tvst

https://doi.org/10.1167/tvst.7.6.28

Article

Unintentional Movements During the Use of Vitreoretinal Forceps

Mahmut Dogramaci[1] and David H. Steel[2]

[1] Princess Alexandra Hospital NHS Trust, Hamstel Road, Harlow, Essex, UK
[2] Sunderland Eye Infirmary, Queen Alexandra Rd, Sunderland SR2 9HP, Institute of Genetic Medicine, Newcastle University, Newcastle Upon Tyne, UK

Correspondence: Mahmut Dogramaci, Princess Alexandra Hospital NHS Trust, Hamstel Rd, Harlow, Essex, CM20 1QX, UK. e-mail: mahmutdogramaci@hotmail.com

Received: 22 February 2018
Accepted: 29 October 2018
Published: 21 December 2018

Keywords: vitrectomy; epiretinal membrane peel; internal limiting membrane peel; intraocular forceps; tremor; pneumatic forceps; vitreoretinal surgery; microsurgery; surgical skills

Citation: Dogramaci M, Steel DH. Unintentional movements during the use of vitreoretinal forceps. Trans Vis Sci Tech. 2018;7(6):28, https://doi.org/10.1167/tvst.7.6.28

Purpose: Intraocular forceps used in vitreoretinal surgery are actuated by squeezing their handles. We studied the relationship between actuation and any accompanying unintentional movements of the instrument tip, and compared different handle designs and gauges.

Methods: Optical sensors were used to measure involuntary movements of forceps tips while monitoring the extent of actuation. Mean root mean square (RMS) and ranges of signals obtained from sensors were computed before and after applying high (7–13 Hz) and low (<5 Hz) frequency filters. Four handle designs, two gauge sizes, and two users were compared to each other.

Results: In the absence of human contact, mean RMS of noise was 6.47 μ and mean range was 21.67 μ. When the forceps were held by the surgeon but kept motionless (no actuation), mean RMS was 58.01 μ and mean range was 156.66 μ. When the forceps were actuated, mean RMS was 214.71 μ and mean range was 566.11 μ. The differences were statistically significant ($P < 0.001$). The process of actuation by both users was positively correlated with unintentional movements mainly at low frequencies. No statistically significant differences were found between users and between two gauges (23 and 27) at mixed and low frequencies. Pneumatic handles showed less RMS and range values at higher frequencies compared to conventional handle designs. Eliminating human error by fixing pneumatic forceps to the model did not reduce unintentional movements, but eliminated their correlation with actuation.

Conclusions: Actuating forceps was associated directly with increased unintentional low frequency movements at the tip of the forceps when held by hand.

Translational Relevance: A novel system of measuring unintentional forceps tip movement during actuation is described which could be used to guide improved design.

Introduction

Vitreoretinal microsurgery is a demanding specialty that often involves the need to peel membranes as thin as 4 to 20 μ from the retinal surface.[1,2] Successful surgery depends upon the surgeon possessing a set of skills that include precise manual dexterity and fine visual-motor coordination only acquired after long hours of training.[3,4] Unplanned movements during surgery may result in tissue damage and irreversible and sight-threatening complications.[5,6]

At present, hand held and actuated vitreoretinal forceps and scissors (referred to as actuator derived intraocular grasping tools [ADIGT]) are the most widely available instruments used to peel membranes from the retinal surface. ADIGT embraces a group of commercially available intraocular instruments, including forceps and scissors with handle mechanisms based on an intuitive mechanical actuation system. This mechanism can be actuated simply by squeezing the handle, which leads the tube forming the shaft to slide forward to close the graspers as described by Gonenc et al.[5]

Manual membrane peeling using ADIGT is a complex activity that requires concurrent and precisely coordinated movements. These include the action of reaching for the target tissue, pinching the handle of the ADIGT to induce forceps closure and grasping of the membrane, and peeling and finally releasing the membrane. All this is done at a distance of approximately 40 mm from the tip of the forceps to the finger position with a pivot point at the sclerotomy, approximately at the mid distance. Additionally, the surgeon needs to maintain visualization with foot control of microscope position to keep the area of peel in view and sharp focus, while maintaining spatial awareness to avoid off center retinal touch or tearing. Research has shown that humans can attend to no more than one muscle at a time and it is possible to shift guiding attention from one activity to another only two or three times per second under optimal conditions.[7–9] Therefore, it is not surprising that unintentional movements can occur during membrane peeling, with loss of precision and potential surgical trauma.

