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Original Article

The Surgeon's Role in Inducing and Controlling Motion Errors During Intraocular Membrane Peeling Procedures

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Abstract

Objectives: To understand the surgeon's role in inducing and correcting movement inaccuracies during intraocular membrane peeling procedures.

Materials and Methods: Optical sensors were used to record movement errors during actuation at the distal tip of 23-gauge pneumatic forceps both when the handle was handheld and when fixed with no human contact. Movements were also recorded at the proximal part of the forceps shaft (near the sclerotomy site) and compared to movement recorded at the distal end. The root mean square (RMS) and range values of the signals obtained from the sensors were calculated before and after applying high (7-13 Hz) and low (<5 Hz) frequency filters.

Results: Comparison of RMS and range values of movement errors at the distal end of the forceps during actuation when the forceps handle was fixed and handheld showed that without human contact, these values were significantly lower in the X axis at all frequencies and in the Z axis at high frequencies compared to handheld ($p<0.05$), while there were no significant differences in the Y axis. Comparison of values from the distal and proximal ends of the forceps showed that when the forceps were fixed, RMS and range values were significantly higher for movement errors at the distal end compared to the proximal end at all frequencies ($p<0.05$). There was significant positive correlation between the extent of actuation and the RMS and range values for high-frequency movement errors but not low-frequency errors in all three axes with the fixed pneumatic handle ($r=0.21-0.51$, $p<0.05$).

Conclusion: Surgeon- and non-surgeon-related errors are apparent in all axes, but skilled surgeons correct these errors through visual feedback, resulting in better correction in the visible planes. Sclerotomy sites provide a pivoting and stabilizing point for the shaft of the forceps and it is likely that skilled surgeons make use of the sclerotomy point to dampen motion errors, a skill worth teaching to beginners.

Keywords: Vitrectomy, epiretinal membrane, intraocular forceps, macular hole, surgical errors

Introduction

Handheld vitreoretinal forceps are widely used to peel membranes from the retinal surface.[1,2] Unintentional movement errors at the forceps tips may occur during membrane peeling, with loss of precision and potential surgical trauma. Previous studies showed that significant movement errors can happen while actuating the system, which adds another layer of activity and consumes the surgeon's attention. This correlation was not restricted to one surgeon or to one type of instrument handle.[3,4,5,6] In an attempt to provide better control over the actuation process and reduce unintentional movements, pneumatically driven handpieces were introduced (CONSTELLATION® Pneumatic Hand Piece, GRIESHABER® Advanced DSP tips). These handles are designed to be lightweight and ergonomic with superior control of actuation through a foot

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pedal. However, opinions about pneumatically powered forceps vary, with some surgeons feeling that it offers an easier way to initiate internal limiting membrane peeling, while others demonstrated using optical sensors that pneumatically driven handles were not superior to manually operated handles in reducing low-frequency inadvertent movements when used by surgeons experienced in manually driven handles.[4,7] This finding suggests that some of these movement errors could be due to surgeons' muscle memory or perhaps the interaction of different parts of the forceps with each other and with surrounding tissues. In this study we aimed to understand surgeons' contributions, both positive and negative, to movement errors in pneumatically driven forceps.

