout images are analyzed to determine the differences between isocenter and the center of the patient. First the edge points of the image are determined. Then, a linear measurement between the edge points is taken in order to determine where the true isocenter of the image is. Next, a pixel by pixel analysis is conducted from the edges of the image until the edges of the patient are detected. The center of the patient is taken as the midpoint of the patient edges. The difference between the isocenter and the patient center determines the offset, and is given in units of centimeters. The utilization of radiology-based software programs to determine the isocenter and provide valuable CT centering data tracking is crucial to improving centering accuracy.

OHSU completed a previous quality improvement initiative that utilized Imalogix™ to track its efficacy. This previous QI consisted of a brief mentioning that CT misalignment was an issue that needed improvement at OHSU during a CT staff meeting. The CT supervisor made this comment on September 10th, 2018. A slight but noticeable improvement was seen after this event. The bulk of the CT centering improvement was seen, however, after an educational presentation was given to all of the CT technologists by one of the lead medical physicist's at OHSU. This training was given the week of February 8th to the 12th, 2019.

The presentation included pertinent information regarding the importance of proper alignment with respect to image quality and the possible risks associated with miscentering.

A few of the topics that were included in the presentation were the impacts of centering and why it matters, effects of misalignment on patient dose and image quality, how well OHSU patients are centered and what can be done to improve. Some general tips were given on proper centering technique but the primary purpose was to raise awareness and impress upon the technologists the clinical impact of misalignment. An example was also given where a diagnosis was missed solely due to miscentering. The efficacy of the presentation resulted in an accuracy improvement from 68.80% to 77.68%, which corresponded to a 30-percentile improvement in a peer ranking among other hospitals among other improvements that are detailed further in reference four.

There are two important date ranges that will be discussed from this previous initiative and compared to the results of the current research. Those dates ranges are January 1st to September 10th, 2018 and February 13th to April 26th, 2019. These will be labelled as baseline (prior to the CT Supervisor mentioning that CT misalignment was an issue at OHSU) and after the QI presentation was given respectively.

As previously mentioned in the introduction, the research at hand will look at the processes and efficacy of implementing a technologist-focused QI initiative utilizing a locally prepared individualized annual centering performance report to counsel CT technologists.

3 MATERIALS AND METHODS

3.1 ANNUAL CT TECHNOLOGIST CENTERING PERFORMANCE COUNSELING TEMPLATE GENERATION AND UTILIZATION

3.1.1 TEMPLATE GENERATION

In order to develop a more technologist centric Quality Improvement approach, an annual centering performance counseling report was generated. This report sought to utilize valuable centering data contained in Imalogix^{TM}, our radiology-based informatics software platform. This template was generated with counseling the technologist in mind.

Therefore, only data that was deemed useful in providing an opportunity for meaningful improvement in centering performance was included. Valuable input from the CT supervisor was sought to this end.

The annual period covered for technologist centering performance review was the 2019 calendar year, from January 1st to December 31st 2019. The report included the number of exams performed that were within 3 cm (Our definition of an accurately centered exam), between 3 and 6 cm, and greater than 6 cm by percentage of total exams completed by each specific technologist. These percentages were displayed in a color coordinated donut shaped chart for adequate visual representation of accuracy performance.

The percentage point target for OHSU exams adequately centered was also listed above the chart. This goal was designated at 85% accuracy, which corresponded to approximately the 80th percentile of all institutions tracked by Imalogix™ at the time of the counselling report generation.

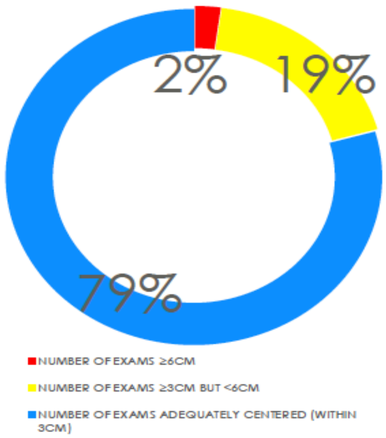
Other categories contained in the template include best vertically aligned protocols, opportunities for improvement, and exams with greatest vertical offset. The best vertically aligned protocols were the three top protocols by percentage listed in Imalogix™. The opportunities for improvement category contained either the three protocols with the lowest percentage of aligned exams or in some cases, those protocols that if improved upon would contribute to the greatest overall centering performance improvement. For example, if the lowest percentage protocol were to only have five exams out of 2000 exams performed, a more heavily weighted protocol was chosen. Although this was not an arbitrary process, the selection of appropriate protocols to include in the opportunities for improvement section was a judgment call.

As previously stated, the template was created in conjunction with the CT supervisor. The exams with greatest vertical offset were generally those exams that were the most misaligned exams. The exams listed in this section included an accession number to allow the supervisor access to those specific exams while counseling the technologist. This allowed the supervisor to provide direct centering guidance, if needed, and allowed the technologist the ability to explain possible challenges during difficult exams. The exams included in this section were generally the most misaligned, but not always, because it was deemed more useful to include a variety of exams that may have had issues with gross misalignment rather than one type of exam. A section for supervisor comments and place holders for both the CT supervisor and technologist's signatures were also included. The technologist specific annual counseling template is presented in figure 3 below.

CT Technologist Annual Centering Report, Insert Tech Name, Jan 1st to Dec 31st 2019

Percentage of Exams Adequately Centered, 79%

OHSU Goal is at least 85%



Summary

TOTAL NUMBER OF CT EXAMS

1792

NUMBER OF EXAMS ≥6CM

39

NUMBER OF EXAMS ≥3CM BUT <6CM

331

NUMBER OF EXAMS ADEQUATELY CENTERED (WITHIN 3CM)

1422

Best Vertically Aligned Protocols

PROTOCOL	NUMBER OF EXAMS	PERCENT WITHIN 3CM	PERCENT ≥3CM ISOCENTER
Abd Multiph Liver WO IVCon	207	86	14
Chst Heart Calc Score	71	87	13
Chst Abd Pelvis W IVCon	50	92	8

Opportunities For Improvement

PROTOCOL	NUMBER OF EXAMS	PERCENT WITHIN 3CM	PERCENT ≥3CM ISOCENTER
Others (Not Categorized/General)	529	72	28
Chst WO IVCon	213	79	21
Abd Pelvis W IVCon	193	79	21

Exams With Greatest Vertical Offset

PROTOCOL	ACCESSION NUMBER	CM FROM ISOCENTER
Abd Pelvis W IVCon	XXXXXXX	6.8
Chst WO IVCon	XXXXXXX	-8.2
Chst WO IVCon	XXXXXXX	-12.21

SUPERVISOR COMMENTS

Supervisor Name: INSERT Supv Name

Signature

Technologist Name: INSERT Tech Name

Signature

Figure 3: Technologist Annual Centering Report Example.

The template was created in Microsoft Excel and formatted to print on a single page. Imalogix™ has the ability to look at each technologist's centering performance individually. This data was downloaded via a CSV (Comma-Separated Value) file into a tab within the excel document. A separate tab was created containing instructions on how to download the data and enable macros. A macros button was created to enable the user of the template to automatically sort the data by centering accuracy once the raw data was imported into the appropriate location of the spreadsheet. Imalogix™ also provides bar charts with corresponding numbers of exams performed, that were checked to ensure accuracy once the template was generated. The colors chosen for the donut shaped chart correspond to those used by Imalogix™ for each respective accuracy category (e.g. within 3 cm of isocenter, between 3 cm and 6 cm or greater than 6 cm).

3.1.2 TEMPLATE DATA REFINEMENT AND VERIFICATION

A list of those technologists desired to be counseled was provided by the CT supervisor, to ensure only those technologists who regularly perform CTs were included. Imalogix™ tracks the data for each technologist by their initials. However, some technologist's used both two and three initials. Therefore, it was necessary to verify each technologist's initials with the CT supervisor to ensure there was no confusion or another technologist with the same or similar initials. The data for those technologists who utilized both two and three initials was combined to formulate the report for that individual technologist. Once the accuracy of the list provided by the supervisor was verified to correspond to the correct initials located in Imalogix™, the data for each technologist was inputted and verified in accordance with the process listed above to generate the technologist specific annual centering report.

3.1.3 TEMPLATE UTILIZATION

The annual centering report was used to counsel each individual CT technologist listed by the CT supervisor. This counselling was conducted by the supervisor the week of January 27th and concluded on the 31st of January 2020.