To our knowledge, no study has investigated the exact relationship between the process of actuation and the extent of unintentional movements. Understanding such relationships is crucial in designing ADIGT handles and also in training new surgeons. We investigated this relationship with a novel methodology using reflective optical sensors.

Methods

A system was developed using optical reflective sensors to enable simultaneous recording of the Cartesian coordinates of the grasping tip of ADIGT while monitoring the extent of its actuation (Fig. 1).

The grasping tip of the ADIGT tool was fitted with three flat circular plastic panels at right angle to each other. The front panel was fitted perpendicular to the end of the grasping tip. Two side panels were fitted parallel to the shaft-forming tube, one of the side panels directed to face the left side of the shaft and the second side panel directed to face the back side of the shaft.

A Reflective Optical Sensor (ROS; Vishay semiconductors, model TCRT5000; Vishay Intertechnology, Malvern, PA) was used. This is a reflective sensor that includes an infrared emitter with a wavelength of 950 nm and phototransistor that is blocked to visible light. The ROS dimensions were 10.2 × 5.8 × 7 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 reflective optical sensors at 10 mm distance and at right angle to the panels. A central ROS also was fitted to the shaft-forming tube facing the first panel, which was perpendicular to the grasping end of the tool.

The shaft of the forceps was introduced into the hemisphere through a hole mimicking a sclerotomy with a diameter of 0.6 mm and a length of 0.8 mm; the hole was designed to have tapered edges to reduce friction and achieve angular freedom at the pivoting point. During the experiments, the tip of the forceps was held in the center of the hemisphere, to enable recordings from all three sensors. Therefore, only the distal 21 mm of the shaft was placed in the hemisphere (note in Fig. 1, the forceps are seen resting to their full extent in the hemisphere for illustrative purposes only). A fixed stylus was fitted to a point at the center of the field and a marker dot also was placed on the front panel in immediate proximity to the tip of the forceps to enable the operator to make subtle adjustments to the instrument while squeezing and releasing to compensate for tip movement.

The following data were recorded: (1) anteroposterior swing (x axis): deflection of the grasping tip towards or away from the user, (2) lateral swing (y axis): deflection of the grasping tip sideways, depth (z axis): the length of the shaft of ADIGT inside the sphere, reflecting the movement of the tool closer and away from the retina, and (4) actuation (a axis): advancement of the shaft forming tube.

Because the user intended to hold the ADIGT tip motionless during the tasks, any movements detected were regarded as unintentional movements. Movements away from the ROS were recorded as positive and movements toward the ROS were recorded as negative. Only absolute data were considered for statistical purposes.

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 the actuation. These data were transformed to a microcontroller (model ATmega328; Atmel, San Jose, CA) at a 500 Hz sampling rate. The data then were transformed into an Excel sheet using the Parallax Data Acquisition (PLX-DAQ) software add-in for Microsoft Excel (Microsoft Corp., Redmond, WA) at a maximum sampling rate of 500 Hz. Calibration was