Materials and Methods

We used optical sensors to record the Cartesian coordinates of the grasping tips of intraocular forceps and simultaneously monitor the extent of their actuation. The testing system has been described previously. Briefly, reflective optical sensors (ROS) (Vishay semiconductors, model TCRT5000) were used. The reflective sensors include infrared emitters with a wavelength of 950 nm and phototransistors that are blocked to visible light. The ROS dimensions were 10.2x5.8x7 mm with a peak operating distance of 2.5 mm and an operating range of 0.2 to 15 mm. Three peripheral ROS were fitted into purpose-built slots on a 42 mm diameter plastic hemisphere. The slots were designed to hold the ROS at a distance of 10 mm from and at a right angle to the panels. A central ROS was also fitted to the shaft-forming tube facing the first panel, which was perpendicular to the grasping end of the tool. Three flat circular plastic panels were also attached to the shaft of the intraocular forceps at right angles to each other.[2] A front panel was fitted perpendicular to the end of the grasping tip and two side panels were fitted parallel to the shaft of the forceps. The shaft of the forceps was introduced into the hemisphere through a hole mimicking a sclerotomy.[4] During the experiments, the tip of a pneumatic hand piece (CONSTELLATION®) attached to a 23-gauge tip (GRIESHABER® Advanced DSP) was held in the center of the hemisphere to enable recordings from all three sensors while the actuation process was carried out. Measurements were repeated for 4 actuation cycles using foot pedal control. When the system was used to record movement errors in the absence of the surgeons' influence, the handle of the forceps was attached to the plastic hemisphere housing the optical sensors to eliminate any movements between the handle and the sensors. However, when the system was used to record the surgeons' influence, two vitreoretinal surgeons who were trained in the United Kingdom, had previous surgical experience of at least 2,000 retinal and 500 macular surgeries, and held substantive vitreoretinal consultant posts in the National Health Service at the time of study were asked to hold the pneumatic handle manually and try to keep the tip under a fixed stylus which was fitted to a point at the center of the field. Each four-cycle experiment was repeated 5 times and carried out under direct viewing system with an operating microscope to mimic the operative situation.

Furthermore, in the current study we also compared the movements of the forceps shaft both at its distal part (away from sclerotomy site) and its proximal part (closer to sclerotomy site) in the absence of the surgeon's influence. This was done by modifying the panels to enable their attachment to the proximal part of the forceps while the handle was attached to the plastic hemisphere and recording the panels' movements during actuation. Figure 1 shows the details of the recording system, the modified panels attached to the proximal and distal parts of the shaft, and the alignment of the axes in relation to the forceps distal end.

During the experiments, data were recorded in 4 meridians: (1) anteroposterior (X axis): deflection of the grasping tip towards or away from the user, an axis that is perpendicular to the user in the sagittal plane and therefore the least visible to the user, (2) lateral (Y axis): deflection of the grasping tip sideways, (3) depth (Z axis): the length of forceps shaft inside the sphere, reflecting the movement of the forceps tip closer to and further from the retina, and (4) actuation (A axis): advancement of the shaft from its actuation tube. Data regarding the distance between the peripheral ROS and the panels were used to determine the position of the grasping tip within the hemisphere, and data regarding the distance between the central ROS and the front panel were used to determine the extent of actuation. Calibration was performed as described in our previous study.[4] Figure 2 shows movement errors in the X, Y, and Z axes and actuation extent recorded from pneumatically driven forceps being held by hand but pneumatically actuated by foot pedal.

Root mean square (RMS) values for the recorded data were calculated before and after applying a third-order Butterworth filter with corner frequencies at 7 and 13 Hz, and a low pass filter with corner frequency of 5 Hz to enable specific analysis of high-frequency (physiologic tremor) and low-frequency (drifts and jerks) involuntary movements, respectively. The resulting data were nonparametric; therefore, the Spearman correlation coefficient was used to determine the significance of the correlation between extent of actuation and involuntary movements, and the Mann-Whitney U test was used to compare the RMS and ranges of involuntary movements for different settings. $P<0.05$ was considered statistically significant.

Results

In the Y axis, the RMS and range values of movement errors for a fixed pneumatic handle at all frequencies, low frequencies, and high frequencies were not significantly different from those for a handheld pneumatic handle. Regarding the X axis, the RMS and range values of movement errors for a fixed pneumatic handle for all frequencies, low frequencies, and high frequencies were significantly lower than those recorded with the handheld pneumatic handle ($p<0.05$). In the Z axis, the RMS and range values of movement errors for a fixed pneumatic handle for all frequencies and low frequencies were not significantly different from those for handheld forceps. However, the RMS and range values of high-frequency movement errors for a fixed pneumatic were significantly higher compared to those detected with handheld handle ($p<0.05$). Table 1 shows the RMS and range values in each axis and all frequencies both with fixed and handheld forceps.