3.2 ANALYSIS OF ANNUAL CT TECHNOLOGIST CENTERING PERFORMANCE COUNSELING REPORT EFFECTIVENESS

In order to determine the efficacy of the technologist counselling a time period named before counselling was designated which covers a 10-week period just prior to the technologist counselling. This time period is from November 16th 2019 to January 25th 2020. This data was compared with results from the period after the counselling was performed. The 10 week after counseling time period is from February 1st to April 11th 2020.

Data was extracted from Imalogix™ by downloading all desired data into a CSV file and analyzed using Microsoft Excel. The data was filtered by date ranges and according to CT scanner. OHSU uses six CT scanners for general scanning purposes. These scanners are located at the main OHSU campus and the Center for Healing and Health on the Willamette River waterfront. Each of the scanners is operated by the same group of CT technologists counselled in this research and are designated for a specific patient population (e.g. CTs 2 & 4 are the emergency department scanners). Once the appropriate date ranges were selected by appropriate scanners the data was further separated into three separate categories. These categories are centering accuracy (within 3 cm)/peer ranking, protocol analysis, and offset from isocenter in centimeters (both vertical and lateral offset). The list of scanners can be seen below.

Table 1: CT names, makes and models of scanners in the study.

Scanner ID	Make	Model
CT 1	Philips	Brilliance 16p
CT 2	Canon	Aquilion ONE VISION
CT 3	Philips	iCT 128
CT 4	Philips	Ingenuity 64
CT 5	Philips	Brilliance 64
CT 6	Philips	iCT 256

The accuracy data was also filtered by technologist. Only those technologists that were counselled were included in the accuracy analysis. There were 20 CT technologists counselled in all.

Although peer ranking data can be viewed on the Imalogix™ home page as stated previously, a month by month analysis needed to be obtained directly from Imalogix™ support staff, because this data is not directly obtainable by the user. Imalogix™ was very responsive in obtaining the appropriate data though. Another important factor in the data obtained for peer ranking is that it is calculated on a month by month basis. Therefore, the date range for analysis conducted for this category is not precisely according to the date ranges for the before and after counselling periods listed above. The before and after periods for peer ranking are November 2019 to December 2019 and January 2020 to February 2020 respectively.

The protocol data was also filtered by technologist and filtered according to whether centering data is provided. Protocols that the scanner does not provide either a vertical or lateral offset were either not included in the data pull process or were deleted. For example, head, neck and procedural exams were not selected. Also, heart exams and/or procedures were left out due to the fact that these exams usually include a variety of anatomy according to the needs of the physician for each particular procedure. This results in a large amount of variability in the scanning region that would not provide for consistent analysis. Protocols were then grouped into specific protocol categories for similar exams. For example, a liver exam and kidney exam were both grouped into the abdominal protocol category, etc. The scanning regions were grouped into categories that have alignment and centering techniques that are similar to ensure only exams that have consistent alignment strategies were grouped together. Data for the top five protocol categories as a number of scans were analyzed.

The overall vertical and lateral offset data was also filtered to ensure exams that did not provide centering measurements were not included in the analysis. The vertical and lateral data was separated into two separate cohorts. Vertical measurements below isocenter are negative and those above isocenter are positive. Lateral measurements indicated as positive values are to the right of isocenter and those that are negative to the left. To further restrict redundancies data points belonging to the same patient and same visit were combined into one single exam. A histogram of this data was created by placing each data point into half centimeter bins and taking a percentage of each number of data points in each bin by divided by the total number of data points. Patient identification information was not recorded for any data analysis.

3.3 STATISTICAL ANALYSIS

Offset data was analyzed using a two-tailed t-test with a test statistic of 0.05. The significance of the test was determined by a p-value which was compared to the test statistic. A goodness-of-fit test to the normal distribution was also conducted along with the t-test in Excel (Microsoft® Corporation, Redmond Washington, USA) using the descriptive statistics function in the data analysis toolkit to determine the validity of using the t-test.

A pooled variance test was used with a hypothesized mean difference of zero. This test was deemed appropriate due to the standard deviations of both data sets being similar.

4 RESULTS

4.1 VERTICAL AND LATERAL OFFSET EFFICACY

As previously stated, the before and after performance review data sets consisted of two separate 10 week periods. One ten week period before the performance reviews and another afterwards. The designation of the 10 weeks was consistent with the last QI initiative that analyzed the efficacy of the medical physicist provided CT centering presentation. For now, the focus will be on the before and after periods of the performance reviews.

In total, there were 3,226 exams in the vertical offset before counselling cohort and 2,836 exams in the vertical offset after counseling cohort with average vertical offsets of 1.37 ± 2.28 cm and 0.95 ± 2.26 cm below isocenter respectively. A two-tailed t-test assuming equal variances showed that the decrease in distance from isocenter after counselling of 0.42 cm was highly significant ($p<0.0001$).

Data for the lateral offset included 3,556 exams for the before counselling cohort and 2,969 exams for the after counselling cohort. The average lateral offset before was .126 ± 1.44 cm and after was .128 ± 1.46 cm, both to the left of isocenter. The lateral offset shifted 0.002 cm away from isocenter and was not a significant change in the mean as demonstrated by a two-tailed t-test ($p = 0.96$). Due to the statistical insignificance of the lateral offset shift, only vertical offset will be discussed and analyzed further.

Bell curves showing the change in vertical offset are shown below in figure 4. These charts show the percent of all exams that were aligned in the given vertical offset bins. The curve for after the counselling session is more balanced about the mean even with the two prominences in the curve. The averages of the two prominences being closer to isocenter than the before counselling curve indicates the shift in the percentage of scans performed at isocenter. The prominences show a slight bimodal tendency for the after counseling group curve. As previously stated, a goodness-of-fit test to the normal distribution was conducted in Excel (Microsoft® Corporation, Redmond Washington, USA) using the descriptive statistics function in the data analysis toolkit. The results showed that the mean was similar to the median (-0.95 and -0.88 respectively) and skewness and kurtosis values were within 2 to -2 at -0.17 and 0.84 respectively. Although this test does not prove that the distribution is normal it does mean that the distribution follows closely to the normal distribution.

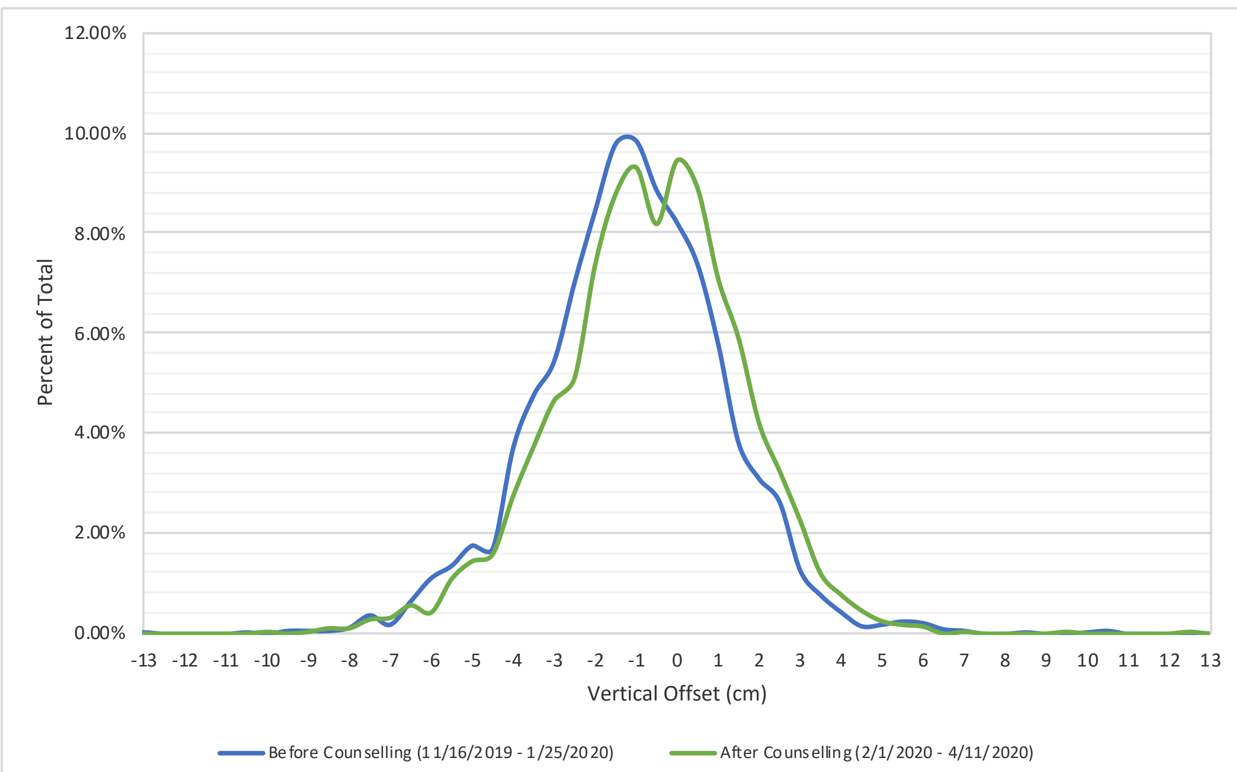


Figure 4: Vertical Offset as a Percentage of Total Scans Histogram.