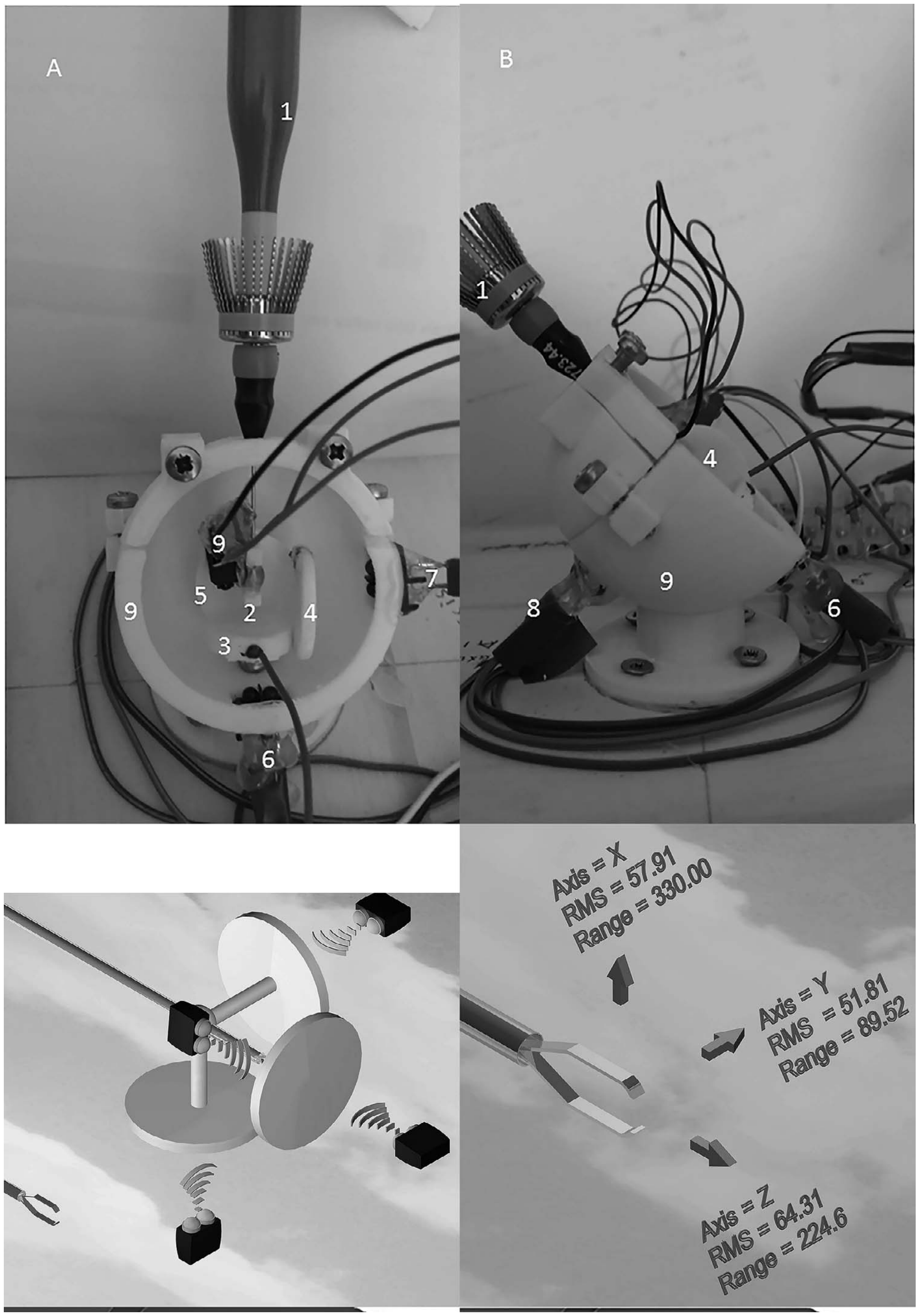

Figure 1. Position of the optical reflective sensors in relation to their opposing panels. *Top left*: front view of the model. *Top right*: side view of the model. *Bottom left*: Schematic view showing the positions of the panels in relation to the forceps tip. *Bottom right*: Schematic view showing the axes of movement in relation to the tip of the forceps. *1*, Grieshaber Revolution handle with DSP internal limiting membrane forceps (23-gauge) used as an example of an actuator derived intraocular microsurgical tool (ADIGT). *2*, Grasping end of the ADIGT. *3*, Front panel. *4*, Side panel. *5*, Posterior panel. *6*, Front Reflective Optical Sensor (ROS). *7*, Left ROS. *8*, Posterior ROS. *9*, Shaft ROS.

performed before every attempt to set the values to zero; therefore, any deviation from zero was taken as the absolute amplitude value. To gauge the RMS and range of errors secondary to ambient infrared light, electrical charge and noise pollution causing unwanted vibrations in the panels, control measurements of the tip were recorded with the ADIGT in place and no human contact.

translational vision science & technology

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 (physiologic tremor) and low (drifts and jerks) frequency involuntary movements, respectively. The resulting data were nonparametric; therefore, the Spearman correlation coefficient used to determine the significance of correlation between the extent of actuation and the 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.

Four sets of experiments were performed.

