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Inter-surgeon variability in the selection of anterior and posterior commissures and its potential effects on target localization

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Abstract

Background—This study reports the inter-surgeon variability in manual selection of the anterior and posterior commissures (AC and PC). The study also investigates the effect of this variability on the localization of targets like STN, Vim and GPi. The additional effect of variation in the selection of the mid-plane on target localization is also evaluated.

Methods—43 neurosurgeons (38 attendings, 5 residents/fellows) were asked to select the AC and the PC points (as routinely used for stereotactic neurosurgical planning) on two MRI scans. The corresponding mid-commissural points (MCP) and target coordinates were calculated.

Results—The collected data show that the MCP point is more reliable than either the AC or the PC points. This data also show that, even for experienced neurosurgeons, variations in selecting the AC and the PC point results in substantial variations at the target points: 1.15 ± 0.89mm, 1.45 ± 1.25mm, 1.21 ± 0.83 for the STN, Vim, and GPi, respectively for the first MR volume and 1.08 ± 1.37mm, 1.35 ± 1.71mm, 1.12 ± 1.17mm for the same structures for the second volume. These variations are larger when residents/fellows are included in the data set.

Conclusions—The data collected in this study highlights the difficulty of establishing a common reference system that can be used to communicate target location across sites. It indicates the need for the development and evaluation of alternative normalization methods that would permit specifying targets directly in image coordinates or the development of improved imaging techniques that would permit direct targeting.

Keywords

inter-surgeon variability; anterior and posterior commissures; manual selections; localization; deep brain stimulation

Introduction

Modern stereotactic functional neurosurgical procedures utilize a coordinate system referenced on the anterior commissure (AC) and posterior commissure (PC) points. Based on the standard convention of the Schaltenbrand-Wahren atlas, AC and PC are defined as two points with the shortest, intraventricular distance between the commissures [1]. Some neurosurgeons continue to use the traditional definition of AC-PC distance to signify the shortest, intraventricular distance based on the traditional method of determining this by ventriculography and true

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lateral skull X-rays. On the other hand, most stereotactic neurosurgery relies on MRI imaging today, and some neurosurgeons use the middle of the commissure versus the intraventricular edge of the commissure to designate the AC and PC points. Because the selection of the AC and PC points defines the reference system by which stereotactic coordinates are communicated in the literature and among surgeons, it is important to quantify errors that may occur in this reference system because of difference in visual localization of AC and PC points. Furthermore, any discussion of localization of targets like the subthalamic nucleus (STN), ventralis intermedius nucleus (Vim) and globus pallidus internus (GPi) based on AC-PC is limited by the variability of visually selected AC and PC selections. We examined the variability of manual AC-PC selections by 43 neurosurgeons who specialize in stereotactic neurosurgery and also evaluated its impact on the localization of three popular deep brain stimulation (DBS) targets.

Methods

During the American Society for Stereotactic and Functional Neurosurgery (ASSFN) conference held in Boston, MA, USA in 2006, 43 neurosurgeons (38 attendings and 5 residents/fellows) selected AC and PC (as they routinely do for surgical planning) on two high resolution MRI volumes. The scans were displayed on a laptop computer with image-viewing software containing simple tools for slice selection, zooming, and point selection. Both MRI volumes were acquired as sagittal T1 sequences (*MRI volume1* with 1mm × 1mm × 1.2mm and *MRI volume2* with 1mm × 1mm × 1mm resolution, TR 8.05ms, TE 3.68ms) on a 1.5T Phillips Medical Systems scanner. Both scans were displayed to the neurosurgeons at a resolution of 1mm × 1mm × 1mm in three standard views (axial, sagittal, and coronal) simultaneously. A point selection made on one view was also displayed on the other two views to allow further refinement on any of the three views. Figure 1(a) shows a snapshot of one of the scans as shown to the neurosurgeons. Every attempt was made to allow the surgeons to select the AC and PC points without verbal cues or assistance so that bias was minimized. Surgeons were not asked to pick the midplane point (MP) to limit interaction time. Instead, the MP was designated by one of the neurosurgical authors (PEK) and remained the same in all measurements. The X, Y, and Z coordinates (in mm) of AC and PC selections were recorded and the mid-commissural point (MCP) was calculated for each neurosurgeon's pair of AC and PC. The data consisting of the coordinates (X, Y, Z) of the manual selections made by the neurosurgeons for each MRI volume were further divided in two sets: *pointset_all* including selections by all 43 neurosurgeons and *pointset_attendings* including selections by only the 38 attending neurosurgeons.