4.2 PERCENT ACCURACY AND PEER RANKING

As previously stated, Imalogix provides peer ranking data on a month by month basis and the associated accuracy data (defined as the percentage of exams aligned within 3 cm of isocenter) for the given month. Before technologist performance reviews were conducted, the accuracy was 75% vertically and afterwards, 80%. Therefore, accuracy improved by 5% from the initial value in vertical alignment compared to the value after the counselling was conducted.

Data from the Imalogix peer rankings among other hospitals averaged in the 57th percentile before individual counselling and in the 69th percentile after. Thus average peer ranking improved by 12 percentile points after the counselling was conducted by the CT Supervisor. Graphs of both the accuracy and the associated peer ranking are shown below in figure 5.

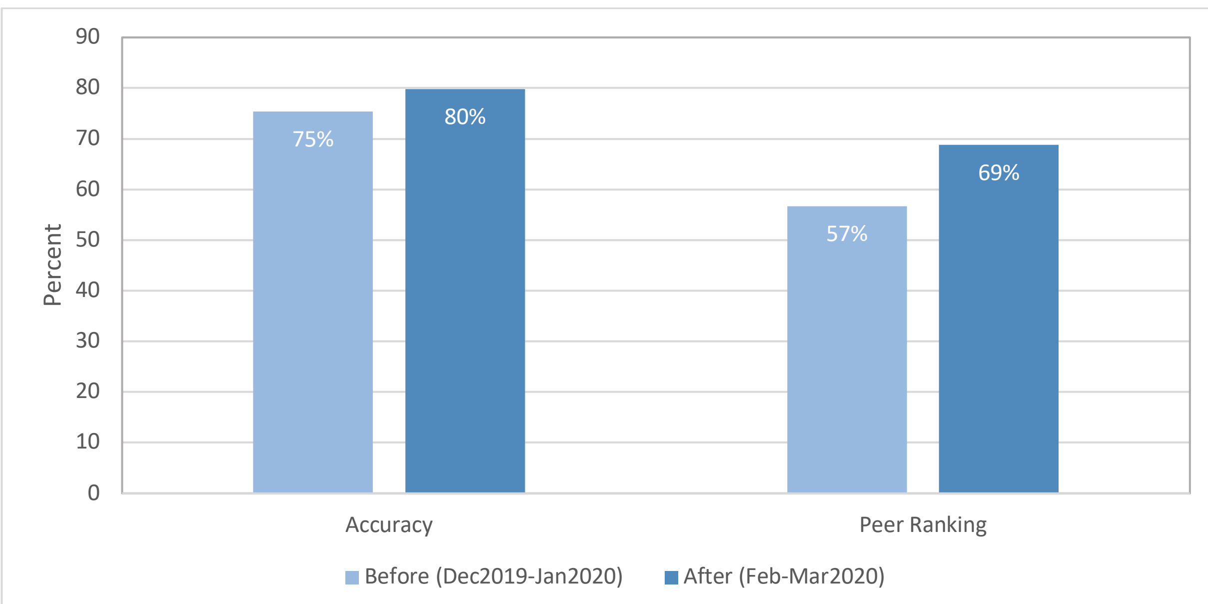


Figure 5: Peer Ranking and Percent Accuracy Before and After Individual Technologist Patient Centering Performance Reviews.

4.3 PROTOCOL DATA ANALYSIS

4.3.1 AVERAGE VERTICAL OFFSET ACCORDING TO PROTOCOL CATEGORY

Vertical offset did not improve in all protocol categories but did improve for all top five protocol categories by number of exams. The most drastic improvement in vertical offset was in the CAP category, while AP and pelvic exams showed the most modest improvement. All of the average offsets were below isocenter for both date ranges. This can be seen below in figure 6.

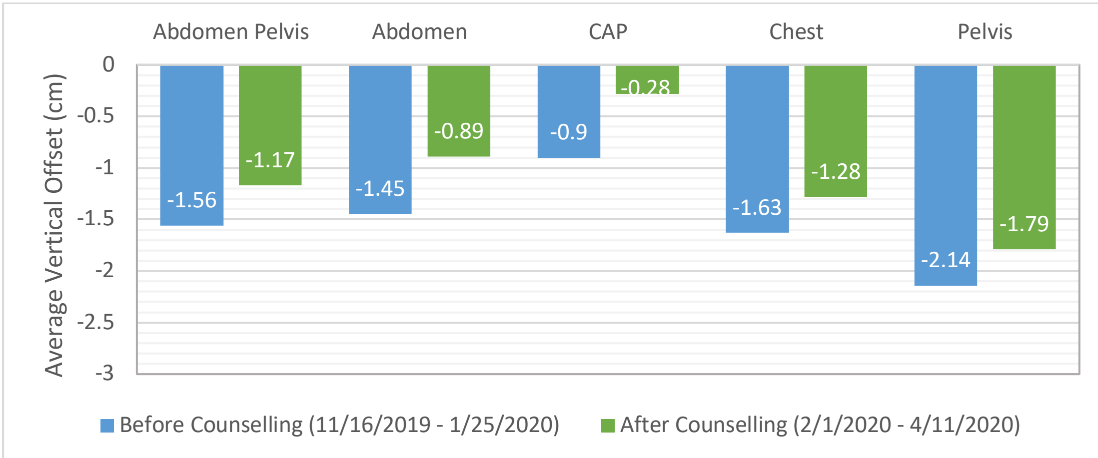


Figure 6: Average vertical offset for each protocol.

4.3.1 ACCURACY ACCORDING TO PROTOCOL CATEGORY

As previously stated, the top five categories by number of scans were analyzed. All five of these categories improved in accuracy and also had a decrease in the number of exams ≥6 cm. The categories organized by the number of scans conducted before the performance reviews are posted below in table 2. They include the abdomen-pelvis (AP), chest-abdomen-pelvis (CAP), chest, abdomen, and pelvis. AP protocols were the most utilized of the data obtained. Pelvic exams were the least common of these data. From this table we can see that the most accurate categories were the CAP and Chest respectively before the counselling, and the CAP and Abdomen respectively after the performance reviews. Abdomen exams edged out the Chest exams as far as accuracy due to the larger increase in accuracy of 7% (from 73.9% to 80.9%) versus the modest increase in Chest exams of 1.1% (from 75.4% to 76.5%).

Table 2: Number of Scans and Percent Accuracy For Top 5 Protocols by Number of Exams.

	Before Counselling (11/16/2019 - 1/25/2020)						
	Number of Scans				Percent of Total		
Protocol Category	Total scans	< 3 cm	3-6 cm	≥6 cm	< 3 cm	3-6 cm	≥6 cm
Abdomen Pelvis	968	711	222	35	73.5%	22.9%	3.6%
CAP	883	729	139	15	82.6%	15.7%	1.7%
Chest	817	616	177	24	75.4%	21.7%	2.9%
Abdomen	417	308	96	13	73.9%	23.0%	3.1%
Pelvis	58	26	26	6	44.8%	44.8%	10.3%

	After Counselling (2/1/20 - 4/11/20)						
	Number of Scans				Percent of Total		
Protocol Category	Total scans	<3 cm	3-6 cm	≥6 cm	<3 cm	3-6 cm	≥6 cm
Abdomen Pelvis	915	717	174	24	78.4%	19.0%	2.6%
CAP	713	610	97	6	85.6%	13.6%	0.8%
Chest	757	579	161	17	76.5%	21.3%	2.2%
Abdomen	298	241	51	6	80.9%	17.1%	2.0%
Pelvis	36	23	10	3	63.9%	27.8%	8.3%

The least accurate (or highest percentage of exams ≥6 cm) were the pelvic exams. The pelvic exams also have the least number of total scans. A graph of the top five protocol's accuracy is shown below in figure 7. Again, all five of the top protocol categories improved in accuracy. The greatest improvement was shown in the pelvis category, with an increase from 44.8% to 63.9%, for an increase of 19.1% accuracy. Chest exams showed the most modest increase, from 75.4% to 76.5%, for an increase of 1.1%. A graph detailing the improvement in the number of exams ≥6 cm is shown in figure 8 below.

