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Toward Frameless Maskless SRS Through Real-Time 6DOF Robotic Motion Compensation

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Abstract

Purpose—Stereotactic radiosurgery (SRS) uses precise dose placement to treat conditions of the CNS. Frame-based SRS uses a metal head ring fixed to the patient's skull to provide high treatment accuracy, but patient comfort and clinical workflow may suffer. Frameless SRS, while potentially more convenient, may increase uncertainty of treatment accuracy and be physiologically confining to some patients. By incorporating highly precise robotics and advanced software algorithms into frameless treatments, we present a novel frameless and maskless SRS system where a robot provides real-time 6DOF head motion stabilization allowing positional accuracies to match or exceed those of traditional frame-based SRS.

Methods—A 6DOF parallel kinematics robot was developed and integrated with a real-time infrared camera in a closed loop configuration. A novel compensation algorithm was developed based on an iterative closest-path correction approach. The robotic SRS system was tested on six volunteers, whose motion was monitored and compensated for in real-time over 15-minute simulated treatments. The system's effectiveness in maintaining the target's 6DOF position within preset thresholds was determined by comparing volunteer head motion with and without compensation.

Results—Comparing corrected and uncorrected motion, the 6DOF robotic system showed an overall improvement factor of 21 in terms of maintaining target position within 0.5 mm and 0.5 degree thresholds. Although the system's effectiveness varied among the volunteers examined, for all volunteers tested the target position remained within the preset tolerances 99.0% of the time when robotic stabilization was used, compared to 4.7% without robotic stabilization.

Conclusion—The pre-clinical robotic SRS compensation system was found to be effective at responding to sub-millimeter and sub-degree cranial motions for all volunteers examined. The system's success with volunteers has demonstrated its capability for implementation with frameless and maskless SRS treatments, potentially able to achieve the same or better treatment accuracies compared to traditional frame-based approaches.

Keywords

6DOF motion compensation; patient motion management; stereotactic radiosurgery

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I. INTRODUCTION

Stereotactic radiosurgery (SRS) is a radiation therapy treatment frequently used to treat benign and malignant intracranial lesions in a single or few high dose fractions with highly precise dose placement, and its clinical use has been growing in recent years (Harrison et al., 2014; Kamath et al., 2005; Kurup, 2010; Loeffler and Alexander, 1990). In order to prevent complications to nearby critical structures such as nerves or other vascular regions, well-planned SRS employs a steep dose fall-off around the target volume.

To achieve this steep dose gradient, strict mechanical, dosimetric, immobilization, and quality assurance tolerances are required. To adhere to the American Association of Physicists in Medicine Task Group Report, TG-42 overall targeting accuracy recommendation of 1–2 mm for intracranial SRS, a metal head ring is rigidly fixed to the patient's skull and then bolted to the treatment couch (Schnell et al., 1995). This frame-based SRS approach relies on fixing the head into a precise 3D stereotactic position, suppressing both voluntary and involuntary patient motion. Unfortunately, the discomfort and invasive nature from using the frame-based approach can limit the number of fractions delivered and/or the number of lesions that may be treated simultaneously, or prohibit its use for some patients entirely (Cerviño et al., 2010). Furthermore, patients can experience anxiety when frames are used for immobilization in SRS (Avbovbo and Appel, 2016). Finally, the clinical workflow is impeded compared to conventional radiotherapy, as imaging, treatment planning, and treatment delivery must occur on the same day. These issues, as well as a large setup time and limitations for fractionated or repeat treatments further highlight some of the current limitations of frame-based SRS.

To overcome the obstacles of frame-based SRS, frameless SRS, in which the head ring is removed and replaced by a thermoplastic mask and a back of the head mold, has seen expanded clinical implementation (Bennion et al., 2016). Here, significant effort is required in order to ensure effective mask immobilization and, in certain cases, even with the mask, large systematic drifts of up to several millimeters from initial setup have been reported (Amelio et al., 2013; Fuss et al., 2004; Murphy, 2009). In a recent study uncertainties as large as 5.84 mm and 2.4 degrees were reported and were found to correspond to cases where patients do not setup appropriately because of the limited manufacturing quality of the mask, loosening or shrinkage of the mask during treatment, or physical changes of the patient's head during treatment due to swelling of the face (Keeling et al., 2016). As a result, treatment interruption for intrafractional patient realignment can occur to ensure proper target coverage. Furthermore, immobilization from thermoplastic masks can still be uncomfortable and highly restrictive. To address these issues, some solutions consider tracking the patient and altering the radiation source position to respond to their motion (Bichay and Mayville, 2016; Kurup, 2010). Another widespread approach uses external camera tracking systems, often with occasional internal snapshots for position verification, and beam gating to ensure proper dose coverage (Dhabaan et al., 2012; Goyal and Kataria, 2014; Jia et al., 2015; Li et al., 2011). Recently, our group has investigated the use of compact robotics to actively assist patients in maintaining a stable head position for long periods of time (D'Souza et al., 2009, 2005; Wiersma et al., 2010). However, these earlier