Surgeon-Pairwise distances as a measure of inter-surgeon variability

Traditionally, the spread of a cluster of points is measured as the mean distance from the centroid of the cluster to a given point, but this does not provide a direct measure of distances between points in the cluster. In this study, which focuses on measuring inter-surgeon differences, we have opted for pairwise distances. Suppose, for instance, that S_1AC, S_2AC, S_3AC, and S_4AC are the AC selections by four surgeons S_1, S_2, S_3 and S_4 and that *distance* (*a*, *b*) is the distance between points *a* and *b*, then we compute distances between the four surgeon selections taken pairwise, i.e., *distance*(S_1AC, S_2AC), *distance*(S_1AC, S_3AC), *distance* (S_1AC, S_4AC), *distance*(S_2AC, S_3AC), *distance*(S_2AC, S_4AC) and *distance*(S_3AC, S_4AC) and call these *surgeon-pairwise distances*. Their mean, standard deviation (SD) and median (to eliminate the effect of outliers) are computed as a measure of the inter-surgeon variability in selecting the AC. This is illustrated in figure 1(b).

Measuring the inter-surgeon variation at AC, PC and MCP and the resultant variation at targets

The method described above was applied to the AC, PC and MCP coordinates for each surgeon pair to calculate the inter-surgeon variability at the commissures and at the MCP. The effect of variation in the selection of AC and PC on target localization was analyzed using coordinates published in the literature for STN [2], GPi [2], and Vim [3]. These standard coordinates are shown in table 1(a). Using the coordinates shown in table 1(a), (X, Y, Z) coordinates for STN, GPi and Vim targets were calculated from each neurosurgeon's AC-PC selections. To generate a 3-dimensional coordinate space, one point in the mid-plane other than AC, PC and MCP was chosen by a neurosurgeon (PEK) on each MRI volume. This mid-plane point remained the same in all cases, and was used in the calculation of each of the targets in X, Y, Z coordinates. The surgeon-pairwise distances were computed from these as a measure of the inter-surgeon variability at the targets. This variability is due only to the variability in selection of the commissures.

Experiment to estimate the effect of mid-plane tilt

To study the effect of variations in the selection of one or more midplane points, which we could not study with the data set acquired at the conference, we carried out a small experiment at our institution. On the same two volumes, we asked two neurosurgeons (HY and JS) to select multiple sets of three points on the falx that could potentially be picked by a neurosurgeon to fit the mid-plane. The AC and PC for each of the volumes were fixed. Mid-planes were then fitted through each set of points selected on the falx for each volume. Pairwise angles between all these planes (inter-plane angles) were then computed to measure the variability in selecting mid-planes. Based on the results of this experiment the effect of mid-plane tilt on target localization was studied.

Results

Variation in AC, PC and MCP selections

Mean and median surgeon-pairwise distances for the AC, PC and MCP selections on *MRI volumes* 1 and 2 and both the datasets are given in table 1(b). It can be noted from the results that the median variation in the selection of the AC is marginally larger than the median variation in selecting the PC. Mean variation for the AC can be substantially larger than that for the PC, especially when all the data points are pooled. Mean variation for MCP is smaller than that for AC and PC for both data sets and both MRI volumes, suggesting that the MCP point has less error than the AC or the PC as a common reference point. One reason for the MCP error to be smaller than the AC and PC is that when selecting the AC and PC points in MRI images, individual surgeons may follow either convention – intraventricular edge or middle of the commissure. If this is indeed the case, our data set should show that when the AC point is selected anteriorly to the mean AC point (i.e., the middle of the anterior commissures is targeted), the PC point should be selected posteriorly to the mean PC point (i.e., the middle of the posterior commissures is targeted). We analyzed our data to determine if such a trend was apparent and found it to be true in the majority (about 65%) of the cases. One notes, however, that the standard deviation for the MCP point remains large when all the data points are pooled (*pointset_all*) in both MRI volumes. The maximum values that are reported in this table show that serious errors are possible.