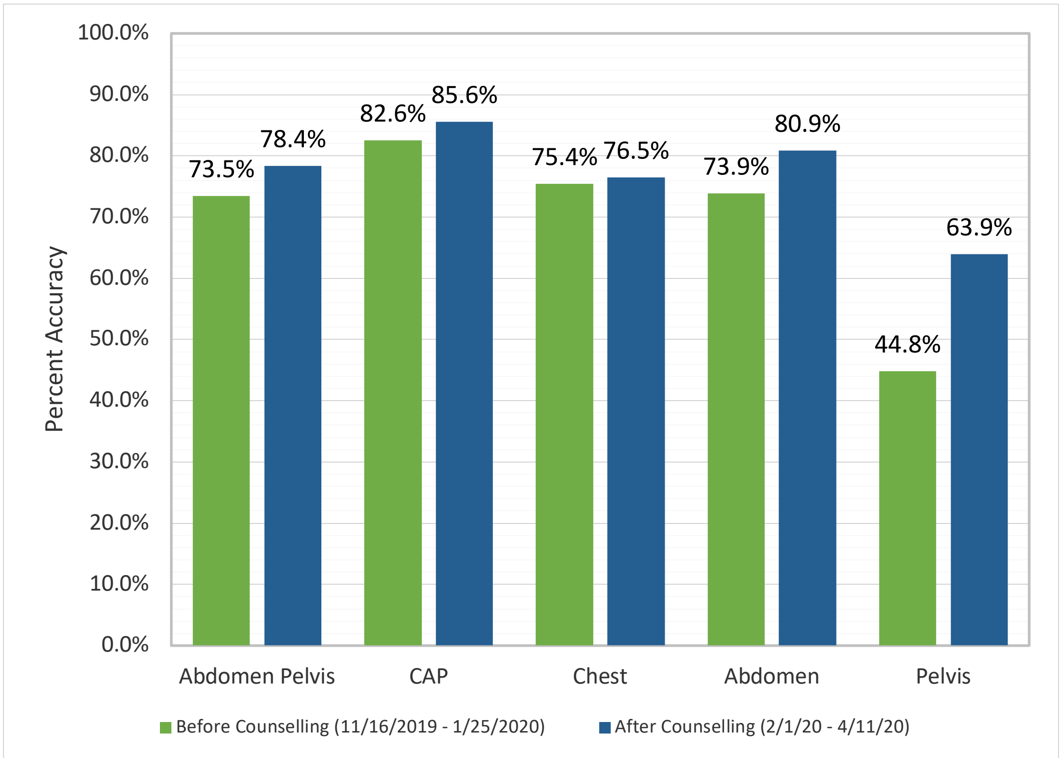


Figure 7: Top Five Protocol Categories Vertical Accuracy Before and After CT Tech Performance Reviews.

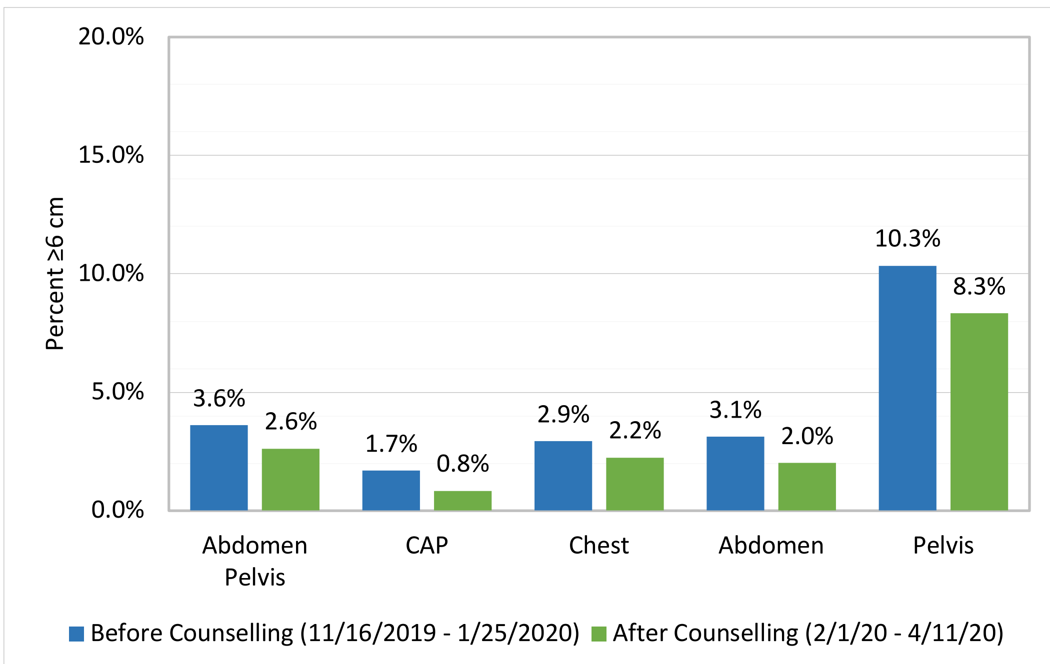


Figure 8: Top Five Protocol Categories Percent of Exams ≥ 6 cm Before and After CT Tech Performance Reviews.

4.5 PERCENT ACCURACY IN ACCORDANCE WITH CT SCANNER

The percent accuracy for each CT is shown below in figure 9. All scanners showed improvement in both categories and date ranges. CTs 3 & 6 made the most dramatic improvements, while CT5 made the smallest improvements but also had the best accuracy for both date ranges. CT3 had similar numbers for after the counselling was conducted with CT4. All CT scanner accuracies and peer rankings improved.

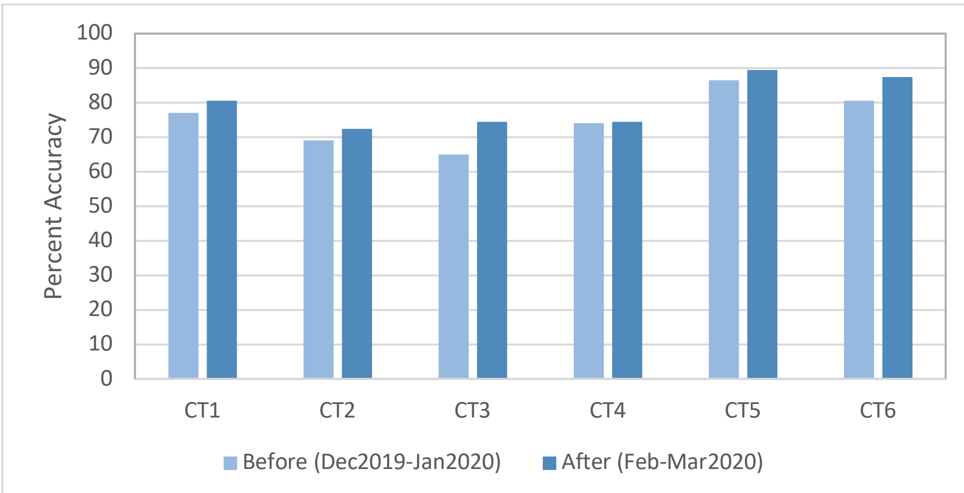


Figure 9: Percent Accuracy Changes According to CT scanner.

4.6 TECHNOLOGIST SPECIFIC RESULTS

4.6.1 INDIVIDUAL TECHNOLOGIST ACCURACY

As previously stated, there were 20 CT technologist's counselled in all. These technologists were those that were full-time CT technologists at the time counselling was conducted by the CT Supervisor. There are other technologists that perform CTs at OHSU who are not full-time CT technologists (For example, qualified technologist's performing scans during a voluntary overtime shift that normally work in another diagnostic modality). The statistics for all technologists counselled are included in table 3 below. The technologists were ordered by the number of scans they performed before the counselling was conducted. The table includes the number of scans and percentage of total scans in each accuracy category (< 3cm, ≥ 3cm but < 6cm, and ≥ 6 cm).