Set 1 Experiments (Aimed to Validate Methodology)

In this set of experiments one vitreoretinal surgeon (user 1) was asked to repeat the following two tasks 10 times: Task 1 involved holding the ADIGT motionless for 20 seconds and task 2 was to squeeze and release the ADIGT handle four times while inspecting the location of a marker dot on the front panel in relation to a fixed stylus. A Grieshaber Revolution handle (Grieshaber, Schaffhausen, Austria) with 23-gauge disposable end grasping tips was used. This handle has a basket-shaped actuator providing the operator with 360° of freedom in squeezing the handle. This set was executed under a 63 mm, ×2.5 magnifier lens. The results of this set were compared to previously published data using various sensors

Set 2 Experiments (Aimed to Compare Two Users)

In this set, a second vitreoretinal surgeon (user 2) was asked to repeat task 2 as described above 10 times. A Grieshaber Revolution handle with 23-gauge disposable end grasping tips again was used. This set was executed under direct viewing with an operating microscope. The results were compared to the results of task 2 obtained from user 1 in set 1 experiments.

Set 3 Experiments (Aimed to Compare Different Handle Designs)

We compared four different handles designs, including handle 1 (Grieshaber Renaissance advanced), handle 2 (Grieshaber Revolution), handle 3 (Grieshaber Sutherland) and handle 4 (Constellation pneumatic DSP). To eliminate user- and gauge-generated bias, all handles were tested by the same user and attached to the same 23-gauge disposable end grasping tips. The results of different handles were compared to each other.

Set 4 Experiments (Aimed to Compare Different Gauge Sizes)

Three 23-gauge and three 27-gauge disposable end grasping tips were used in this experiment. To eliminate user generated bias the tips were attached to handle 4 (Constellation pneumatic DSP) which was itself fixed to the plastic sphere. The results obtained from the different gauges were compared to each other.

Results

Results of Set 1 Experiments

In the absence of human contact, and while the ADIGT was placed within the sphere, the overall mean RMS (mean of *x*, *y*, and *z* axes) was 6.47 μ (standard deviation [SD] 5.28) at a mean range of 21.66 μ (SD 20.26). When the ADIGT was held by the surgeon, but kept motionless (with no actuation) the mean RMS was 58.01 μ (SD 33.13) at mean range of 156.66 μ (SD 68.32).When the ADIGT was actuated, the mean RMS was 214.71 μ (SD 95.07) at mean range of 566.11 μ (SD 181.00). The differences were statistically significant ($P < 0.001$). Supplementary Table S1 shows the breakdown of the RMS values and their corresponding ranges obtained from set 1 experiments. The mean RMS of low frequency movements (<5 Hz) was similar to the mean RMS before applying filters, that is, the low frequency movements were of much greater amplitude than the high frequency movements. Figure 2 shows an averaged Fourier frequency analysis of the unintentional movements recorded during actuation and while holding the instrument motionless. Figure 3 shows an example of a time domain graph of a sample recording from an individual attempt.

Results of Set 2 Experiments

Supplementary Table S2 shows mean RMS values and their corresponding mean ranges obtained from surgeons 1 and 2. Supplementary Table S3 shows the correlation between the extent of actuation and unintentional movements for surgeons 1 and 2. No statistically significant differences were found in mean

