Defining Spatial Design Requirements of Dexterous Instruments for Combined Endoscopic Third Ventriculostomy and Pineal Region Tumor Biopsy/Excision

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Introduction

Recent innovations to expand the scope of intraventricular neuroendoscopy have focused on transitioning multiple incision procedures into single corridor approaches. However, the successful adoption of these combined procedures requires minimizing the unwanted forces or tearing applied to surrounding healthy structures. Dexterous curved instruments with increased distal ranges-of-motion, similar to designs successfully adopted in laparoscopy, can address this challenge.

Objectives

To define the geometry of relevant anatomical structures in endoscopic third ventriculostomy (ETV) and pineal region tumor biopsy (ETB). Also, to determine the optimal instrument shaft path required for collision-free single burr-hole ETV/ETB.

Methods

- Magnetic resonance and computed tomography data from fifteen pediatric patients who underwent both ETV and ETB procedures between 2006-2014 was segmented using the *3DSlicer* software package to create virtual 3D patient models (Fig. 1) [5].
- Using *3DSlicer, a*natomical structures were measured including the foramen of Monroe (FM), the massa intermedia (MI), the floor of the third ventricle and the tumor margin (TM) [5].
- With the MATLab software package, virtual dexterous instruments were inserted into the models and optimal burr-hole positions were calculated to find the shortest instrument length and least aggressive tip curvature.
- Bonferroni-Dunn post hoc analysis was implemented with the R v3.2.0 statistical software package.

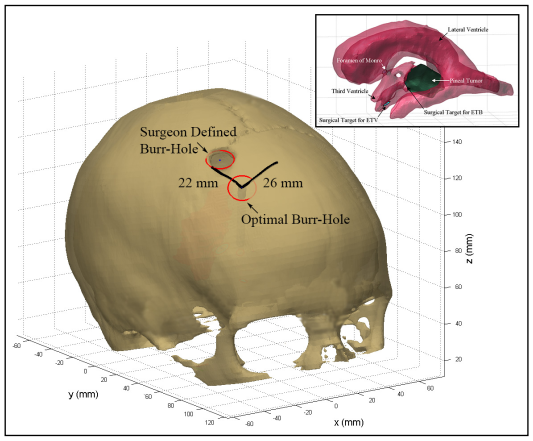

Figure 1: Patient models as seen in MATLab: [Left] Depicts the measurement tool utilized to locate the burr-hole. [Top Right] Depicts ETV/ETB target sites.

Results

Table 1: Anatomical Measurements using *3DSlicer*

Units (mm) Anatomical Feature	Mean *(Standard Error)*	Previously Reported
FM Diameter	6.85 *(0.155)*	6.1 – 6.9[4], 5.6 - 7.8[1]
MI Diameter (A-P)	4.01 *(0.136)*	4.3-5.1[4]
MI Diameter (S-I)	5.05 *(0.174)*	
Anterior 3rd Ventricle Diameter	14.20 *(0.329)*	12.1-14.3[4]
Max Tumor Diameter	28.51 *(0.544)*	24.9-25.6[4]
Tumor - MI	7.30 *(0.326)*	8.1-9.0[4]
Tumor - Midbrain	6.74 *(0.132)*	

Table 2: Comparison of surgical incision locations with respect to skull sutures

Units (mm)	Mean (*Standard Error)*			Comparison Between Means ($p < 0.05$ sig)		
	Surgeon Burr-Hole	*Optimal Bur-Hole*	*(Lun et. al)* [4] *Literature Burr-Hole*	*Surgeon to Optimal Bur-Hole p*	*Surgeon to Literature Burr-Hole p*	*Optimal to Literature Burr-Hole p*
Coronal Suture	14.3 *(0.849)*	22.5 *(1.53)*	17[1] *(0.618)*	**0.041***	1.00	0.257
Sagittal Suture	26.8 *(0.527)*	30.1 *(2.33)*	30[1] *(0.618)*	0.878	0.721	1.00

Table 3: Estimated geometry of virtual collision -free instruments compared by burr-hole location

Units (mm)	Measurement Means & (*Standard Error)* by Burr Hole		
	Surgeon Defined	Optimal	p
Total Instrument Length to TM	100.2 *(2.02)*	90.0 *(2.49)*	**0.002***
Total Instrument Length to floor of 3rd Ventricle	99.1 *(2.00)*	89.6 *(2.44)*	**0.003***
Length of Linear Segment	66.3 *(0.456)*	56.8 *(2.30)*	**0.001***
Arc Length from Trocar to TM	33.9 *(1.23)*	33.2 *(1.23)*	0.970
Radius of Curvature from Trocar to TM	49.9 *(8.11)*	47.7 *(3.04)*	0.517
Arc Length from Trocar to floor of 3rd Ventricle	32.7 *(0.768)*	32.8 *(0.85)*	1.00
Curvature from Trocar to floor of 3rd Ventricle	121.3 *(31.0)*	47.5 *(2.79)*	**0.008***

Discussion

- The anatomical measurements performed agree with previously published data [1,3,4]. We have also included standard error to describe the variation between patients' anatomy.
- Using a previously published algorithm [2], an 'optimal' average burr-hole location was found, and it is statistically different than the surgeon defined burr-holes used in the patients' origional surgeries.
- The assumed 'straight segment – curved segment' instrument design (Fig. 2) was chosen for simulation because this configuration has been successfully implemented in laparoscopic devices, such as the SILS™ Hand Instrument line produced by Covidien.
- The 'optimal' burr-hole significantly reduces the overall instrument length. Shorter lengths of the overall tool increases its stiffness and the achievable tip forces at the distal end.

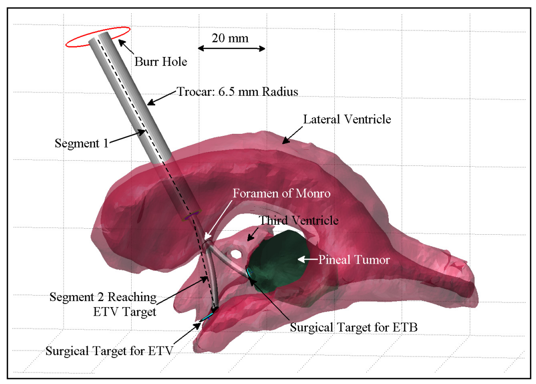

Figure 2: Surgical targets with superimposed 'virtual' curved instruments and endoscope. The curved instruments have a straight segment inside the trocar and a distal curved segment.

- The 'optimal' burr-hole ensures equal tip curvature to reach both surgical targets. Thus, a single instrument design can be developed.

Conclusion

We have established a platform for estimating the shape of novel curved dexterous instruments for collision-free targeting of multiple intraventricular points, which is both patient and tool specific and can be integrated with image guidance. In the future, we will discuss how we have used this method to develop novel dexterous instruments.

Learning Objectives

1) Understand the role of curved, procedure specific instruments in neuroendoscopy, 2) Describe the geometry of the anatomical features of ETV/ETB, 3) Understand the design requirements of dexterous neuroendoscopic tools.

References

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