Another column has been added that gives a weighting factor for the before vs. after counselling scan numbers to provide a sense of how many scans a technologist did in the before versus after counselling date ranges.

Table 3: 3A. List of CT Technologists by Number of Scans, Percent Accuracies, and Scan Weighting Before Counselling. 3B. After Counselling.

A	Before Counselling (11/16/2019 - 1/25/2020)						
	Number of Scans				*Percent of Total*		
Technologist	Total scans	<3 cm	3-6 cm	≥6 cm	<3 cm	3-6 cm	≥6 cm
1	593	506	84	3	85.3%	14.2%	0.5%
2	522	407	105	10	78.0%	20.1%	1.9%
3	427	367	49	11	85.9%	11.5%	2.6%
4	413	316	88	9	76.5%	21.3%	2.2%
5	411	294	95	22	71.5%	23.1%	5.4%
6	401	344	51	6	85.8%	12.7%	1.5%
7	378	301	67	10	79.6%	17.7%	2.6%
8	293	228	55	10	77.8%	18.8%	3.4%
9	289	209	69	11	72.3%	23.9%	3.8%
10	282	203	72	7	72.0%	25.5%	2.5%
11	264	209	49	6	79.2%	18.6%	2.3%
12	231	123	77	31	53.2%	33.3%	13.4%
13	224	118	84	22	52.7%	37.5%	9.8%
14	136	84	38	14	61.8%	27.9%	10.3%
15	119	84	26	9	70.6%	21.8%	7.6%
16	73	48	25	0	65.8%	34.2%	0.0%
17	67	54	13	0	80.6%	19.4%	0.0%
18	65	48	13	4	73.8%	20.0%	6.2%
19	62	44	12	6	71.0%	19.4%	9.7%
20	15	12	3	0	80.0%	20.0%	0.0%

B	After Counselling (2/1/20 - 4/11/20)							
	Number of Scans				*Percent of Total*			*Total Scan Weighting*
Technologist	Total scans	<3 cm	3-6 cm	≥6 cm	<3 cm	3-6 cm	≥6 cm	(#Scans Before/#Scans After)
1	308	259	40	9	84.1%	13.0%	2.9%	1.93
2	299	244	47	8	81.6%	15.7%	2.7%	1.75
3	209	168	29	12	80.4%	13.9%	5.7%	2.04
4	690	539	130	21	78.1%	18.8%	3.0%	0.60
5	275	223	46	6	81.1%	16.7%	2.2%	1.49
6	290	259	30	1	89.3%	10.3%	0.3%	1.38
7	226	185	33	8	81.9%	14.6%	3.5%	1.67
8	222	165	45	12	74.3%	20.3%	5.4%	1.32
9	180	135	40	5	75.0%	22.2%	2.8%	1.61
10	263	219	39	5	83.3%	14.8%	1.9%	1.07
11	426	352	63	11	82.6%	14.8%	2.6%	0.62
12	217	145	54	18	66.8%	24.9%	8.3%	1.06
13	162	125	35	2	77.2%	21.6%	1.2%	1.38
14	163	103	41	19	63.2%	25.2%	11.7%	0.83
15	139	106	30	3	76.3%	21.6%	2.2%	0.86
16	108	71	34	3	65.7%	31.5%	2.8%	0.68
17	50	28	20	2	56.0%	40.0%	4.0%	1.34
18	140	93	41	6	66.4%	29.3%	4.3%	0.46
19	4	2	2	0	50.0%	50.0%	0.0%	15.50
20	9	8	1	0	88.9%	11.1%	0.0%	1.67

15 out of the 20 technologists counselled performed greater than 100 scans for both date ranges, before and after counselling respectively.

Vertical accuracy improved for 11 out of 15 of the same technologists. Two technologists performed less than 10 scans individually after the counselling was performed. The percent vertical accuracy for each of the technologists are provided in bar chart form below in figures 10 and 11. The figures are separated into the top and bottom 10 technologists per number of scans conducted.

Technologist's 5, 10, 12, and 13 all made accuracy improvements of greater than 10% at 10.5, 11.3, 13.6, and 24.5 percentage points each respectively. Only technologists 17 and 19 decreased by more than 10% accuracy at 24.6% and 21% decreases respectively. Both technologists completed less than 100 scans in the after counselling date range. Technologist 17 completed 50 scans and technologist 19 only 4.

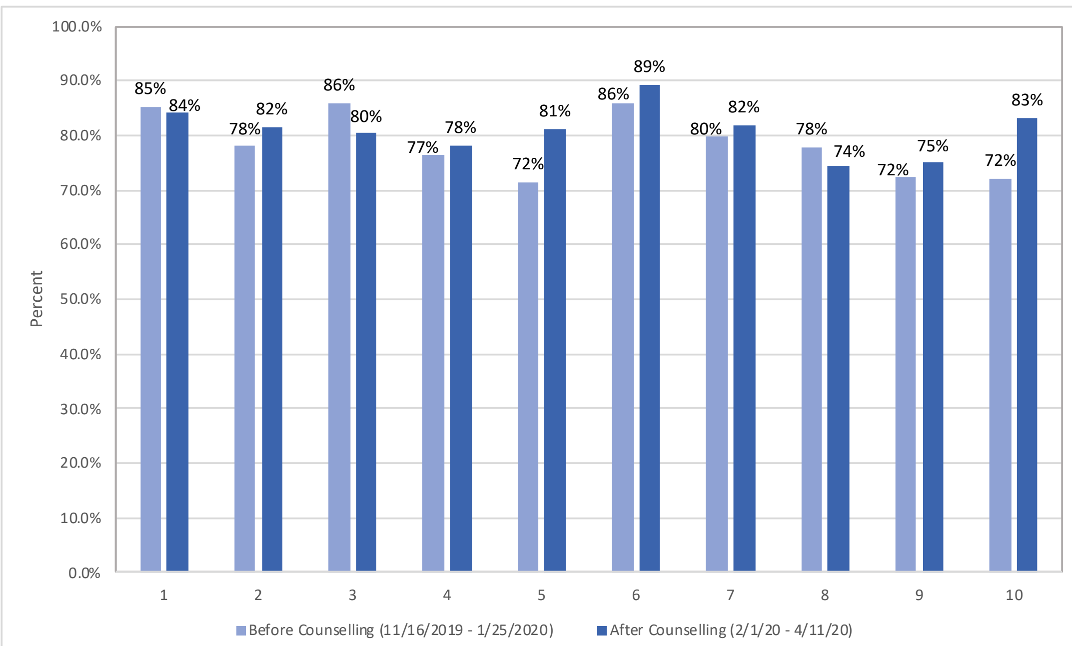


Figure 10: Percentage of Accuracy (<3cm) Before and After Individual Technologist Performance Reviews for Top 10 Technologist's by Number of Exams.

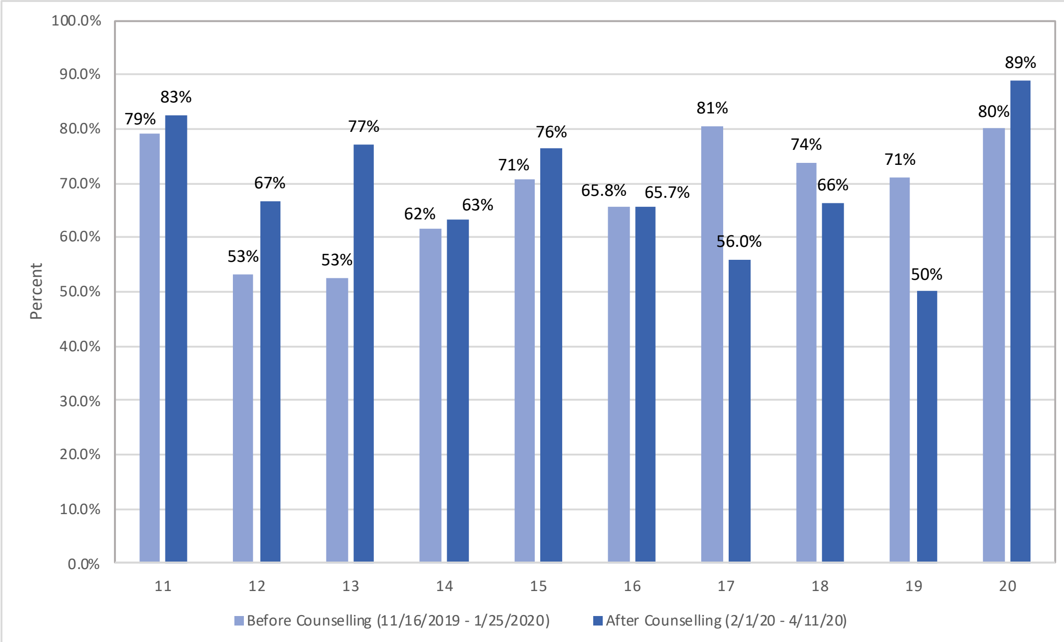


Figure 11: Percentage of Accuracy (<3cm) Before and After Individual Technologist Performance Reviews for Bottom 10 Technologist's by Number of Exams.

