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Respiratory Biofeedback during CT-guided Procedures

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Abstract

PURPOSE—Respiratory motion can be a complicating factor during image-guided interventions. The ability to reproduce breath-holds may facilitate safer needle-based procedures. The purpose of this study was to evaluate if respiratory biofeedback decreased variability among breath-holds and if the signals from the respiratory bellows belt can be used to measure target motion.

MATERIALS AND METHODS—In phase 1 of the study, a respiratory bellows belt was applied to patients before image-guided interventional procedures. Belt stretch from respiratory motion was converted into voltage readings and displayed on a monitor as biofeedback. Patients were asked to perform inspiratory, expiratory, and midcycle breath-holds with and without the biofeedback. The variability in voltage readings between breath-holds with and without biofeedback was compared. In phase 2, the respiratory bellows belt was used during computed tomography (CT)–guided procedures with the patients blinded to the biofeedback. Voltage readings and CT series numbers were recorded as patients were asked to hold their breath during scans. The variability of CT z-axis targets was compared with the variability of voltage readings.

RESULTS—A significant decrease in variability was found during expiratory breath-holds ($P = .0083$) with trends toward significance with midcycle and inspiratory breath-holds. A positive correlation (Kendall $\tau = 0.5$; $P = .024$) was shown between CT z-axis and belt stretch variability in subjects who received smaller doses of moderate sedation compared with those who received larger doses or general anesthesia.

CONCLUSIONS—Biofeedback may help the patient to have a more consistent breath-hold. The belt could decrease the error and unpredictability from craniocaudal motion of targets during image-guided interventions.

PATIENT respiratory motion can be a complicating factor when targeting a tumor for computed tomography (CT)–guided interventional procedures. Respiration-induced motion during the normal breathing cycle can result in significant shifts in tumor position, especially near the diaphragm, in the lung and abdomen (1). Consistent and reproducible breath-holds could reduce procedure time and the number of needle manipulations, promoting a safer procedure. Without a documented measure of their breath-hold position in the respiratory cycle, the patient cannot be expected to precisely reproduce similar pre- and intraprocedural breath-holds. The air bellows belt measures chest wall or abdomen excursion and provides patients with visual biofeedback during their respiratory cycle.

MATERIALS AND METHODS

In the present study, a tool consisting of an air bellows belt (Philips Medical Systems, Cleveland, OH) attached to a visual feedback system shown to patients was evaluated for its ability to assist patients to more precisely reproduce preprocedural breath-holds at deep inspiration, deep expiration, and mid-breath-hold. This type of tool is currently commercially available for use in gating magnetic resonance imaging and radiation oncology but not during CT-guided procedures. Correlation of CT anatomy motion with belt motion during actual CT-guided biopsies was also performed.

Monitoring patient respiratory motion was accomplished through the use of a flexible, nonconstrictive air bellows belt that was wrapped around the patient's abdomen (Fig 1). Expansions and contractions of the belt length caused by patient inspiration and expiration resulted in pressure changes within the belt, which were transduced as a voltage reading. The generated signal was graphed and displayed on a monitor in real time (Fig 2).

Patient Population

Data were collected from nine men and seven women with a mean age of 53 years (range, 28–79 y) who required an image-guided procedure (Table 1). Patients younger than 18 years of age, with altered mental status, or who could not hold their breath for more than 5 seconds were excluded from the study. This was an institutional review board–approved protocol and all subjects provided written informed consent after consultation with the research team.

Study Design

The study consisted of two phases. Phase 1 was a crossover study design before the image-guided procedures. Phase 2 involved a different cohort of patients and took place during CT-guided procedures. The first phase examined how closely patients ($N = 10$) could reproduce the same point in their respiratory cycle with and without biofeedback.

While wearing the respiratory belt across their chest or abdomen, the subjects were asked to perform a breath-hold at full inspiration, full exhalation, and midcycle without biofeedback. This was repeated three times per breath-hold location with time for normalization of breathing in between breath-holds. The subjects were then asked to perform the same three breath-hold levels while being shown a visual representation of their breathing cycle and the stop points of their previous breath hold. This level was preselected by the researcher on the graphical user interface by placing a translucent target box over the breath-hold level location (Fig 2). All belts were placed at the lower rib cage near the thoracoabdominal junction. Belt stretch voltage was recorded with each breath-hold. Eighteen voltage readings were collected from each subject (three inspiratory, three expiratory, and three midcycle with and without biofeedback). Comparisons were made between voltage readings with and without feedback within a breathing level group (ie, inspiratory, expiratory, midcycle). The outcome measure was the standard error of the mean (SEM) of the three belt voltage readings in each breathing level group.