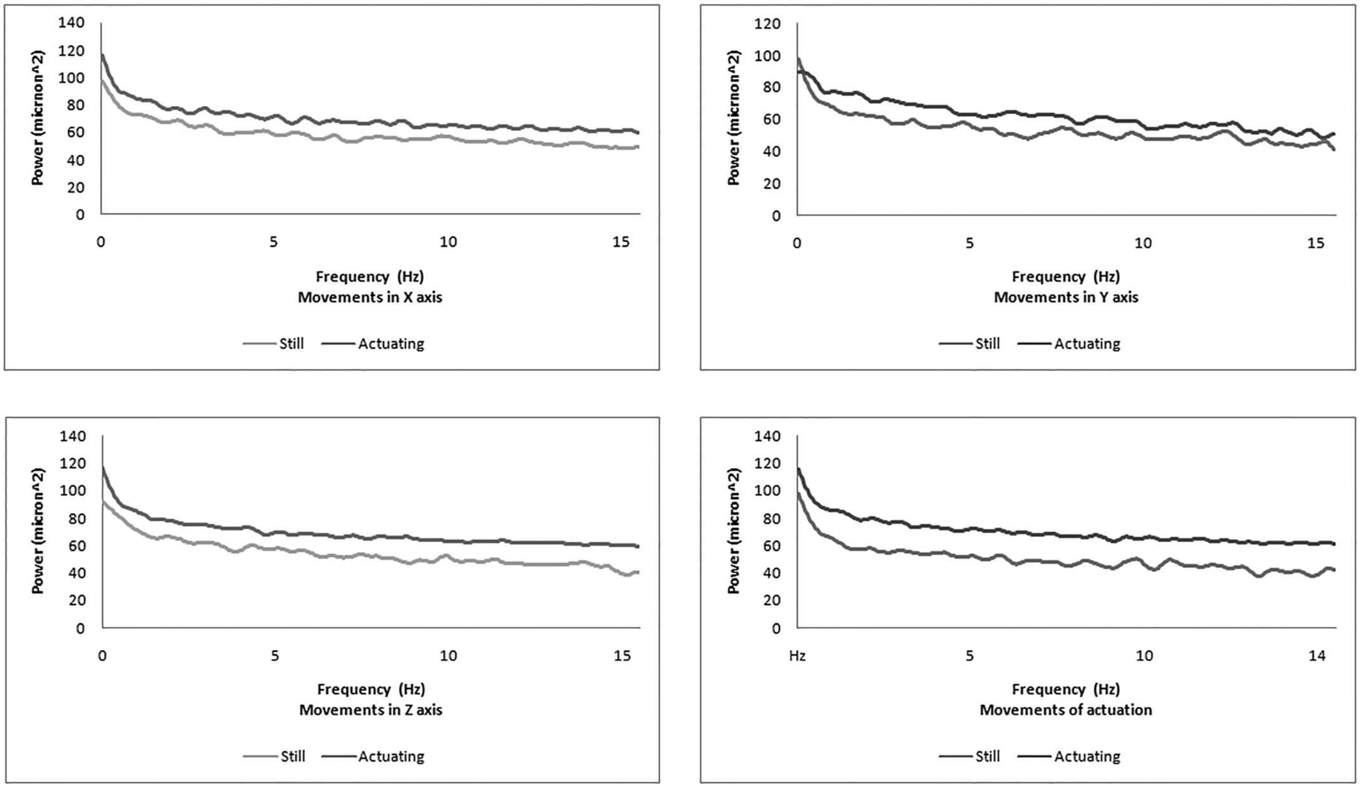

Figure 2. Averaged Fourier frequency analysis of the movements in *x*, *y*, and *z* axes and also of the actuator, referred to as the *a* axis recorded during actuation and holding the instrument motionless. Note there is an area of higher amplitude with narrow peaks at <5 Hz and areas of lower amplitudes with broader peaks at 7 to 13 Hz.

RMS and range values at mixed and low frequencies between the two users. However, user 2 had statistically significantly higher values at high frequencies. Statistically significant positive correlation with actuation at mixed and low frequencies was found with both users. For user 2, this correlation was present at higher frequencies as well.

Results of Set 3 Experiments

No statistically significant differences were found in RMS and range values among different handle designs at mixed and at low frequencies, including handle 4, the pneumatically powered handle operated by a foot pedal. However, at high frequencies, handle 4 showed statistically significantly lower RMS values compared to other handles and statistically significantly lower ranges when compared to handles 1 and 2. Also, at higher frequencies handle 3 showed statistically significantly lower RMS values when compared to handles 1 and 2. Supplementary Table S4 shows the mean RMS values and their corresponding mean ranges obtained from the four different handles.

Statistically significantly positive correlations with actuation for different handles were as follows: For handle 1, this correlation was with RMS values in the *y* axis at mixed and *z* axis in low and high frequencies, and with range values in all axes at mixed and low frequencies and only in *z* axes at high frequencies. For handle 2 this correlation was with RMS and range values in all axes at mixed, low and high frequencies. For handle 3 this correlation was with RMS values in *y* and *z* axes at mixed, low, and high frequencies and with range values at all axes at mixed frequencies, and in *y* and *z* axes at low frequencies, and only in *z* axes at high frequencies. For handle 4 this correlation was with RMS and range values in all axes at mixed and low frequencies, but at high frequencies the effect was limited to RMS values in *y* and *z* axes. Supplementary Table S5 shows the correlation between the extent of actuation and unintentional movements for four different handle designs.