4.6.2 TECHNOLOGIST PERCENTAGE OF EXAMS ≥6 CM

Although the vertical accuracy improved for 11 of the 15 technologists who performed greater than 100 scans, the number of exams ≥6cm improved for only 7 out of the same 15. However, the average number of exams ≥ 6 cm as a percentage did decrease for those same 15 technologists (4.6% before and 3.8% after counselling respectively as seen in figure 13 below). Technologist's 1, 3, and 8 showed the largest (or worst) increase in the number of exams ≥ 6 cm at 2.4%, 2.1% and 2.0%, respectively. Whereas technologist's 12, 13, and 15 showed the greatest (or best) decrease in the number of exams ≥ 6 cm at 5.1%, 9.6%, and 5.4% decreases respectively. Figures 12 and 13 below show the percentage of exams ≥6cm for the top and bottom 10 technologists by the number of scans completed.

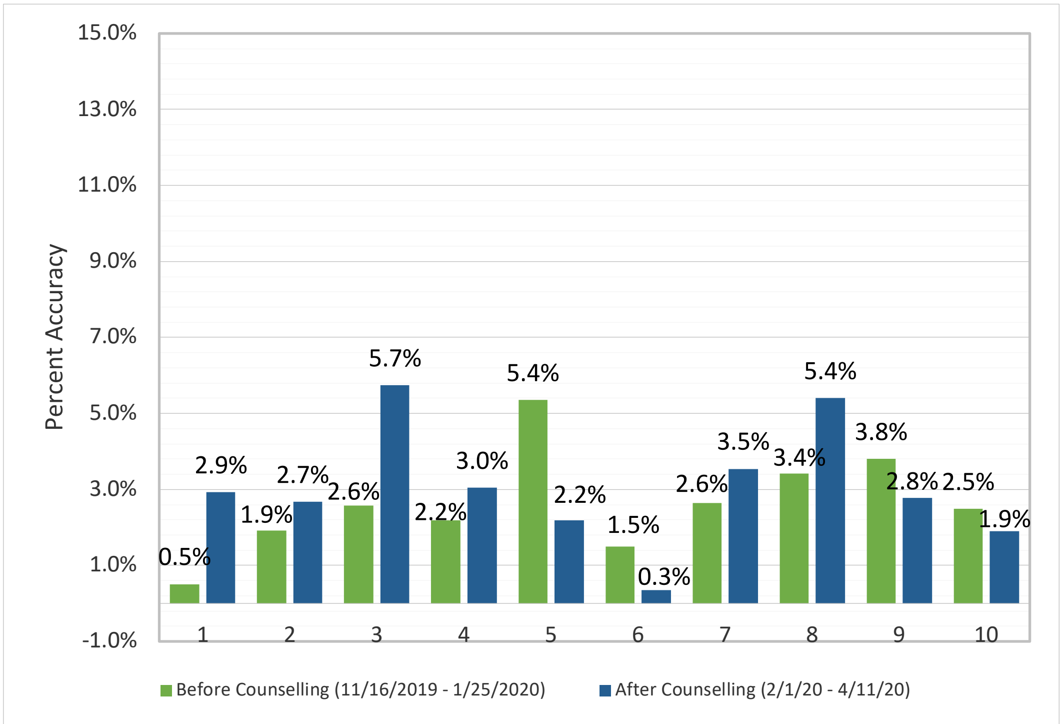


Figure 12: Percentage of Exams ≥6 cm Before and After Individual Technologist Performance Reviews for Top 10 Technologist's by Number of Exams.

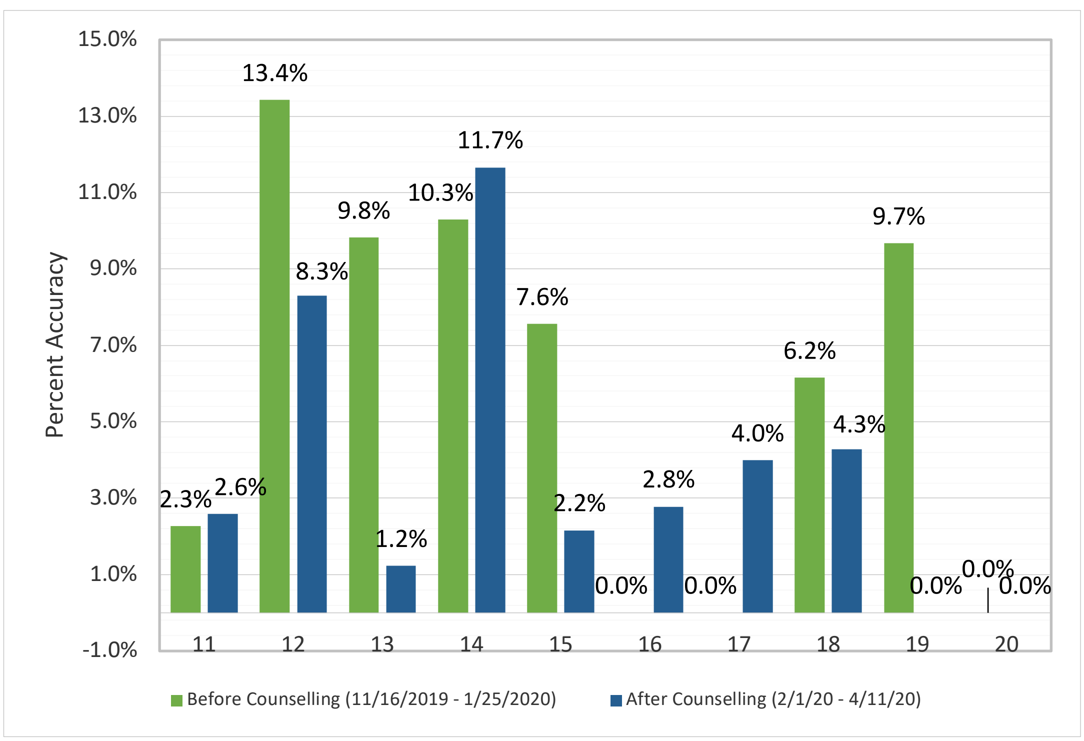


Figure 13: Percentage of Exams ≥6 cm Before and After Individual Technologist Performance Reviews for Bottom 10 Technologist's by Number of Exams.

5 DISCUSSION

5.1 CT TECHNOLOGIST PERFORMANCE REVIEW EFFICACY

Various improvements were seen in vertical alignment from before the CT technologist performance reviews were given to afterwards. These improvements include overall vertical offset, vertical offset per protocol, percent accuracy, and peer ranking when compared to other institutions that also use Imalogix^{TM}. As previously stated the change in lateral offset was very small and statistically insignificant. Also, the lateral offset was already highly accurate and improvement in lateral offset was not necessary.

The average vertical offset improved from -1.37 ± 2.28 cm before the performance reviews to -0.95 ± 2.26 after the individual technologist reviews for a 0.42 cm improvement toward isocenter. The average vertical offset for all of the top 5 protocols also improved, as seen previously in figure 7. The overall percent accuracy improved from 75% to 80% for an increase in 5% accuracy. This corresponded to a 12 percentile point increase in peer ranking. These numbers provide an overview of the performance review efficacy and indicate that the counselling conducted by the CT Supervisor was successful. The information included in the performance reviews provided an adequate snapshot in time of where each technologist's performance was and a goal for improvement. It would not have been possible to provide the appropriate information for this counselling without the use of Imalogix.

Aside from overall improvements, other aspects of vertical accuracy were analyzed. Those aspects included protocol specific accuracy for the top five protocols by number of exams, the amount of exams ≥ 6 cm in the same protocol categories, and accuracy increases by CT scanner. Individual technologist data was provided and the percentage of exams ≥ 6 cm as a number of the total exams conducted by each technologist counselled were analyzed as well. Improvements in all of these categories were realized.