studies did not provide full 6DOF (3 translational degrees of freedom, and 3 rotational degrees of freedom) head motion control, and were limited to either 3DOF translational (X or left-right (LR), Y or superior-inferior (SI), and Z or anterior-posterior (AP)) or 4DOF (XYZ + pitch (around X)) due to robot design and 6DOF trajectory control algorithm complexities (Gevaert et al., 2012).

As shown in previous studies, failure to provide full 6DOF motion control can lead to serious issues in the exposure of healthy brain tissues to high levels of radiation and poor target dose conformality (Beltran et al., 2012; Guckenberger et al., 2012; Peng et al., 2011). This is of particular concern in cases when lesions are non-spherical or located far from the isocenter as in single-isocenter multi-target treatments (Beltran et al., 2012; Lu et al., 2011; Peng et al., 2011). There is growing evidence to support treating more than 3, even upwards of 15, sites at once in the brain, and rotational errors will be more pronounced in such cases when the lesion distances increase from isocenter (Clark et al., 2010; Roper et al., 2015). These single-isocenter multi-target treatments can reduce overall treatment time and increase clinic throughput, but it is essential that treatment efficiency is not degraded at the cost of temporal improvements. In such cases, real-time 6DOF tracking information can be more effectively utilized to inform high-accuracy immobilization techniques in a frameless and maskless setting.

In this work, we present a novel real-time 6DOF robotic pre-clinical SRS system that is both frameless and maskless. The system can be used with any real-time 6DOF motion tracking device, and depending on the accuracy of the tracking device, is capable of matching or exceeding traditional frame-based SRS positional accuracy requirements. By using a robot to automatically respond to measured 6DOF head position errors, therapist intervention can be reduced, as the system is automatically ensuring proper patient head positioning both translationally and rotationally in real-time. System efficacy was evaluated on several healthy volunteers as a step toward clinical implementation for the improvement of current intracranial SRS regimes. This robotic SRS system has the potential to improve dose delivery accuracy compared to frameless approaches and patient comfort in frame-based and frameless SRS techniques, while improving the clinical workflow for intracranial SRS, especially for non-spherical lesions or in the single-isocenter multiple-target case. The SRS solution described in this work incorporates a novel robotic system into radiotherapy treatments to reduce overall treatment time without sacrificing delivery accuracy due to poor immobilization, and the system's flexibility may open the door for previously unworkable therapeutic options, including cases when frames or thermoplastic masks cannot be used due to special patient conditions.

II. METHODS

A robot capable of performing highly precise movements from translational and rotational inputs was designed and fabricated following the Stewart-Gough platform archetype of parallel kinematics, with response time, weight load, repeatability, and compactness serving as the primary considerations for the design and choice over stacked serial systems (Belcher et al., 2014; Stewart, 1965). The robotic stage is capable of performing 6DOF motions of a mobile top platform relative to the stationary bottom platform using inverse kinematics

control. The final design consisted of six linear actuators connecting a bottom, fixed plate to the upper mobile platform; universal joints connect the actuators to the metal platforms, allowing free rotational movement at the joint position for full 6DOF capabilities of the top platform. The top platform moves in 6DOF based upon the linear trajectories of each of the six linear actuators connecting the top and bottom platforms. This system can move translationally up to 42 mm, 51 mm, and 15 mm in the LR, SI, and AP directions, respectively, and rotate up to 14 degrees, 15 degrees, and 41 degrees about those axes, respectively. The device is capable of achieving speeds of 40 mm/s, 38 mm/s, 19 mm/s, 17 degrees/s, 18 degrees/s, and 45 degrees/s in these axes, respectively (Belcher et al., 2014).