Results of Set 4 Experiments

No statistically significant differences were found in mean RMS and mean range values between 23- and

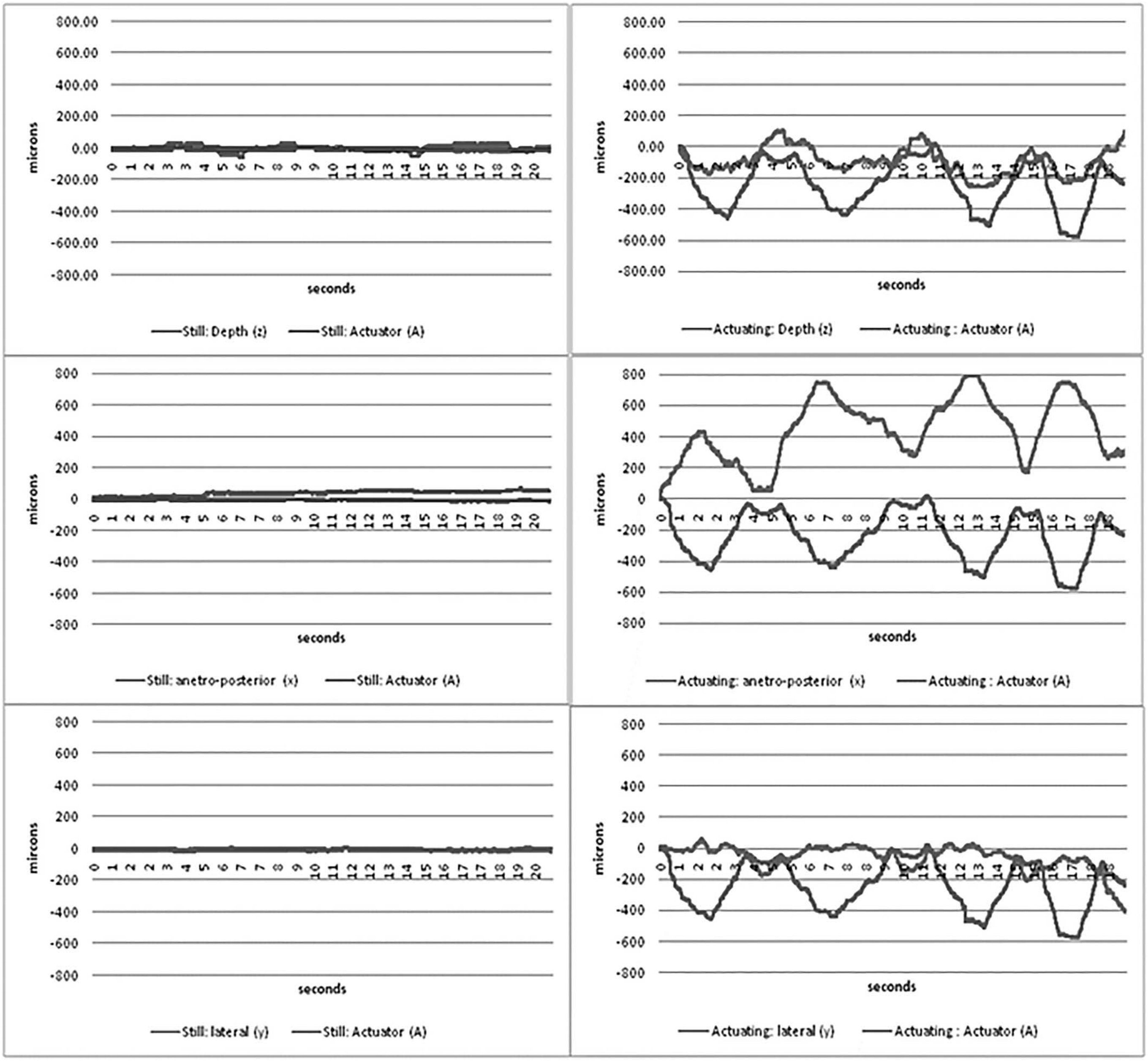

Figure 3. Sample recordings from an individual attempt. The *left column* represents the unintentional movements during actuation and the *right column* represents the subject attempting to hold the instrument motionless. The large actuation artefact is clearly visible in the curves in the left column.

27-gauge forceps at any frequency. Supplementary Table S6 shows mean RMS values and their corresponding mean ranges obtained from the two different forceps gauges. Statistically significant positive correlations with actuation were restricted to range values with gauge 23 only, and only in the x axis at low frequency and z axis at high frequencies. Supplementary Table S7 shows the correlation between the extent of actuation and unintentional movements for two different gauge sizes.