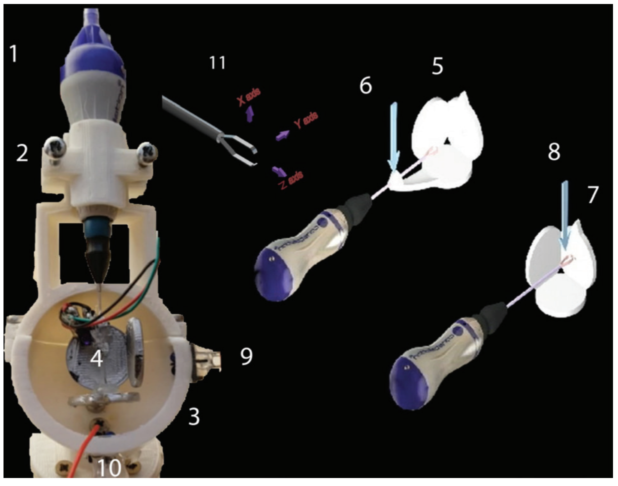

Figure 1. The system used to record movement errors. 1: Pneumatically powered handle (Constellation pneumatic DSP). 2: Specially designed slot for secure attachment of the handle to the hemisphere that houses the optical sensor, to eliminate surgeon related errors. 3: A plastic hemisphere, housing 3 optical sensors to monitor movements in directions X, Y, and Z. 4: An optical sensor attached to the shaft of the forceps to monitor the extent of actuation. 5: Plastic panels designed to translate movements from the proximal part of the shaft of the forceps, closer to sclerotomy site. 6: Proximal attachment location. 7: Plastic panels designed to translate movements from the distal part of the forceps away from sclerotomy site. 8: Distal attachment location. 9: Optical sensors detecting movement errors in the Y axis. 10: Optical sensors detecting movement in the Z axis. Note optical sensors detecting movements in the X axis are located behind the forceps. 11: The definition of the X, Y, and Z axes in relation to the distal end of the forceps

When the distal and proximal parts of the forceps were compared, RMS and range values of overall movement errors in all 3 axes in all frequencies, low frequencies, and high frequencies for the distal end of the forceps were significantly higher than those for the proximal parts of the forceps. Table 2 shows the RMS and range values for the distal and the proximal parts of the forceps shaft.

Regarding the relationship between movement errors and extent of actuation, there was a statistically significant positive correlation between the extent of actuation and the RMS and range values for high-frequency movement errors with the fixed pneumatic handle with no human contact in all three axes ($p\leq0.05$). Spearman's rho correlation coefficients for this correlation were 0.285 and 0.205 in the X axis, 0.478 and 0.415 in the Y axis, and 0.506 and 0.431 in the Z axis, respectively. However, correlations between the extent of actuation and low-frequency movement and all-frequency movements were not statistically significant. Table 3 shows the correlation between the extent of actuation and low-frequency errors at the distal end of a 23-gauge forceps attached to a fixed pneumatic handle.

Discussion

Movement errors during intraocular membrane peel procedures may result in tissue damage and irreversible sight-threatening complications.[8,9] Such errors have been previously investigated and separated into high-frequency movement errors representing physiological tremor, and low-frequency movement errors representing jerks, deflections, and drifts. Low-frequency movement errors are of greater amplitude than high-frequency ones and could be more harmful and more noticeable when the operator attempts to actuate the forceps manually by squeezing the handle to achieve closure of the forceps blades.[3,4,10,11,12,13,14] Therefore, pneumatically powered forceps remotely actuated via foot pedals were introduced to reduce such errors. However, previous studies showed that