Variation in localization of STN, Vim and GPi targets due to variation in AC-PC selections

Mean and median surgeon-pairwise distances for the STN, Vim and GPi coordinates on *MRI volumes* 1 and 2 and both the datasets are given in table 1(c). As would be expected the variations at the targets are larger than the variation observed at the MCP, which is used as the

origin of the coordinate system. The additional error is caused by the variation in the coordinate system orientation produced by variations in selecting the AC and the PC points. Results presented in this table show standard deviations that are relatively large (e.g., 1.71mm for the Vim on *MRI volume2*) for the *pointset_attendings* and very large when the data sets are pooled in *pointset_all* (e.g., 8.61mm for the GPi for *MRI volume2*). Histograms of surgeon-pairwise distances are useful to visualize the spread in these distances. These are shown for the AC, PC, MCP, STN, Vim, and GPi in figure 2.To eliminate the effect of outliers on the histograms, we eliminated the AC and PC points that were farther away than three times the standard deviation. It can be seen that the histogram for MCP is the tightest and we calculated that it has 90% of the surgeon-pairwise distances within 1.06mm. The AC and PC histograms have the largest spread with 90% of the distances within 1.80mm and 1.70mm respectively. The STN, Vim and GPi histograms are tighter than the AC and PC histograms with 90% of their surgeon-pairwise distances within 1.24mm, 1.67mm and 1.44mm, respectively.

Effect of variation of mid-plane

The maximum pairwise inter-plane angle was found to be 1.00° for *MRI volume1* and 1.70° for *MRI volume2*. We found that the effect of mid-plane orientation is maximum in terms of Euclidean shift on the localization of GPi (error = 0.71mm) as it is farthest away from the mid-plane laterally, followed by STN (error = 0.44mm) and then Vim (error = 0.43mm) for a 2.00° tilt in the mid-plane.

Discussion and Conclusions

Our dataset with 43 neurosurgeons localizing AC and PC on the same two MRI volumes is unique. The data we have collected show that variation in manual selection of the AC and the PC can have a substantial effect on target point location. It also shows that the MCP is a more consistent reference point than either the AC or the PC. This is likely due to canceling of differences among neurosurgeons using different conventions.

It is noteworthy that the error in designating AC and PC has the most effect on targeting error located more lateral from the midline. For instance, if the ideal therapeutic target for GPi was 1.4mm inferior, 20.2mm lateral, and 4.9mm anterior to the MCP, then two different neurosurgeons (experienced attendings in this example) on average would place their target 1.44mm apart based solely on the error of determining AC and PC. This would amount to the difference between two contacts on a standard DBS electrode array (1.5mm center-to-center distance on Model 3387 electrode lead; Medronic Neurological Inc., Minneapolis, MN).

The two data sets that were used in this study are of high quality, with very limited motion artifacts because the images have been acquired with the patient under anesthesia. The data we have collected, therefore, does not address the effect of quality of the images or the effect of large variability in brain anatomy (such as ventricular size). This may have a significant impact on the surgeons' ability to select AC and PC accurately. The data suggests that even with high quality images, selection of the AC and the PC points had more variability for *MRI volume1* than for *MRI volume2*. We would expect that blurring due to motion artifacts in image volumes acquired with awake patients will worsen the results.

Our data set also strongly suggests that experience plays an important role in one's ability to select the points accurately. For *MRI volume1* the mean surgeon-pairwise distances for the attendings group are lower than those for the pooled group by 20% for AC and 36% for PC. These percentages for *MRI volume2* are 10% for AC and 31% for PC. This translates into a mean increase in the surgeon-pairwise distance of targeting error in the pooled data (including residents/fellows) versus experienced stereotactic neurosurgeons (attendings) by 130%, 90% and 174% for STN, Vim and GPi respectively for *MRI volume1*. For *MRI volume2*, the increase

in percentage targeting errors between the pooled data and attendings only are 34%, 35% and 37% for STN, Vim and GPi respectively.