When looking at the protocol specific results, figure 7 showed that the most improved protocol concerning average vertical offset was the CAP category, starting at an average offset of -0.90 cm and ending in -0.28 cm for a 0.62 cm improvement toward isocenter. The most modest improvement was for the AP and Pelvis categories. They both moved 0.39 and 0.25 cm closer to isocenter respectively.

This same correlation did not play out exactly in the same manner for the number of exams ≥ 6 cm as seen in figure 9. This figure shows that although pelvic exams had the most modest accuracy gains, the amount of exams ≥ 6 cm in pelvic exams decreased the most from 10.3% to 8.3%. It is difficult to pinpoint why the number of exams ≥ 6 cm decreased without knowing precisely what was spoken to each technologist during the individual counselling sessions, other than attributing these gains to a general heightened sense of technologist awareness after counselling. However, it is important to determine how to make improvements concerning the number of exams greater than or equal to 6 cm. As previously discussed, various studies have shown that noise in CT images can mask the presence of lesions.[10,11,12,13] Szczykutowicz et al. have shown that misalignment of only as much as 10 centimeters can cause a statistically significant change of 20 HU in CT imaging, which has been noted in a different study as the clinical threshold to adequately diagnose kidney stones.[5, 23] Also, Matsubara et al. found that the mAs can vary by 75-141% compared with gantry isocenter in the 16-MDCT scanner and 78-124% in the 64-MDCT scanner they tested from five centimeters above and five centimeters below gantry isocenter.[15]

CT scanner accuracy per scanner was also examined. All scanners showed improvement in both categories and date ranges. CTs 3 & 6 made the most dramatic improvements, while CT5 made the smallest improvements but also had the best peer ranking and accuracy for both date ranges. CT3 and CT4 ended up with similar accuracy numbers after the counselling was conducted. CT2 was close behind CT's 3 and 4, but was the worst with respect to accuracy. This could be because the technologists are more familiar as a group operating the Phillips scanners, whereas CT2 is the only Toshiba scanner among the lot. Also, CT's 2 and 4 are trauma scanners and improvements in accuracy and the number of exams ≥ 6 cm may be the most challenging due to the situations and timeliness required with emergency procedures. This is likely the reason why the most modest improvements were seen on these scanners from before and after the performance reviews.

When looking at the technologist's performance individually before and after the counselling, 11 out of 15 technologists who conducted over 100 exams made improvements in accuracy.

Only 7 of those same 15 technologists had improvements in the percentage of exams ≥ 6 cm that occurred. However, the overall average percentage of exams ≥6 cm for these technologists decreased from 4.6% to 3.8%. Also, Technologist's 5, 10, 12, and 13 all made accuracy improvements of greater than 10%. Only technologists 17 and 19 decreased by more than 10% accuracy at 24.6% and 21% respectively. Also, these two technologists only performed a small number of exams after the performance review, at 50 and 4 exams respectively. Again, the important factor here is determining how to hone in on why some technologists may have performed well, and especially finding the reason that others did not. Performing less than optimally appears to be the exception rather than the rule when looking at technologists who performed 100 or greater scans in both the before and after counselling date ranges.

5.2 STUDY LIMITATIONS

As previously stated, various studies have demonstrated either lower image quality with CT misalignment or improved image quality and dose optimization with more accurate CT alignment. The previous OHSU CT Centering QI initiative looked at dose changes and found that they were not significant or were slight enough to not be attributable to the work at hand. Therefore, the current project did not venture to look any deeper at the effects on dose because the improvement in vertical offset was close to the same for both initiatives (0.49 cm and 0.42 cm for QI project one and two respectively).

If dose were to be examined the scanner's displayed values would be utilized instead of a direct measurement of dose. Matsubara et al. noted this as a limitation in their 2009 study, but Marsh et al. indicated in a 2017 study that large discrepancies were not indicated in their phantom study between the scanner's displayed values[15, 22].

Also, other than showing that the change in lateral alignment was very small and statistically insignificant (the same as was done in the last QI initiative), lateral alignment was not looked at further due to the insignificance of the small changes that took place in both QI initiatives. Lateral alignment, in general, is known to be more accurate than vertical offset. This has been noted in at least one other study.[5]

The scope of the current project also did not include asking each individual technologist for feedback concerning their counselling experience. Asking for feedback may prove especially helpful for the few technologists that did not realize improvements because it is important to understand why this occurred. A more tailored approach to performance reviews may be helpful and/or even necessary for further refinements beyond maintaining the current improvements achieved. To this end, an in depth protocol analysis for each individual technologist was not conducted, although this may be the best option going forward to provide further CT alignment refinements. It would be especially important to look at the pelvis category because the number of exams ≥6 cm was still close to 10% (at 8.3%), even after the performance reviews were conducted.

5.3 OVERVIEW OF COMBINED OHSU CT CENTERING QI INITIATIVES VERTICAL ALIGNMENT EFFICACY

To look at the efficacy of the overall QI initiative completed at OHSU we need to take a closer look at the 2018 baseline data. During the time period from January 1, 2018 to September 10, 2018 a total of 13,632 vertical alignment data points were extracted from Imalogix and analyzed. The average vertical offset across all data points was 2.05 ± 2.45 cm below isocenter.[4]

After the brief mention of CT centering being an issue at the CT staff meeting (September 10th 2018) there were 7,908 exams in the vertical offset cohort between September 11, 2018 and February 7, 2019 that were analyzed, and 4,050 exams between February 13 and April 26, 2019 cohort once the presentation was given.[4]

Average vertical offset before the presentation was 1.70 ± 2.48 cm below isocenter; showing a 0.35 cm shift toward isocenter after the brief mention. After the presentation, the average vertical offset was closer to isocenter at 1.21 ± 2.33 cm below isocenter. A two-tailed t-test assuming equal variances showed that the decrease in distance from isocenter was 0.49 cm.[4]

There were 3,226 exams in the vertical offset before counselling cohort and 2,836 exams in the vertical offset after performance review cohort with average vertical offsets of 1.37 ± 2.28 cm and 0.95 ± 2.26 cm below isocenter respectively. A two-tailed t-test assuming equal variances showed that the decrease in distance from isocenter after counselling of 0.42 cm was highly significant ($p<0.0001$). This is a combined shift of 0.91 cm closer to isocenter after the presentation and counselling were conducted, and an approximate shift of 1.1 cm shift toward isocenter when combined with the slight improvement shown after mentioning the problem with CT centering at the staff meeting (from 2.05 cm below isocenter at the 2018 baseline to 0.95 cm below after the counselling was conducted). A combined histogram across all OHSU centering initiatives is presented below in Figure 14. Looking at the curve from the 10 week period just after the brief mention of CT misalignment being an issue (the yellow curve) and the progression from after the presentation and counselling sessions shows a slight broadening of the curve and shift to isocenter.

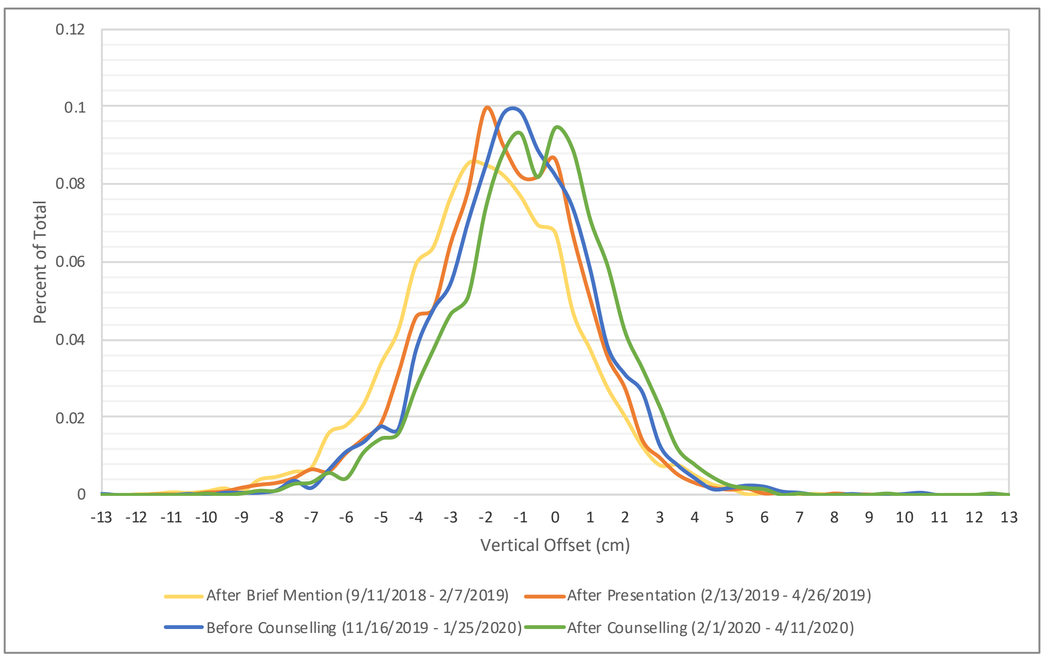


Figure 14: Percent of Total Scans Vertical Offset Histogram Across All OHSU Centering Initiatives.