In phase 2, data were collected from six subjects during procedures guided with CT (MX-8000; Philips Medical Systems). Sixteen–detector row CT scans were obtained with 3-mm collimation with 50% overlap. The belt was placed at the thoracoabdominal junction or above or below the sterile field if it involved the thoracoabdominal junction. The patients wore the respiratory belt during their procedures but were blinded to the monitor. The patients were asked to hold their breath during the first CT scan, which was done immediately before the procedure. If the patient was under general anesthesia ($n = 2$), the anesthesiologist was asked to stop ventilation during CT scans. Patients under moderate sedation ($n = 4$) were asked to

hold their breath during subsequent CT scans done to confirm needle position or exclude complications such as bleeding or pneumothorax. The intended needle entry point was marked. The area was sterilized, and intravenous sedation and local anesthesia were given. The procedure occurred in the standard fashion. CT scan series number and voltage readings were recorded with each breath-hold. The outcome measures were the voltage readings and CT z-axis position of nearby anatomy or target during each breath hold. CT target positions in the z-axis were documented retrospectively (Table 2). Target positions were documented in one of three ways: taking the axial image that showed the largest target diameter (and thereby estimated craniocaudal center point) at each breath-hold, following a consistently observable part of a target at each breath hold such as an area of calcification, or following the tip of nearby spleen or kidney.

Statistical Methods

Statistical calculations were performed with Stata software (version 9; Stata, College Station, TX). In phase 1 of the study, one-sided paired *t* tests were performed on the null hypothesis that the mean variabilities (as reflected in the SEM of the means of the triplicate readings) were the same with and without biofeedback. A *P* value less than .05 was considered significant.

In phase 2, the data did not meet the assumptions for parametric analysis. Therefore, the Kendall τ test was used as a nonparametric test of correlation between belt stretch (ie, voltage) and z-axis. The change in voltage and the change in z-axis (or craniocaudal movement at a specific point on the CT scan) between scans were calculated for each patient individually. Plots for each subject were created comparing change in voltage and change in z-axis (Fig 3). Kendall τ was used to test (i) the null hypothesis that change in voltage and change in z-axis were independent and (ii) the strength of any correlation for each patient ($n = 6$), for the abdominal procedures alone ($n = 5$) and with and without subject 11 ($n = 5$). To further evaluate the relationship between belt stretch and z-axis, a nonparametric linear regression was performed with StatsDirect (version 2.6.2; StatsDirect, Cheshire, UK). The slope of the regression line was then interpreted as the median change in z-axis.

RESULTS

In phase 1 of the study, the *P* values for inspiratory, expiratory, and mid–breath-hold were .0693, .0083, and .0530, respectively. This led to rejection of the null hypothesis and the conclusion that the mean variabilities were smaller with biofeedback in the expiratory phase. There were also trends toward significance in inspiration and midcycle. Although the data were statistically significant only for the expiratory phase, the raw data showed that 10 of 10 subjects had less variability with biofeedback during the inspiratory and expiratory breath-holds, as did eight of 10 subjects during mid–breath-hold (Fig 4).

In phase 2, when analyzing the data from individual subjects, none were statistically significant (Table 2). When evaluating the plots of each subject's data in phase 2, it appeared that the largest difference between change in voltage and change in z-axis was with subject 11 (Fig 3). This subject had the largest dose of moderate sedation (Table 2). Analyzing the abdominal data alone or excluding subject 11 led to rejection of the null hypothesis and was statistically significant (Kendall τ [positive correlation] = 0.3; $P = .0479$ and $P = .0198$, respectively). In addition, the two subjects who received general anesthesia showed no correlation between belt stretch and z-axis. When these two subjects and subject 11 were omitted from analysis, a Kendall τ value of 0.5 ($P = .024$) was seen for the remaining data. Therefore, belt stretch voltage and target z-axis were positively associated during abdominal interventions or when subjects received a lower dose of moderate sedation. There was also a trend toward significance with

all patients included ($P = .0554$). Table 2 shows how doses of sedation affected correlation between belt stretch and target z-axis.