As discussed earlier, selection of the midplane point (MP) was held constant during the survey to reduce interaction time. Because of this, the effect of variation in selecting points on the falx on target selection could not be assessed in the subject population. But, experiments performed at our institution indicates that this could introduce an additional error of 0.71mm, 0.44mm, and 0.43mm at the GPi, STN, and Vim, respectively for a 2° tilt in the mid-plane. Although this is relatively small compared to the error of AC-PC selection, we feel that this error can become more significant in patients with a curved falx. The variations results presented herein should thus be considered as a lower bound. The study we have performed highlights the difficulty of establishing a common reference system to communicate location of target points based on visual inspection of the MRI for AC-PC reference points. It suggests a more accurate reference for stereotaxy would be to eliminate visual inspection of the AC-PC on MRI scans, and instead automate the selection based on imaging criteria. The first is to develop automatic methods that would permit the accurate and consistent localization of the AC and the PC points [4,5,6,7]. The second is to develop algorithms that permit the automatic non-rigid registration of MRI images. We have published the successful use of such algorithms to improve stereotactic localization accuracy in deep brain stimulator implant surgery [8]. This would provide normalization mechanisms that are superior to the visual inspection of MRI images and manual transcription of targets onto the Schaltenbrand and Wahren atlas. It also permits defining target points in image coordinates. An alternative approach is also being developed at other centers whereby higher resolution MRI images which permit direct targeting and stereotactic localization without reliance on AC-PC coordinates. Yet, when comparing therapeutic target locations, a method of normalizing targets with respect to a common reference system (AC-PC coordinates) is highly useful. The source of error we have measured is only one among several sources of errors that complicates the surgical procedures. Others include the accuracy of the stereotactic frame used to place the electrode or anatomical differences between patients. It is therefore difficult to measure directly the impact of AC and PC localization errors on the overall procedure or its outcome. It is, however, reasonable to believe that any source of error in the reference process could potentially lengthen the procedure by requiring more intra-operative adjustment or lead to suboptimal placements. This, in turn, could lead to less than optimal therapeutic response from the procedure.

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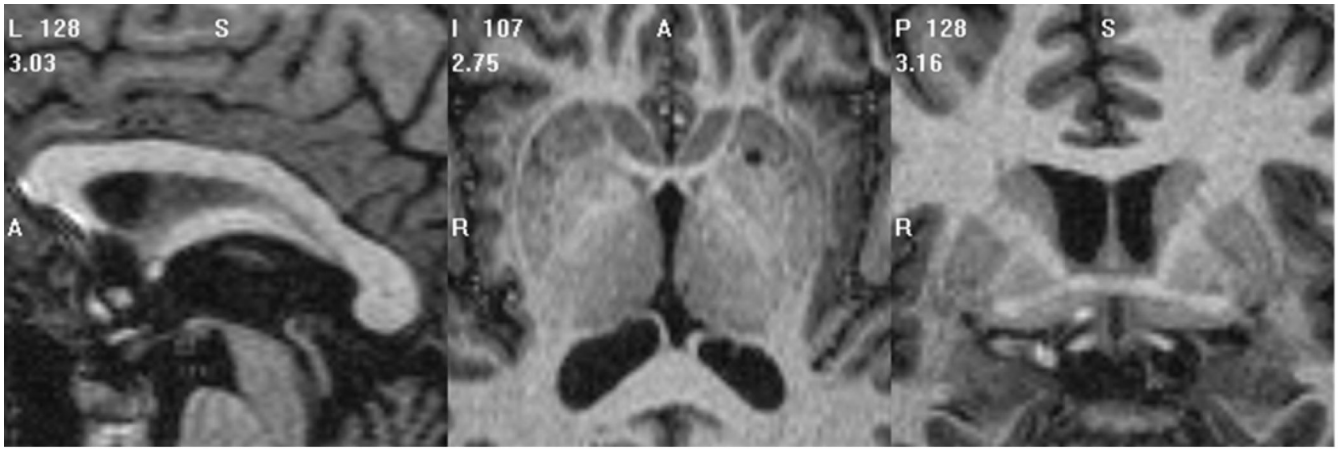
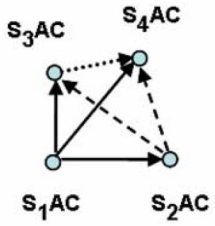


(a)



S_1AC, S_2AC, S_3AC and S_4AC represent the AC selections by 4 surgeons S_1, S_2, S_3 and S_4.