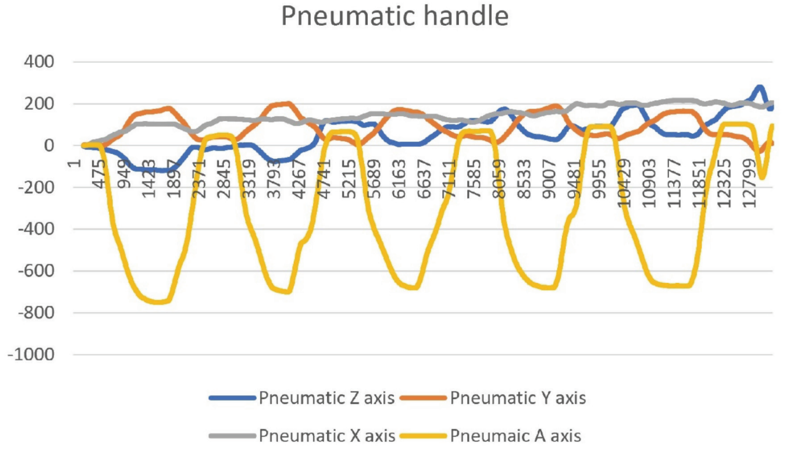

Figure 2. Movement errors before applying frequency filters detected in the X, Y and Z axes along with actuation extent recorded for pneumatically driven forceps being held by hand but pneumatically actuated by foot pedal

such forceps were only superior to manually actuated ones in reducing high-frequency movement errors. Previous studies have suggested that the effect of actuation on movement errors was less prominent when the surgeon factor was eliminated; however, the nature of the surgeon's influence on movement errors was not investigated further.[4] In this study, we performed an in-depth analysis of surgeons' influence on inducing/dampening movement errors in different axes and frequencies using pneumatically powered and foot pedal-controlled forceps. We chose to use optical sensors to record movements at different parts of the forceps shaft. This methodology is not only proven to be reliable but also gives the option of eliminating surgeon influence by attaching the handle to the frame of the testing rig.[4]

Our study showed that holding pneumatically powered forceps by hand influenced movement errors in different ways in different axes. In the Y and Z axes, for example, holding the forceps by hand did not significantly influence movement errors with the exception of an increase in high-frequency errors in the Z axis. However, eliminating the influence of the surgeons' hand by attaching the forceps to the frame of the rig improved movement errors in all frequencies in the X axis. This meant that surgeon-related movement errors were more prominent in the X axis. One possible explanation for this finding is that the X axis was less visible to the surgeons during the experiments, while the Y and Z axes were in the plane perpendicular to their visual axis, which possibly provided visual feedback on movement errors caused by their hands and enabled them to dampen these errors.

The current study also revealed that movement errors are more pronounced at the distal end, away from the pivoting point at the sclerotomy site. Previous studies also showed higher movement errors when the sensors were attached to the handle end of the forceps away from sclerotomy site.[15]

Table 1. Comparison of the RMS and range values of all-, low-, and high-frequency movement errors with a handheld pneumatically powered forceps and fixed pneumatically powered forceps with no human contact. The data show that eliminating the surgeon factor reduces movement errors, but only in the X axis, the axis not visible to the operating surgeon

			Vector Y			Vector X			Vector S		
Frequency	**Parameter**	**Operator**	**Mean**	**SD**	**p value***	**Mean**	**SD**	**p value***	**Mean**	**SD**	**p value***
All	RMS	Fixed	165.16	77.69	0.10	34.35	22.66	<0.001	277.90	196.50	0.93
		Handheld	89.98	36.66		148.93	26.27		220.83	94.26	
	Range	Fixed	438.67	166.94	0.12	116.67	45.30	<0.001	1032.67	570.53	0.31
		Handheld	326.00	115.02		438.00	179.78		678.00	294.48	
Low (<5 Hz)	RMS	Fixed	164.21	77.67	0.10	34.06	22.77	<0.001	276.37	196.56	0.93
		Handheld	89.22	36.67		148.05	25.85		219.87	94.29	
	Range	Fixed	416.07	157.92	0.12	104.92	41.34	<0.001	935.36	552.34	0.55
		Handheld	316.46	121.91		410.92	166.78		665.52	289.31	
High (7-13 Hz)	RMS	Fixed	2.43	0.84	0.14	0.78	0.21	<0.001	9.62	4.09	<0.001
		Handheld	1.82	0.27		1.82	0.29		1.89	0.45	
	Range	Fixed	35.99	12.16	0.05	8.73	2.82	<0.001	154.49	59.61	<0.001
		Handheld	21.40	10.11		19.35	4.71		24.28	4.33	