A nonparametric linear regression was then performed with all subjects and again without subjects 11, 13, and 16. The median slope with all data ($N = 27$) was 4.8 mm (95% CI, 0–22.7 mm). The median slope without subjects 11, 13, and 16 ($n = 13$) was 21 mm (95% CI, 0–37.5 mm) according to linear regression. For each 0.06 voltage points, the z-axis changes a median of 21 mm when the subjects received lower doses of moderate sedation.

DISCUSSION

During CT-guided interventions such as biopsy or ablation, standard techniques include a preprocedural CT scan. The patient is asked to stop breathing during the scan. The patient is again asked to hold his or her breath at the previous breath-hold level while the physician advances the needle toward the target. Repeat CT scans are taken to verify the needle tip position during the procedure. Because the needle is not monitored continuously, it is important that the two breath-holds coincide with the same point in the patient's respiratory phase. This helps ensure the target is in the same place during needle advancement. Other than patient coaching, no technology to facilitate this process is in common use. Use of a respiratory bellows belt during these interventions helps accomplish this goal.

The belt's measurements are based on chest wall or abdomen excursion. It is an assumption that external skin motion will have some definable relationship to internal motion. The correlation of belt stretch to target z-axis was evaluated in clinical subjects. The limited data in this study showed a positive albeit weak (0.3) correlation between belt stretch and z-axis. In addition, z-axis variability based on belt stretch voltage of 21 mm per 0.06 voltage points shows that the z-axis cannot be accurately ascertained from belt stretch voltage in clinical patients. This result contradicts previous phantom work that showed z-axis variation of 1.5–5.6 mm when predicted from belt stretch (2). Unlike our study, this recent similar study was conducted only on phantoms. In addition, end expiratory phase breath-holds were shown to be most reproducible, which has also been shown in previous work (3).

The amount of sedatives received alters the correlation between z-axis and belt stretch. As seen in Figure 3, subject 11 appeared to have the most variability between belt stretch and zaxis and also received the largest dose of moderate sedation. Also, the results show that controlled ventilation during conscious sedation confounds correlation between belt stretch and zaxis.

Reports from previous studies have shown that liver motion is complex. Respiration-induced craniocaudal, lateral, and anteroposterior motions have been observed (1). Motion in the craniocaudal direction is the most significant of the three, with translations of the liver ranging from 10 to 26 mm during quiet respiration and larger translations, as much as 55–60 mm, seen during deep respiration (1,4). In addition, Shirato et al (5) reported anteroposterior motions ranging from 4 to 8 mm, along with motions of 5–9 mm in the lateral axis. Clearly this depends on the tissue and organ location. Even within an organ, the motion can be quite complex, such as in the lung, with radial expansion from the hilum occurring simultaneous to diaphragmatic motion. Organs can deform during needle manipulations as well.

Previous studies have analyzed the correlation between respiratory motion and external respiratory signals like skin markers, flow meters, and respiratory belts (6–9). Respiratory motion compensation has also been intensively studied, especially for radiation therapy procedures (10,11).

Carlson et al (2) reported a system for breath-hold monitoring and feedback. The system detects and displays the respiratory phase with use of a bellows system. Reliability and feasibility of

the system was evaluated in phantoms and normal volunteers. In addition, they looked at multiple outcome measures such as patient cooperation, number of needle puncture attempts, and radiation exposure in seven patients during CT fluoroscopy– guided biopsies of the lung and upper abdominal procedures. The system was subsequently evaluated in a randomized controlled clinical trial (12). The study evaluated the efficacy of a breath-hold monitoring and feedback system for lung and upper abdominal biopsies. Fluoroscopy time, needle puncture attempts, and pneumothoraces were significantly decreased in procedures in which feedback was given.

Previous studies have used alternative methods of measuring or gating breathing motion, such as strain gauge determination of abdominal circumference, spirometric measurement of lung volume, and optical tracking of markers, to monitor the respiratory cycles of patients (6–9). Strain gauges make use of an elastic belt that stretches according to abdominal motion. However, the instruments for this technique are harder to manufacture and handle than the air bellows belt. Compensation for signal fluctuations may also be needed.

Spirometric measurements of airflow rate and lung volume may be accurate. This method requires the patient to breathe through a mouthpiece and have the nose clamped. This method of measurement not only may cause patient discomfort, but there is also the possibility of significant abdominal movement with no mouth or nasal airflow. This movement could translate into target movement.

Optical tracking makes use of a mounted infrared camera that monitors the motion of a reflective marker box placed on the patient's abdomen. Placement of the marker box can be difficult. It is required to be parallel to the treatment table and have a direct line of sight to the camera without intervening structures. Patient motion can displace the marker box during a procedure. Uniform placement on all patients cannot be guaranteed as a result of the natural contours of the abdomen.