A novel motion control algorithm was developed based on an iterative closest path approach, responding to 6DOF errors detected in real time by an external camera tracking system. The algorithm uses the measured cranial motion and rapidly calculates a trajectory iteratively for each linear actuator in order to cancel the head movements translationally and rotationally. This iterative approach, which responds to the measured 6DOF errors in small steps as they are measured and without predictive modeling, was necessary to correct for cranial motion in this non-rigid body coupling between the robot and the patient's head. The control algorithm used for motion correction is outlined in the control diagram in Figure 1. This compensation system automatically transforms the camera-measured 6DOF cranial motion, determines the errors in each axis for the position of the simulated target within the brain, and computes the linear actuator trajectories necessary to cancel the observed motion of the target position. Specifically, the camera measurements track the translational and rotational movements a set of four reflective infrared (IR) markers, which are fixed to the forehead of the volunteer (Figure 2) and which define a coordinate frame within the volunteer's head. In clinical practice, this coordinate frame, called the virtual point, would be positioned at the treatment isocenter; but for use with volunteers, it was placed near the center of the head to help simulate a typical treatment condition. The camera system which monitors the movements of these four markers is a stereoscopic infrared (IR) marker tracking system (Polaris, Northern Digital, Inc., Waterloo, ON, Canada) (Wiersma et al., 2013). This device functions by having two IR cameras simultaneously track the set of four spherical markers which are IR-reflective and attached to a plate which is fixed to the forehead of the volunteer (Figure 2), and which act as external surrogates for motion of the internal target.

When the measured cranial motion, defined by the coordinate frame of the virtual point, exceeds a threshold of 0.25 mm or 0.25 degrees, which was chosen to reduce response to measurement noise, the robotic system is engaged and the necessary cancellation trajectory is performed automatically. This cancellation trajectory is calculated based on an iterative closest-point algorithm using inverse kinematics, which determines the movements of each linear actuator necessary to produce the desired 6DOF movement of the robot's mobile top platform. The 0.25 mm / 0.25 degree movement thresholds were selected based upon the accuracy and noise of the Polaris camera system used in this study (Wiersma et al., 2013). While the robotic system is actively compensating for the cranial motion, the 6DOF errors of the simulated target are continually being monitored and the trajectory is being updated to constantly respond to the patient's motion. To prevent rapid response to large motions such as coughing, as well as robot over-correction, the algorithm divides the measured 6DOF error into smaller and more manageable parts, such that correction iteration responds to a

smaller measurement error than the total observed deviation of the virtual point. Although this can slow down the response time from returning the target to within the desired thresholds, it has been shown to substantially improve overall system performance.

The real-time 6DOF monitoring of the volunteers with the Polaris IR marker tracking system was performed at a 12-Hz sampling frequency, based on camera specifications. The individual's head motion, through the tracking of the four reflective IR markers, was subsequently transmitted automatically to an in-house developed LabVIEW (2012, National Instruments) code (Figure 1) which controls the robotic device shown in the volunteer setup in Figure 2. This control code communicates between the IR camera system and the robotic device simultaneously, transmitting the six linear actuator trajectories using an 8-axis stepper motor controller (PCI-7358, National Instruments) (Belcher et al., 2014). The real-time head stabilization response of the robot produces a response motion in the volunteer's head by moving the cranial support structure, which is rigidly connected to the mobile top platform of the robot and upon which the volunteer's head rests. After 15 minutes of head tracking, the percent-of-time within the clinical threshold of 0.5 mm and 0.5 degrees was calculated, and a comparison is made between the corrected and uncorrected regimes.

In order to perform motion compensation and effectively cancel out the real-time measured 6DOF motion of the virtual point with respect to its initial position, a calibration procedure was developed to connect the three coordinate frames of the camera, the virtual point, and the parallel kinematics robot (Belcher et al., 2016; Kabsch, 1976). By knowing the displacement vectors and rotation matrices which can be used to associate these three coordinate frames, one can intelligently use the head motion measured using the camera and determine what trajectory for the robotic motion system would be necessary to effectively cancel out these 6DOF positioning errors. The calibration procedure is performed using a head phantom positioned similar to the volunteers, again with the virtual point target coordinate frame located within the phantom's head. When the volunteer is positioned on the head support, the forehead marker positioning is shifted in 6DOF compared to the phantom setup and the 6DOF relationship between the robot control coordinate frame and the virtual point is shifted. To overcome this change in setup, the relative virtual point position is updated, and all camera measurements of the error are subsequently made relative to this new initialized position. In this way, the virtual point, defined by the configuration of the IR marker set, is updated for the specific setup position of each volunteer.