The following surgeon-pairwise combinations can be formed with the AC selections of the four surgeons:

(S_1AC, S_2AC), (S_1AC, S_3AC), (S_1AC, S_4AC) indicated by the solid arrow ⟶

(S_2AC, S_3AC), (S_2AC, S_4AC) indicated by the dashed arrow ------▸

(S_3AC, S_4AC) indicated by the dotted arrow ·····▸

Distance between the two points in each pair is called a surgeon-pairwise distance. For n points there are ${}^nC_2 = n*(n-1)/2$ such pairwise combinations and hence pairwise distances. The mean and standard deviation of these distances are computed as a measure of the inter-surgeon variation in the selection of AC. The same is done for PC, MCP, STN, Vim and GPi.

(b)

Figure 1.
(a) Sample display from the image viewer software. The number on the top in the upper-left corner of each view refers to the slice number and the bottom number refers to the zoom factor. L=left, R=right, I=inferior, S= superior, A=anterior, P=posterior. (b) Illustration of the computation of “surgeon-pairwise distances” between surgeon selections.

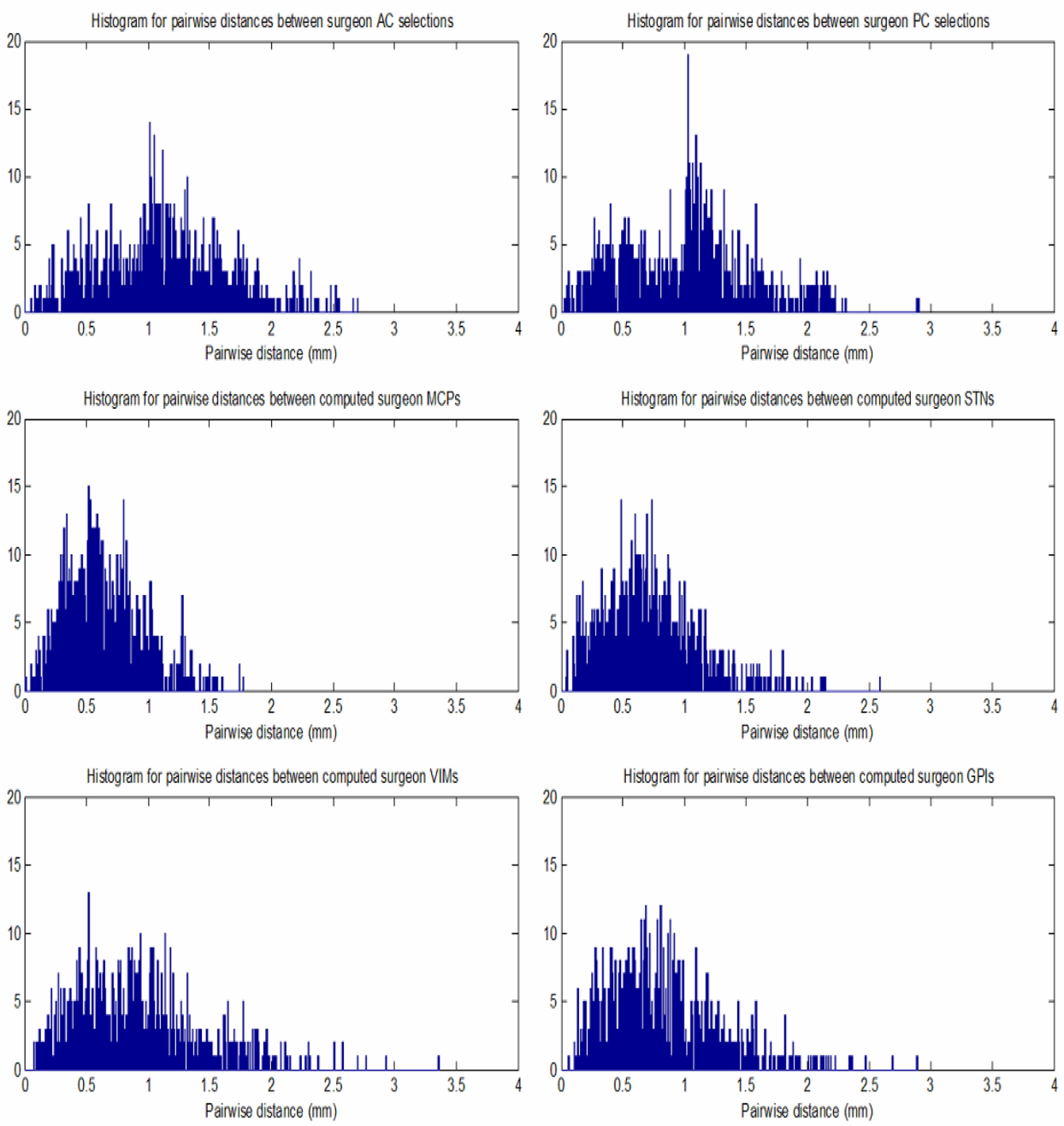


Figure 2.
Histograms for surgeon-pairwise distances (mm) between surgeon selections of AC, PC and the computed coordinates of MCP, STN, Vim and GPi.

Table 1

Table 1(a): Literature targets for STN, Vim and GPi with respect to the AC-PC coordinate system [2] [3], **Table 1 (b)**: Mean and median of the surgeon-pairwise distances of surgeon AC-PC selections for *MRI volumes* 1 and 2 on both the datasets., **Table 1(c)**: Mean and median of the surgeon-pairwise distances of target localizations for STN, Vim and GPi based on surgeon AC-PC selections for *MRI volumes* 1 and 2 on both the datasets.