Several approaches have been proposed to compensate for respiratory motion such as breath-holding, respiratory gating, and real-time tumor tracking. Breath-holding is commonly employed in needle-based interventions. The patient is instructed to hold his or her breath during the needle insertion to emulate a static target. However, the breath-hold level is not always reproducible (13). One approach to control breath-hold level is to use a device to control patient breathing. The patient breathes through a mouthpiece tube that can be closed at the desired moment (14,15). Although these systems provide a way to impose a breath-hold at a chosen point, they may not be suited for all patients. A second approach is to provide the patients with feedback on their respiratory stage and instruct them to voluntarily hold their breath at the desired respiratory phase.

Another system for respiratory level feedback was developed by Nelson et al (16), who proposed a feedback- guided breath-hold system to be used in radiation therapy. The respiratory cycle was monitored with a realtime position management system (RPM; Varian Medical Systems, Palo Alto, Calif). The respiratory signal was displayed for the patient together with the gating window. When the respiratory signal was in the gating window, the radiation beam was activated. The display of the respiratory trace provided the patients with respiratory phase feedback, allowing them to potentially achieve more repeatable breath-hold levels.

A respiratory gating system has been used for CT-guided needle biopsy of small pulmonary nodules (8). Breathing was monitored with use of a spirometer. A light signal turned on when the breathing stage was beyond a threshold level. The patients were instructed to hold their breath when the light was on, thereby allowing patients to have a more reproducible breath-hold.

In one study (10), the potential benefits of gated dose delivery methods were investigated during intensitymodulated radiation therapy. Irradiation without gating led to significant underdosages by as much as 33%. Gating made it possible to reduce this underdosage to 9% but increased treatment time by 20%–100% (10). The benefit of this device is that it has the potential to prolong beam-on time by increasing the duty cycle (11).

The air bellows belt has also been used in respiration-gated radiation therapy of tumors (17). The belt monitored patient breathing and allowed for the delivery of radiation doses during time points synchronous with a desired point in the patient respiratory cycle. The goal was to minimize underdosage in the tumor and overdosage in the surrounding normal tissue. Treatment time can be minimized if the patient is able to reproduce breath-holds with the assistance of the air bellows belt.

The respiratory belt can also be used for multiphasic reconstructions for radiation therapy planning. The belt can be used to record the respiratory signal of the patient during the acquisition of the CT images. After the scan, the source data and respiratory signal can be used to retrospectively reconstruct the images. This results in several three-dimensional image volumes that correspond to different phases of the respiratory cycle (17).

Continuous CT fluoroscopy can be used for real-time imaging of the target and needles. However, greater radiation exposures for the patient and operator are present. The operator is also required to use a device to hold the needle, which diminishes tactile feedback during needle manipulation. Intermittent CT fluoroscopy can be used to help reduce radiation exposure and is usually the preferred method, but it is not real-time imaging.

Respiratory motion can also interfere with the fusion of positron emission tomography and CT images. Respiratory motion results in attenuation and image blurring artifacts. If the patient's respiratory cycle was monitored during both scans, it could be possible to retrospectively gate the scans to fuse matching images. This information could also be used to adjust the positron emission tomography scan raw data to correct the motion and more accurately reflect the corresponding location of signal.

Integrated interventional systems with electromagnetic sensors on the skin and inside needle tips may also provide a simple solution to this complex problem of dynamic motion compensation (18). Currently, studies of electromagnetic tracking of respiratory motion are under way at our institution. The use of skin trackers that move with breathing may be a more robust and accurate method of dynamic motion compensation than belt use, but they have not been directly compared (18).

Earlier works have focused on employing visual respiratory biofeedback in radiation therapy interventions. The use of visual respiratory biofeedback during CT-guided interventions has been less investigated. Respiratory biofeedback with an external belt can improve a patient's ability to hold his/ her breath at reproducible breath levels, which could translate into safer and more accurate procedures with the potential for less radiation exposure.

The major limitations of this study should be clarified. Craniocaudal accuracy was limited by source data image acquisition with 3-mm collimation and 50% overlap. Volume averaging can be a major limitation in selecting the exact same point on the craniocaudal axis in different scan series. A larger sample size may have given the study more statistical power to detect a difference between groups. Also, we did not control for the learning process that may have occurred from repeated breath-holds, which could have contributed to some of the decrease in variability in phase 1 of the study. The equipment was not calibrated between patients and the variability in sizes of the subjects' abdomens may have altered the true variability.