The study used six healthy volunteers to evaluate the efficacy of the 6DOF motion compensation system; volunteers were aged between 25 and 45, and included 4 males and 2 females. Due to volunteer availability, each volunteer contributed at least one motion-compensated data set and one non-compensated (uncorrected) set, though some volunteer 6DOF cranial movements were measured multiple times. The volunteers were requested to lay down on a simulated treatment couch, with their head positioned to maximize contact with the head rest and their comfort. The head support is rigidly connected to the robot so that when the robot performs its response trajectory, the head support also follows this 6DOF motion. Good contact between the head support and the volunteer's head is maintained through the use of four plastic posts such that the volunteer will be effectively repositioned and the target position stabilized. In this study, the head support consisted of

four cushioned pads angled to help ensure contact with the volunteer, which were each connected to the robot's mobile top platform and free to swivel around the AP axis to provide improved universal contact between volunteers while maintaining sufficient levels of comfort (Figure 2). The block of four reflective IR markers, which define the measurement coordinate frame, was fixed to their forehead for tracking; the marker block was attached to a curved metal plate to contour the forehead and attached with medical tape. Volunteers were asked to breathe normally and relax in a supine position over the 15-minute monitoring duration, in order to mimic standard treatment conditions for intracranial SRS; volunteers were also resting in the same configuration for 2–3 minutes prior to tracking to allow them to become comfortable with the setup, similar to clinical procedures. No external immobilization was used to simulate a frameless maskless system. The choice to enable or disable the robotic compensation system was selected randomly prior to the start of tracking and the volunteer was not informed. This served to provide information about each volunteer's movement habits with and without correction, but also to prevent unintended bias from the volunteers. In the uncorrected cases, the volunteer's motion was simply monitored in 6DOF; in the corrected cases, the volunteer's cranial movements were measured and responded to in real-time by the parallel kinematics robot. To evaluate the system efficacy, the uncorrected and corrected cases were compared in terms of percent of time within the algorithm's clinical threshold.

III. RESULTS

The motion compensation system performance was evaluated on six volunteers. Comparing the uncorrected case, in which the 6DOF cranial motion was monitored but not corrected for, and the corrected case, in which the robotic system performed a compensation trajectory to return the volunteer's head to the initial position, improvements in 6DOF immobilization were observed. Figure 3 displays example motions for each volunteer, with an uncorrected case shown to the left of a corrected case. For the 15-minute tracking periods, an improvement factor of 21 was observed in this frameless maskless simulated SRS regime, comparing the uncorrected and corrected cases. When the robotic system was used to respond to volunteer head motion, the 6DOF localization of the virtual point, which was located at a simulated treatment isocenter within the brain, was within the clinical threshold of 0.5 mm and 0.5 degrees more than 99% of the 15-minute tracking period, compared to less than 5% when no correction was used, over the same 15-minute time span, for all volunteers aggregated. In this way, the 6DOF head stabilization system was able to maintain the position and orientation of the target within the pre-set clinical threshold for nearly the entire tracking period.

The volunteer-specific results and overall quantitative improvements are presented in Table 1. In this table, if the six volunteers are considered collectively, a factor of 21 improvement between the uncorrected and corrected cases was achieved using the 6DOF motion compensation system. For the motion corrected cases, volunteer head motion remained within the 0.5 mm and 0.5 degree threshold 99.0% of the time, compared to 4.7% when no correction is used. For a 15-minute simulated treatment period, this corresponded to only 9 seconds outside the threshold when correction was used, compared to 14 minutes and 17 seconds when no 6DOF robotic correction was used. Finally, a cumulative distribution plot

was constructed to compare the uncorrected and corrected cases for the set of all volunteers (Figure 4). Examining the threshold of 0.5 mm / 0.5 degrees, it appears that the robotic motion compensation system ensures the volunteer's head motion rarely exceeds this cutoff, compared to the uncorrected cranial motion. A root-mean-square error (RMSE) analysis was also performed on the corrected motion cases, and for all volunteer data aggregated, the translational RMSE was found to be 0.11 mm, 0.14 mm, and 0.07 mm in LR, SI, and AP, respectively; the rotational RMSE was calculated to be 0.06 degrees, 0.05 degrees, and 0.06 degrees for pitch, roll, and yaw, respectively.

