Robot-Assisted Stereotaxy Minimizes Target Error: A Meta-Analysis of 8,902 Trajectories

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assfn American Society for Stereotactic and Functional Neurosurgery 2018 BIENNIAL MEETING DENVER | June 2-5, 2018

Introduction

Despite a growing number of frame-based, fiducial-based, and robot-assisted stereotactic methods, accuracy remains the driving force behind stereotaxy. At present, a direct comparison of all stereotactic methods has yet to be performed. The present study serves as a meta-analysis of 26 publications, reporting the overall accuracy of frame-based and skull fiducial-based systems, and further takes into account the influence of robot-assistance.

Methods

A PubMed search was performed for the following terms: “Leksell,” “Cosman-Robert-Wells,” “CRW,” “NexFrame,” “STarFix,” “ClearPoint,” “NeuroMate,” “ROSA,” “accuracy,” and “error.” No date restrictions were placed. Raw accuracy data was extrapolated and recorded. System-specific accuracy means and standard deviations were calculated; and z-scores were calculated to compare differences between each system.

Table 1: Euclidian Target Error of Stereotactic Systems

	ALL TRIALS		CLINICAL TRIALS		PHANTOM TRIALS	
	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD
Frame-based	**2249**	**1.89 ± 1.12**	**449**	**2.47 ± 1.42**	**1800**	**1.75 ± 1.05**
CRW	970	1.86 ± 1.15	70	2.65 ± 1.84	900	1.80 ± 1.10
Leksell	1279	1.92 ± 1.10	379	2.44 ± 1.34	900	1.70 ± 1.00
Fiducial-based	**1630**	**1.93 ± 1.07**	**1070**	**2.29 ± 1.31**	**560**	**1.25 ± 0.60**
ClearPoint	18	1.00 ± 0.57	18	1.00 ± 0.57		
NexFrame	1067	1.72 ± 0.93	507	2.25 ± 1.30	560	1.25 ± 0.60
STarFix	545	2.36 ± 1.35	545	2.36 ± 1.35		
Robot-assisted	**4506**	**1.68 ± 0.65**	**2506**	**1.90 ± 0.88**	**2000**	**1.41 ± 0.38**
NeuroMate	3080	1.62 ± 0.70	1080	2.01 ± 1.28	2000	1.41 ± 0.38
ROSA	1426	1.81 ± 0.55	1426	1.81 ± 0.55		
Robot + frame-based	1030	0.86 ± 0.32	30	0.86 ± 0.32	1000	0.86 ± 0.32
Robot + fiducial-based	3476	1.92 ± 0.75	2476	1.91 ± 0.88	1000	1.95 ± 0.44

A comparison of Euclidian target error between stereotactic methods.

Results

Across 24 studies and a total of 8,902 measurements, the average Euclidean target error for frame-based, fiducial-based, and robot-assisted procedures was 1.89 ± 1.12 mm (N = 2,249), 1.93 ± 1.07 mm (N = 1,630), and 1.68 ± 0.65 mm (N = 4,506), respectively. These data yield no statistical difference between frame-based and fiducial-based systems ($p = 0.36$), however, the use of a robotic system yielded a statistically significant increase in target accuracy ($p < 0.01$). Interestingly, when examining only clinically-derived measurements, fiducial-based systems demonstrate a statistically significant increase in accuracy over frame-based systems ($p = 0.008$), with mean target errors of 2.29 ± 1.31 mm (N = 1,070) versus 2.47 ± 1.42 mm (N = 449), respectively. Still, robot-assisted procedures were reported to have the greatest accuracy ($p < 0.001$), with a mean clinical target error of 1.90 ± 0.88 mm.

Conclusions

There are incremental improvements from frame-based to fiducial-based and from fiducial-based to robot-assisted of 0.39 mm and 0.18 mm, respectively. All systems demonstrated a mean Euclidean target error of < 2.5 mm and have demonstrated the ability to provide reliable electrode placement.