The data from phase 1 illustrated that biofeedback reduces the variability when patients reproduced specific levels of breath-hold. Phase 2 examined if the level of graphed respiration from the belt correlated with the target position on CT. The positive correlation measured between the change in z-axis and belt stretch showed that the signals from the respiratory belt can be used to measure target motion, although with a large range of variability. This suggests that biofeedback may help the patient to have a more consistent breath-hold, and that this could decrease the error and unpredictability from craniocaudal motion of targets. Future studies could compare standard techniques without the belt versus techniques involving the belt during procedures. It is possible that focusing on the belt tasks distracts the patient from perceived pain, although this is speculative. However, more studies with larger sample sizes are needed.

The role of respiratory feedback for interventional radiology procedures has not been well studied. Although biofeedback helps patients reproduce breath-holds, it is difficult to accurately predict target tissue motion from the belt. Consistent and reproducible breath-holds could translate to safer and more accurate procedures. Although speculative, reduction in procedure time may lead to the potential for less radiation exposure. Fewer needle manipulations may reduce the possibility of complications such as injury to nontargeted tissue. Future prospective studies are needed to analyze physicians' use of the feedback to appropriately time a needle manipulation and assess patient perception during procedures. Whether the benefit will justify the additional time and effort remains to be seen.

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References

1. Clifford MA, Banovac F, Levy E, Cleary K. Assessment of hepatic motion secondary to respiration for computer assisted interventions. *Comput Aided Surg* 2002;7:291–299. [PubMed: 12582982]
2. Carlson SK, Felmlee JP, Bender CE, et al. Intermittent-mode CT fluoroscopy-guided biopsy of the lung or upper abdomen with breath-hold monitoring and feedback: system development and feasibility. *Radiology* 2003;229:906–912. [PubMed: 14657321]
3. Minohara S, Kanai T, Endo M, Noda K, Kanazawa M. Respiratory gated irradiation system for heavy-ion radiotherapy. *Int J Radiat Oncol Biol Phys* 2000;47:1097–1103. [PubMed: 10863083]
4. Suramo I, Paivansalo M, Myllyla V. Cranio-caudal movements of the liver, pancreas and kidneys in respiration. *Acta Radiol Diagn (Stockh)* 1984;25:129–131. [PubMed: 6731017]
5. Shirato H, Seppenwoolde Y, Kitamura K, Onimura R, Shimizu S. Intrafractional tumor motion: lung and liver. *Semin Radiat Oncol* 2004;14:10–18. [PubMed: 14752729]
6. Berson AM, Emery R, Rodriguez L, et al. Clinical experience using respiratory gated radiation therapy: comparison of free-breathing and breath-hold techniques. *Int J Radiat Oncol Biol Phys* 2004;60:419–426. [PubMed: 15380575]
7. Riviere, CN.; Thakral, A.; Iordachita, IL.; Mitroi, G.; Stoianovici, D. Predicting respiratory motion for active canceling during percutaneous needle insertion; From the 2001 Proceedings of the 23rd Annual EMBS International Congress; Istanbul, Turkey. October 25–28; (Available at <http://ieeexplore.ieee.org/ie15/7934/21932/01019580.pdf?isNumber=>) Accessed April 19, 2007.
8. Tomiyama N, Mihara N, Maeda M, et al. CT-guided needle biopsy of small pulmonary nodules: value of respiratory gating. *Radiology* 2000;217:907–910. [PubMed: 11110962]
9. Wink N, Panknin C, Solberg TD. Phase versus amplitude sorting of 4D-CT data. *J Appl Clin Med Phys* 2006;7:77–85. [PubMed: 16518319]
10. Dietrich L, Tucking T, Nill S, Oelfke U. Compensation for respiratory motion by gated radiotherapy: an experimental study. *Phys Med Biol* 2005;50:2405–2414. [PubMed: 15876675]