IV. DISCUSSION

To address issues with current SRS techniques, a novel robotic SRS system demonstrated high cranial motion control is achievable without the use of a metal frame or thermoplastic mask. The system was tested on six volunteers to evaluate performance in maintaining head stabilization throughout mock SRS deliveries. Comparing corrected and uncorrected head motion, the 6DOF parallel kinematics robotic system demonstrated an overall improvement factor of 21 with regards to maintaining cranial localization within the 0.5 mm / 0.5 degree threshold. Although variations in effectiveness between cases were observed, such as the large instantaneous motion caused by a rapid shift in Volunteer 4, which was corrected, for the aggregated volunteer data, the target position remained within the clinical tolerances 99.0% of the time when the robotic motion compensation system was used, compared to only 4.7% of the time when the system was disabled. This technique therefore has been shown to be effective with volunteers, and has the potential to improve upon current SRS treatment approaches.

The use of a 6DOF robotic real-time compensation platform may improve target coverage even more when rotations have a larger impact, such as the treatment of non-spherical lesions, or in the single-isocenter multi-target regime. In these cases, when rotations occur, a larger volume of the target lesion or lesions will deviate from the intended position, further increasing the deleterious effects of poor immobilization (Winey and Bussiere, 2014). For such cases, the improvements demonstrated here can have a more profound effect, and future studies will consider the dosimetric difference between corrected and uncorrected motion in these cases. However, the current study demonstrated the feasibility of integrating 6DOF robotic systems into intracranial frameless maskless SRS treatments in order to improve the intrafractional immobilization by responding to measured head motion in real time.

The platform on which the volunteers rested their heads consisted of four posts on a swivel, and since contact with these points is critical for correction, an improved setup can increase the percent of time within clinical threshold by enhancing volunteer comfort and better ensuring constant contact. Additionally, this study placed the robotic system directly beneath the volunteer's head (Figure 2), but such a configuration may not be ideal for some clinical cases since posterior beams cannot be utilized in the treatment delivery. The proposed solution is to place the robotic system beneath the patient's neck, away from the treatment beam, and control their cranial motion from that position. Since the calibration technique, and the motion compensation algorithm, are general approaches to associate the coordinate

frames considered for motion correction and perform real-time correction, no fundamental changes to the overall control algorithm are expected (Belcher et al., 2016). Also important to note is the potential difference between the healthy volunteers used in this study, and patients who may be more difficult to stabilize in a clinical setting. Though implementing the robotic head motion compensation system with real patients undergoing SRS treatments is beyond the scope of this study, the setup conditions and 15-minute tracking duration for each volunteer were chosen to mimic expected setup and typical treatment times.

The robotic SRS system was evaluated in this study using a stereoscopic IR camera, but it should be noted that its functionality is not restricted to any specific tracking system. The only requirement is that the tracking system is able to provide real-time 6DOF positional data. The robot uses this measurement data in the closed loop feedback configuration shown in Figure 1, where it attempts to zero out detected camera deviations, after appropriate transformations have been applied. Given that the robot can perform such corrections at the sub-millimeter level (Belcher et al., 2014), overall accuracy was primarily limited by the 6DOF tracking accuracy of the head tracking system. This can be observed in Figure 4, where positional control is limited by the 0.25 mm accuracy of the IR camera used for this pre-clinical evaluation. In this study, the real-time 6DOF motion was measured by tracking IR markers fixed to the volunteer's forehead using tape and a contoured metal plate with the stereoscopic IR camera. Such a configuration is sufficient to demonstrate the goal of the study, where, given real-time 6DOF input, the robotic SRS system is able to stabilize motion to a sub-millimeter and sub-degree level. In actual clinical scenarios, it is necessary that the camera tracking point is accurate in terms of absolute target position as well, and therefore calibrated to the treatment isocenter (Grelewicz et al., 2012). To this end, the tracked surrogates, such as the reflective IR markers used in this study, must be rigidly connected to the internal tracking target. Unfortunately, examination of the accuracies of various 6DOF tracking systems is beyond the goals of this study, which focuses on the robot and the motion control algorithm, however, some clinically suitable head tracking methods include the use of IR markers attached to a patient dental block, or a 3D surface map tracking of the rigid facial structures (Belcher et al., 2016; Cerviño et al., 2010; Jia et al., 2015; Schöffel et al., 2007; Wang et al., 2010; Wiersma et al., 2013).