1(a)

Target nucleus	Coordinates (mm)		
	Vertical (origin)	Lateral (origin)	AP (origin)
STN	−4 (MCP)	12 (MCP)	−3 (MCP)
Vim	0 (MCP)	12.3 (MCP)	6.3 (PC)
GPi	−1.4 (MCP)	20.2 (MCP)	4.9 (MCP)

1(b)

	Surgeon pairwise deviation (mm) *MRI Volume1*						Surgeon pairwise deviation (mm) *MRI Volume2*					
	pointset_all			*pointset_attendings*			*pointset_attendings*			*pointset_all*		
	AC	**PC**	**MCP**	**AC**	**PC**	**MCP**	**AC**	**PC**	**MCP**	**AC**	**PC**	**MCP**
Mean	1.92	2.27	1.47	1.53	1.45	0.85	1.44	2.05	1.26	1.29	1.41	0.88
SD	1.96	3.92	2.01	1.44	1.24	0.42	1.05	3.46	1.68	0.77	1.62	0.78
Median	1.26	1.23	0.89	1.21	1.17	0.81	1.18	1.08	0.69	1.16	1.08	0.65
Max	8.50	20.50	13.20	8.50	7.19	2.23	5.83	17.07	10.27	4.46	9.20	5.63

1(c)

	Surgeon pairwise deviation (mm) *MRI Volume1*						Surgeon pairwise deviation (mm) *MRI Volume2*					
	pointset_all			*pointset_attendings*			*pointset_all*			*pointset_attendings*		
	STN	**VIM**	**GPI**	**STN**	**VIM**	**GPI**	**STN**	**VIM**	**GPI**	**STN**	**VIM**	**GPI**
Mean	2.64	2.75	3.31	1.15	1.45	1.21	1.45	1.82	1.54	1.08	1.35	1.12
SD	6.32	6.09	8.61	0.89	1.25	0.83	2.07	2.83	2.01	1.37	1.71	1.17
Median	1.02	1.24	1.15	0.94	1.20	1.02	0.77	0.95	0.87	0.73	0.93	0.81
Max	32.18	30.78	42.73	5.24	7.15	4.61	9.77	14.15	13.33	7.83	10.04	7.01