11. Takeda A, Kunieda E, Shigematsu N, et al. Small lung tumors: long-scan-time CT for planning of hypofractionated stereotactic radiation therapy-initial findings. *Radiology* 2005;237:295–300. [PubMed: 16118151]
12. Carlson SK, Felmlee JP, Bender CE, et al. CT fluoroscopy-guided biopsy of the lung or upper abdomen with a breath-hold monitoring and feedback system: a prospective randomized controlled clinical trial. *Radiology* 2005;237:701–708. [PubMed: 16244278]
13. Plathow C, Ley S, Zaporozhan J, et al. Assessment of reproducibility and stability of different breath-hold maneuvers by dynamic MRI: comparison between healthy adults and patients with pulmonary hypertension. *Eur Radiol* 2006;16:173–179. [PubMed: 15968516]
14. Wong JW, Sharpe MB, Jaffray DA, et al. The use of active breathing control(ABC) to reduce margin for breathing-motion. *Int J Radiat Oncol Biol Phys* 1999;44:911–919. [PubMed: 10386650]
15. Dawson LA, Brock KK, Kazanjian S, et al. The reproducibility of organ position using active breathing control(ABC) during liver radiotherapy. *Int J Radiat Oncol Biol Phys* 2001;51:1410–1421. [PubMed: 11728702]
16. Nelson C, Starkschall G, Balter P, et al. Respiration-correlated treatment delivery using feedback-guided breath-hold: a technical study. *Med Phys* 2005;32:175–181. [PubMed: 15719968]
17. Klahr P, Subramanian P, Yanof JH. Respiratory-correlated multislice CT for radiation therapy planning: imaging and visualization methods. *Medi camundi* 2005;49:2–5.
18. Borgert J, Kruger S, Timinger H, et al. Respiratory motion compensation with tracked internal and external sensors during CT-guided procedures. *Comput Aided Surg* 2006;11:119–125. [PubMed: 16829505]

Figure 1. Flexible air bellows belt. Accordion-type tube placed on or near the thoracoabdominal junction. The Velcro strap was wrapped around the patient and secured. The small tube was attached to the interface box and the signal was converted to a voltage reading displayed on the monitor.

Figure 2.

Visual biofeedback shown to the patient on a monitor. Respiratory variation was noted as waves on the screen. **(a)** The ball moves with respiratory variation and corresponds to the waveform. **(b)** The box was placed at the desired level. The patient was asked to hold his/her breath at the level where the ball was in the box. The voltage reading noted on the right side of the monitor was recorded.

Figure 3. Phase 2 data comparing belt stretch with craniocaudal target tissue movement, plotted for each subject individually. Subject 11 received large doses of sedation (7 mg midazolam and 400 μ g fentanyl) during the procedure and had the greatest differences between belt stretch and z-axis.

Figure 4. Phase 1 raw data: SEM of the triplicate readings by patient with and without visual feedback during breath holds. There is a trend toward more reproducible breath-holds in all phases of the respiratory cycle. (Available in color at www.jvir.org.)

Table 1**Study Subjects' Diagnoses and Procedures**

Study Subject	Diagnosis	Procedure	Study Phase
1	Renal cell carcinoma	Adrenal mass biopsy	1
2	Lymphoma	Inguinal node biopsy	1
3	Prostate carcinoma	Supraclavicular lymph node biopsy	1
4	Prostate carcinoma	Adrenal biopsy	1
5	Myelodysplastic syndrome	Central catheter placement	1
6	Ocular melanoma	Liver biopsy	1
7	Hepatitis C, HIV	Liver biopsy	1
8	Hepatitis C, HIV	Liver biopsy	1
9	Non-small-cell lung cancer	Lung biopsy	1
10	Breast carcinoma	Splenic mass biopsy	1
11	Multiple endocrine neoplasia	Liver biopsy	2
12	Pancreatic carcinoma	Celiac block	2
13	Chronic granulomatous disease	Lung biopsy	2
14	Renal cell carcinoma	Retroperitoneal mass biopsy	2
15	Lymphoma	Retroperitoneal biopsy	2
16	Pancreatic carcinoma	Celiac block	2

Table 2

Phase 2 Procedures and CT Z-axis Location

Study ID	Procedure	Z-axis Location	Sedation (mg Midazolam/ µg Fentanyl)	Kendall τ / P Value
11	Liver biopsy	Superior right kidney tip	7/400	0.3/.5458
12	Celiac block	Calcium in spleen	2/100	0.5/.3122
13	Lung biopsy	Calcium in pulmonary blood vessel	General anesthesia	0.0/1.0
14	Retroperitoneal mass biopsy	Retroperitoneal tumor	3.5/175	0.8/.2453
15	Retroperitoneal mass biopsy	Nephrostomy tube segments	1/50	1.0/.2963
16	Celiac block	Inferior spleen tip	General anesthesia	0.0/1.0