Discussion

Human hand movement has certain inherent involuntary components that manifest themselves most obviously during fine movements, and are obvious to any surgeon who has performed membrane peeling. By using optical sensors to determine the extent of actuation and simultaneously define the position of the grasping tip of the forceps, we were able to define the exact nature of these movements and show that their amplitude was directly related to the actuation.

We chose optical sensors over magnetic and inertial sensors to avoid positional inaccuracies and the additional weight added to the instruments using these sensor types.[10] Our set 1 experiments showed that while holding the instruments motionless the values of mean RMS and ranges were similar to those reported by Song et al.[11,12] using swept source optical coherence tomography recording, validating the reliability of our methodology. Mean RMS values for movements at high frequencies (7–13 Hz) while holding the instrument motionless were approximately 1.5 μ across all axes. Similar values were reported by Riviere et al.[13] for *z* axis at matching frequencies when measured using Hall effect sensors (mean RMS, 2.2 μ). However, another study by Gomex-Blanco et al.[14] reported higher RMS values of approximately 10 μ in similar experimental conditions using inertial sensing devices fixed at the proximal (handle) end of ADIGT. We believe that the reason for these higher results was partly due to the position of the sensors. Calculated by trigonometry if the grasping tip of a 140 mm long ADIGT is inserted 22 mm into the eye, a 1 μ deflection at the grasping tip will be accompanied by a deflection approximately 5 times greater at the proximal end in an opposite direction. Another study by Riviere et al.[15] reported very high RMS values of approximately 60 to 90 μ across all axes, respectively, using an optical tracking system to track a white Delrin ball of 4.7 mm in diameter attached to the tip of the microsurgical instrument that was held motionless by the surgeon. The authors attributed their large values to partial occlusion of the viewing field by the marker ball affecting the stereo view provided by the operating microscope used in their study.

Riviere et al.[16] noted that pressing certain parts of ADIGT handles to induce actuation unavoidably deflected the instrument tip, resulting in inadvertent and undesirable movements during surgery; however, they did not quantify this relationship. Our set 1 experiments also showed that when the ADIGT was actuated, the mean RMS for low frequency movements increased by a factor of approximately 5. Sets 2 and 3 experiments showed that such correlation was neither restricted to one surgeon nor to one type of instrument handle, but the correlation was less evident with handle 1 (Grieshaber Renaissance advanced) compared to the other hand actuated handles.

Other investigators separated involuntary movements into high frequency components, representing physiological tremor, and low frequency components, representing "jerks, deflections, and drifts," and showed that the lower frequency components of unintentional instrument movement were of greater amplitude than the high frequency components.[11,12,16–19] Similarly Fourier frequency analysis of all our experimental data showed an area of higher amplitude component with narrow peaks at <5 Hz representing drifts and a second area of lower amplitudes component with broader peaks at 7 to 13 Hz representing physiologic tremor.

While intuitively surgeons have worried about tremor, actually low frequency drifting movements are of greater concern. Importantly, our sets 1 to 3 experiments also showed that the process of actuation was positively correlated with low frequency movements. We postulated that the range of the actuating mechanism might have a role in increasing these involuntary movements as would increased instrument weight. The fact that we found some differences between handle designs, which have different actuation forces and distance relationships would support this, and is an area that could be investigated further. It is interesting that the pneumatically driven handle 4 showed low frequency inadvertent movements comparable to the other hand-actuated handles suggesting that muscular action to position the tips was an important part, although high frequency movements were reduced. It is also possible that the user being an experienced surgeon was inadvertently using their hand actuating muscles during foot pedal actuation from long-term muscle memory. The results may have been different with inexperienced surgeons or conversely surgeons experienced with pneumatically driven forceps, which the tested user was not.

Set 4 showed no statistically significant difference in mean RMS and mean range values between 23- and 27-gauge forceps at any frequencies. Set 4 also showed that when human factor is eliminated, the relationship between the actuation and movements become less prominent.

One of the study's limitations was that the hole in the model that we used to mimic a sclerotomy was within the rigid plastic sphere wall which would have provided firmer support to the shaft of the ADGT compared to the more elastic sclera in real life. However, the hole was designed to have tapered edges, reducing the contact surface area and, as a result, the friction between the shaft of the forceps and the plastic wall. Reduced frictions increased the angular freedom of the forceps minimizing the effect of the material property of the model. Therefore, the effect of the friction at sclerotomy site is believed to be minimal.