Figure 15 below shows the improvements in accuracy across the entire initiative, detailing the vertical accuracy after the presentation at 75%, and after the technologist performance reviews at 80%.

This is an improvement of 14% in accuracy after the presentation and 5% after the performance reviews and a total improvement of 19% from the baseline, which started at 61%. The percent accuracy for the before counselling date range was 75% (shown in figure 6 above), which was 9 months after the educational presentation, but was still at the same percentage point as just after the presentation was given (also 75% percentage points), indicating the presentation produced long-term performance improvement results. The peer ranking also increased from the 28th percentile at baseline to the 55th percentile and 69th percentile after the presentation and counselling sessions respectively, representing an increase of 41 percentile points over the entire QI initiative in peer ranking.

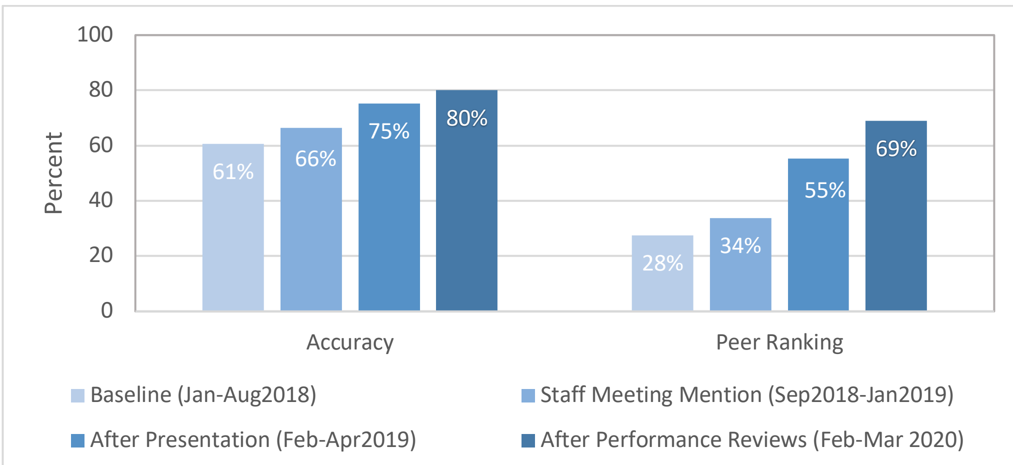


Figure 15: Percent Accuracy and Peer Ranking Increases across all OHSU QI initiatives.

6 SUMMARY AND CONCLUSIONS

6.1 FUTURE DIRECTIONS

One of the most important aspects that needs to be examined in any future OHSU centering initiatives is get the technologist's feedback concerning their counselling experience (and/or looking at the notes provided by the CT Supervisor during the counselling sessions), the current initiative did not look more specifically at the possible reasons why some technologists and/or protocols did not realize better improvements in the number of exams ≥ 6 cm and/or accuracy.

OHSU did provide valuable training concerning specific alignment techniques tailored to protocols previously in the medical physicist provided CT centering presentation, but it would be valuable to determine if renewed training efforts are necessary and/or further protocol analysis would be warranted on a technologist by technologist basis. Especially to determine if the number of exams $\geq$ 6 cm can be consistently reduced. A deeper look at each individual technologist's performance by protocol could be conducted looking more specifically at protocols that they may have struggled with. The current research did list areas of greatest opportunity for improvement, but that was based mostly on the protocols that could be improved upon to increase accuracy percentages.

In the future, it would be important to look at protocols where more exams were conducted equal to or beyond 6cm to see if improvements in those protocols/type of exams can be realized.

Szczykutowicz et al. referenced in their study on the effects of CT misalignment on the Hounsfield Unit (CT number) that the difference in alignment according to a patient's geometric center of mass vs. their attenuation center of mass can make a difference in image quality. This subtle difference may be beyond the scope of broadly improving the performance of technologist's general centering performance because this is not a factor in all exam types. But understanding this phenomena does provide some insight into some less often seen effects on image quality. For instance, Szczykutowicz et al. showed this negative effect on a CT image from virtual colonoscopy examination performed with a patient in decubitus position where gas-filled bowel pushed the center of attenuation for patient further from geometric center. Moderate streaking noise artifact was observed in posterior region of this exam.[5]

There are also complexities that exist between the CT scanner's perceived isocenter and how a scanner's algorithm determines what the "true" isocenter is perceived to be that have to do with the geometric vs. attenuation isocenter (e.g. how does each scanner determine the true isocenter?). Is the isocenter as determined by the scanner's algorithm calculated geometrically or based off the attenuation isocenter? Will this affect the scanner's performance and/or the algorithm that determines if a technologist has centered a patient correctly? A precise answer to this question was beyond the scope of this current research, but is an interesting question to entertain.

Especially in light of other factors mentioned in the background such as magnification and minification effects in the scout image and the fact that the scanner generally bases its evaluation of where the isocenter is from the scout image. But what if the scout image is inaccurate? These factors may focus too much on the minutia of CT centering details, but a thorough understanding of these complexities and their interworking may also prove fruitful.

Concerning the generation of the CT technologist annual CT centering performance review template, the OHSU minimum accuracy goal during the annual technologist centering performance reviews was originally set at 85%. This does not seem like much of a problem, other than attempting to achieve high standards (some may say too high), but this 85% goal does not take into account whether or not the accuracy being obtained at other institutions (and calculated by Imalogix) included scanners that used automated centering technology. It is therefore not certain that the OHSU goal of 85% accuracy (which corresponded to the 80th percentile peer ranking at the time of report generation) is truly obtainable without the use of automated centering technology. After all, it is hard to compete with the scanner's own algorithm. Without determining the precise facts concerning this it is possible the 85% goal was utterly unattainable. Setting an unattainable goal could obviously prove to be highly counterproductive. For example, if 10% of the accuracy making up the top percentile of the peer ranking statistic is an automated centering technology, OHSU was effectively asking their technologist's to be in the 95th accuracy percentile of all technologist's using Imalogix. Of course, this would be an outstanding feet, albeit impractical to ask anyone to perform consistently at this level. After a few counselling sessions one may begin to wonder what the point is if they can never achieve the goal that is set before them. It should be noted though that the type script of this 85% goal was very small on the annual CT centering performance reviews, and any oversights with respect to this topic was thereby solely the error of the creator of the template (and author of this paper).

6.2 CONCLUSIONS

The efficacy of OHSU's QI initiatives have been successful. Both initiatives showed a 0.49 cm and 0.42 cm improvement in average vertical offset for the presentation and individual technologist performance reviews respectively. This is a 0.91 cm improvement in average vertical offset across both QI initiatives and slightly better when considering the effect of the brief mention.

The evidence also seems to indicate that the initial technologist centering presentation was even effective in providing long term results. Figures 6 and 12 above indicate that the technologists were performing consistently almost a year after the presentation as seen by the same percent accuracy being maintained at 75%. This type of long-term positive effect is likely a change that any organization would be very proud of.

The entire CT Centering QI initiative thus far has shown a 19% increase in accuracy from the before counselling vs. 2018 baseline data (80% and 61% respectively). The performance reviews themselves showed a 5% improvement from the before counselling data set. The fact that the counselling sessions also proved to be effective indicate that annual or even semi-annual performance reviews would prove to keep centering performance at an optimal level and would likely provide even further improvements.

Although 100% accuracy is not achievable, this study showed that CT centering accuracy can be improved upon and the number of exams ≥ 6 cm reduced through the use of current radiology-based informatics software, medical physicist provided specialized training, and technologist centric performance reviews. Further effort is warranted in fine-tuning future QI initiatives to realize more CT centering efficiencies and help ensure the best quality control in CT patient care.

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