For clinical implementation, it will be necessary to incorporate beam gating into the treatment technique. The robotic system described above can respond to 6DOF cranial motion in real-time using the iterative algorithm, however, for large discrete head movements which exceed the preset clinical threshold, gating the beam would help minimize any risk of patient mistreatment. Here it is important that such a gating system has sub-second response times due to the high dose rates used in SRS treatments (Wiersma et al., 2016). Once the patient resettles, the robot will automatically bring back the patient's head to the planned position, and the beam turned on. In this way, clinician intervention would be reduced, and the treatment workflow would improve upon current frameless techniques, where it is necessary to interrupt the treatment and enter the room in order to reposition the patient.

VI. CONCLUSION

A robotic SRS system was developed for use in real-time translational and rotational cranial motion stabilization. The system performance was evaluated on six healthy volunteers, and was shown to dramatically improve target localization within a 0.5 mm and 0.5 degree threshold over 15-minute tracking periods. Using a novel iterative closest-point compensation algorithm, the robot was shown to effectively cancel measured 6DOF cranial motions without the use of a frame or thermoplastic mask. The system's success with volunteers established its potential for clinical implementation in a frameless maskless SRS approach with improved workflow, and stabilization capabilities that exceed the immobilization requirements of intracranial SRS. Incorporating a 6DOF robot into SRS procedures, reduced treatment times and minimal therapist intervention may be possible without sacrificing treatment efficacy and patient comfort.

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Figure 1.

Control diagram for motion compensation. Camera inputs are automatically transformed using the calibration method, and 6DOF errors are determined. A cancellation trajectory is calculated, and the six linear actuator motions to accomplish the cranial compensation are transmitted to the motors. The 6DOF errors continue to be updated 12 times per second. The blue robotic control loop's behavior is governed by the camera system inputs and measurement transformations (black), and the user's parameter inputs (red). The inverse kinematics calculation (green) uses these inputs to determine the necessary linear actuator cancellation trajectories. These necessary movements are finally communicated to the linear actuator's motors (purple), which are then recorded and used for subsequent loop iterations.

Figure 2.

Volunteer setup with robotic device, control computer, and IR marker tracking system. The four reflective IR markers are fixed to the volunteer's head, to permit measurement of their 6DOF cranial motion. Because this setup is frameless and maskless, the robot and the head are weakly coupled, a complication which was overcome using an iterative compensation algorithm. Top left insert shows the head support and the robot in greater detail.

Figure 3.

Example motions for all six volunteers, comparing uncorrected (left) to corrected (right) motion. For each volunteer's case presented, the percent of time the target was within the clinical threshold of 0.5 mm and 0.5 degrees over the tracking period is also displayed in each sector. Direct comparison shows that the corrected cases have improved the 6DOF positioning errors of the simulated tumor position by several factors.

Figure 4.

Cumulative distribution for all six volunteers, comparing uncorrected to corrected motion. The compensation threshold of 0.25 mm / 0.25 degrees was used in the control algorithm to determine when to engage the robotic system for correction; the clinical threshold of 0.5 mm / 0.5 degrees was used as a measure of system performance, chosen to reflect the target localization goal in treatment. The plot compares the corrected motion (solid lines) with the uncorrected motion (dashed lines) for all volunteers, with their anonymized labels, in terms of the percent of time they remained within the motion thresholds defined on the horizontal axis.

Table 1

Numerical results for motion compensation on 6 volunteers with 15 minutes of tracking in each session. The shaded rows for each volunteer show the uncorrected percent of time within the clinical threshold of 0.5 mm and 0.5 degrees, while the unshaded rows show the percent of time the volunteer's motion was within the same clinical threshold when motion correction was enabled.

Volunteer	Translational Percentage	Rotational Percentage	6DOF Percentage	Improvement Ratio
1	99.4	99.9	99.4	121
	1.0	3.0	0.8	
2	98.0	99.9	98.0	14
	7.2	14.6	7.2	
3	99.3	100.0	99.3	7
	13.9	23.1	13.8	
4	99.9	99.9	98.9	80
	1.2	9.1	1.2	
5	99.8	99.9	99.7	40
	2.5	27.1	2.5	
6	99.9	100.0	99.9	25
	4.0	10.8	4.0	
Overall	99.0	99.9	99.0	21
	4.8	9.5	4.7	