In conclusion, we showed, using a novel system of optical sensors, that low frequency unintentional movements predominate during the actuation of vitreoretinal forceps and that their amplitude is directly related to the extent and force of actuation. There are no defined thresholds for unintentional movements that might be considered to be clinically meaningful or surgically problematic. However, for improved surgical safety and outcomes they should clearly be minimized. By quantifying and understanding the relationship of these movements to forceps use and actuation, we postulated that designs could be improved. Furthermore, although we tested the system with only experienced surgeons, the technology to quantify unintentional movements may have value in training vitreoretinal surgeons and assist them in making ergonomic adjustments for better outcomes.

Acknowledgments

Disclosure: **M. Dogramaci**, None; **D.H. Steel**, None

References

1. Dogramaci M, Williamson TH. Dynamics of epiretinal membrane removal off the retinal surface: a computer simulation project. *Br J Ophthalmol*. 2013;97:1202–1207.
2. Henrich PB, Monnier CA, Halfter W, et al. Nanoscale topographic and biomechanical studies of the human internal limiting membrane nanoscale studies of the human ILM. *Invest Ophthalmol Vis Sci*. 2012;53:2561–2570.
3. Balicki M, Uneri A, Iordachita I, Handa J, Gehlbach P, Taylor R. Micro-force sensing in robot assisted membrane peeling for vitreoretinal surgery. *Med Image Comput Comput-Assist Int*. 2010;13:303–310.
4. Mazinani BA, Rajendram A, Walter P, Roessler GF. Does surgical experience have an effect on the success of retinal detachment surgery? *Retina*. 2012;32:32–37.
5. Gonenc B, Balicki MA, Handa J, et al. Evaluation of a Micro-Force Sensing Handheld Robot for Vitreoretinal Surgery. *Rep U S*. 2012;2012: 4125–4130.
6. Hubschman JP, Bourges JL, Choi W, et al. 'The Microhand': a new concept of micro-forceps for ocular robotic surgery. *Eye (Lond)*. 2010;24:364–367.
7. Kottke FJ, Halpern D, Easton JK, Ozel AT, Burrill CA. The training of coordination. *Arch Phys Med Rehab*. 1978;59:567–572.
8. McLaurin CA. External power in upper extremity prosthetics. *Orthop Prosthet Appl J*. 1966;145–155.
9. Lansing RW, Schwartz E, Lindsley DB. Reaction time and EEG activation under alerted and nonalerted conditions. *J Exp Physiol*. 1959;58:1–7.
10. Gomez-Blanco M, Riviere CN, Khosla PK. *Sensing hand tremor in a vitreoretinal microsurgical instrument*. Carnegie Mellon University, The Robotics Institute, 1999.
11. Song C, Gehlbach PL, Kang JU. Swept source optical coherence tomography based smart handheld vitreoretinal microsurgical tool for tremor suppression. *Conf Proc IEEE Eng Med Biol Soc*. 2012:1405–1408.
12. Song C, Gehlbach PL, Kang JU. Active tremor cancellation by a "Smart" handheld vitreoretinal microsurgical tool using swept source optical coherence tomography. *Optics Exp*. 2012;20: 23414–23421.
13. Riviere CN, Rader RS, Thakor NV. Adaptive cancelling of physiological tremor for improved precision in microsurgery. *IEE Trans Biomed Eng*. 1998;45:839–846.
14. Gomez-Blanco M, Riviere CN, Khosla PK. Intraoperative tremor monitoring for vitreoretinal microsurgery. *Stud Health Technol Inform*. 2000;70:99–101.
15. Riviere CN, Ang WT, Khosla PK. Toward active tremor canceling in handheld microsurgical instruments. *IEEE Trans Robot Autom*. 2003;19: 793–800.
16. Riviere CN, Rader RS, Khosla PK. Characteristics of hand motion of eye surgeons. *Conf Proc IEEE Eng Med Biol Soc*. 1997:1690–1693.
17. Harwell RC, Ferguson RL. Physiologic tremor and microsurgery. *Microsurgery*. 1983;4:187–192.
18. Schenker PS, Barlow EC, Boswell C, et al. Development of a telemanipulator for dexterity enhanced microsurgery. *Proc 2nd Intl Symp Med Robot Comput Assist Surg*. 1995:81–88.
19. Riviere CN, Khosla PK. Accuracy in positioning of handheld instruments. *Conf Proc IEEE Eng Med Biol Soc*. 1996:212–213.