*Mann-Whitney U test, RMS: Root mean square, SD: Standard deviation

Table 2. Comparison of the RMS and range values of movement errors at the distal and proximal parts of the forceps shaft revealed significant differences between movement errors at the distal end and proximal parts of the forceps

Frequency	**Location**	RMS			Range		
		Mean	**SD**	**p value***	**Mean**	**SD**	**p value***
All	Distal	160.94	170.62	<0.001	543.78	631.05	<0.001
	Proximal	55.51	47.82		140.78	88.45	
Low (<5 Hz)	Distal	150.83	170.53	<0.001	448.63	535.60	<0.001
	Proximal	54.68	47.15		132.20	86.93	
High (7-13 Hz)	Distal	15.48	36.99	0.05	164.80	302.18	0.04
	Proximal	1.29	1.16		19.07	21.04	

*Mann-Whitney U test, RMS: Root mean square, SD: Standard deviation

Table 3. Correlations between the extent of actuation and movement errors of different frequencies and in different axes for the distal end of a 23-gauge tip mounted on a pneumatically driven fixed handle in the absence of human contact. There was a statistically significant positive correlation between the extent of actuation and high-frequency movement errors but no significant correlation with all- and low-frequency movement errors

Correlations Spearman's rho RMS							
Frekans		**X_RMS**	**Y_RMS**	**Z_RMS**	**X_RMS**	**Y_RMS**	**Z_RMS**
All	Correlation coefficient	-0.06	0.01	-0.14	-0.13	-0.07	-0.11
	Sig. (2-tailed)	0.61	0.91	0.18	0.22	0.54	0.30
Low	Correlation coefficient	0.00	0.06	-0.07	-0.08	0.01	-0.08
	Sig. (2-tailed)	0.98	0.56	0.51	0.43	0.91	0.48
High	Correlation coefficient	0.29	0.48	0.51	0.21	0.42	0.43
	Sig. (2-tailed)	0.01	<0.001	<0.001	0.05	<0.001	<0.001

RMS: Root mean square

This finding is most likely due to the stabilizing effect of the sclerotomy site. However, it should be noted that the distal end of the forceps is where the action of peeling takes place. The distance between the distal end of the forceps and the finger position of the surgeon is roughly 40 mm with a pivot point at sclerotomy site located approximately at the mid-distance.[4] It is likely that experienced surgeons are making the use of the stabilizing effect of sclerotomy sites to dampen movement errors that they become aware of through visual feedback.[5,16]

Another interesting finding of the current study was the disappearance of the correlation between low-frequency movement errors and the actuation process when the influence of the surgeons' hand was eliminated. This kind of correlation was previously reported not only with manually actuated forceps but also with pneumatically powered forceps when held by hand.[4] Our finding supports the hypothesis put forward in previous studies, that surgeons who are more experienced in manually actuating forceps tend to inadvertently use their hand muscles during foot pedal actuation due to long-term muscle memory.

Study Limitations

One of the limitations of the study was the influence of surgeons' experience on the outcome. However both surgeons were experienced, and bias was further reduced by repeating the experiments multiple times.

Conclusion

In conclusion, surgeon- and non-surgeon-related motion errors are apparent in all axes, but skilled surgeons adopt a mechanism to correct these errors. The correction mechanism works best in the plane that provides the most visual feedback to the surgeon. Sclerotomy sites provide a pivoting and stabilizing point for the shaft of the forceps and it is likely that skilled surgeons with good visual-motor coordination make use of the sclerotomy point to dampen motion errors, a skill worth teaching to beginners.[17] Eye surgery simulation systems like Eye Si could play an important part in developing visual-motor coordination and reducing unintentional hand movements.[17,18,19,20]

Ethics

Ethics Committee Approval: Since this research is a laboratory study, ethics committee approval is not required.

Peer-review: Externally peer reviewed.

Authorship Contributions

Surgical and Medical Practices: M.D., D.S., Concept: M.D., D.S., Design: M.D., D.S., Data Collection or Processing: M.D., D.S., Analysis or Interpretation: M.D., D.S., Literature Search: M.D., Writing: M.D.

Conflict of Interest: No conflict of interest was declared by the authors.

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