Virtual Repository of Microscopic and Neuro-endoscopic Instrumentation in Neurosurgery

Ramandeep Singh
Centre for Biomedical Engineering
Indian Institute of Technology Delhi, New Delhi, India
ramanvirdis@gmail.com

Britty Baby
Amarnath Shashi Khosla School of IT
Indian Institute of Technology Delhi, New Delhi, India
bbritbabez@gmail.com

Ashish Suri
Department of Neurosurgery
All India Institute of Medical Sciences, New Delhi, India
surineuro@gmail.com

Sneh Anand
Centre for Biomedical Engineering
Indian Institute of Technology Delhi, New Delhi, India
snehanand@rediffmail.com

***Abstract*—** Neurosurgical procedures are performed by microscopic and neuro-endoscopic approaches. Microscopy involves stereoscopic operating microscope and neuro-endoscopy includes rigid or flexible endoscopes for visualization. A set of functionally similar but morphologically different microscopic and neuro-endoscopic instruments are used in neurosurgery. There has been a significant advancement in the optics, but the instruments have many limitations. They have deprived ergonomics, single function and limited degrees of freedom. Hence, there is a need for the development of improved instruments. Training in neurosurgery for these procedures involves physical/ synthetic and virtual simulators. Virtual training modules are being developed for the training of surgical procedures and validation of surgical skills. For both these requirements, the virtual model of related neurosurgical instruments is the primary requirement. In the present work, we have developed a virtual repository of microscopic and neuro-endoscopic instruments of neurosurgery. The surface data of these instruments was acquired using blue light scanning technique and processed using computer aided designing to create solid models. These virtual models can be used for surgeon specific modification in the existing designs and for creating new designs. They can be directly fabricated using rapid prototyping methods for developing low-cost training apparatus and for the development of virtual reality trainers, video based neuro-navigation, and e-learning platforms.

Keywords*— *Blue light scanning, Neurosurgical Instruments, Microscopy, Endoscopy, Virtual repository, Motion simulation

I. Introduction

Neurosurgery is a surgical specialty related to the treatment of disorders of central nervous system. Neurosurgery is either performed using operating microscope or by using neuro-endoscopes. Operating microscopes provide stereoscopic vision and high magnification and neuro-endoscopy provides a display of surgical site on a 2D monitor. Both techniques are used separately and sometimes combined with various types of neurosurgical disorders [1–3]. Neurosurgical instruments are used for performing different functions such as cutting, punching, grasping, holding, dilating and retracting. For each function, there are dedicated sets of instruments available [4, 5].

The sterile neurosurgical instruments are used in the operating rooms or in the surgical training labs and hence difficult to access. The present literature lacks any database of existing instrumentation that can be used for conducting research for various applications of neurosurgery. Such a database can be used by surgeons for user-specific modifications in the existing designs and create personalized new designs. They can be directly fabricated using rapid prototyping methods for developing low-cost training apparatus [6]. Database can be used by researchers for development of virtual reality trainers, video based neuro-navigation and neurosurgical e-learning platforms [7, 8]. Hence, a repository of the scanned data, CAD models and motion simulations can be of significant importance.

For creating virtual models of the fine instruments, accurate measurement of dimensions is required. This can be achieved using commercially available surface scanners [9–11]. Among these, blue light scanning is a suitable technology for scanning of neurosurgical instruments [12, 13]. Reverse engineering is then performed on scanned data using computer aided designing tools. It involves extraction of 3D curves and interpolation of surfaces. Stereolithographic files can be created that allows direct fabrication of prototypes using additive manufacturing [14]. A range of additive manufacturing technologies is now commercially available that can fabricate prototypes in various materials. Direct metals laser sintering (DMLS) is the most appropriate method for neurosurgical instruments. DMLS allows fabrication in medical grade stainless steel and titanium materials. Fused

This work was financially supported by Dept. of Science and Technology (DST), Ministry of Science and Technology, Govt. of India under Instrumentation Development Program (IDP).

978-9-3805-4421-2/16/$31.00 ©2016 IEEE

deposition modeling and poly-jet printing can also be used for fabrication using plastic and rubber materials respectively [15, 16].

The aim of the present study was the development of a virtual repository of neurosurgical instruments. The existing instruments were classified according to their function and approach. The surface data was acquired using blue light scanning. Reverse engineering was performed by Computer Aided Designing and motion simulations were created. Using the developed repository, selected instruments were manufactured by additive manufacturing technique. One neurosurgical instrument was modified according to the feedback of neurosurgeons. A surgical animation for microscopic aneurysm clipping was developed. Computer vision based algorithm was also implemented to demonstrate the application of repository in skills evaluation.

II. METHODOLOGY

A. Classification

During a neurosurgical procedure, the surgeons create access to the anatomical site of importance with the help of various instruments. Each instrument is used for a particular task and instruments are switched according to the need. Figure 1. illustrates the various instrument used in a typical neuro-endoscopic endonasal surgical approach. Currently available microscopic and neuro-endoscopic instruments were classified into various categories based on their function.

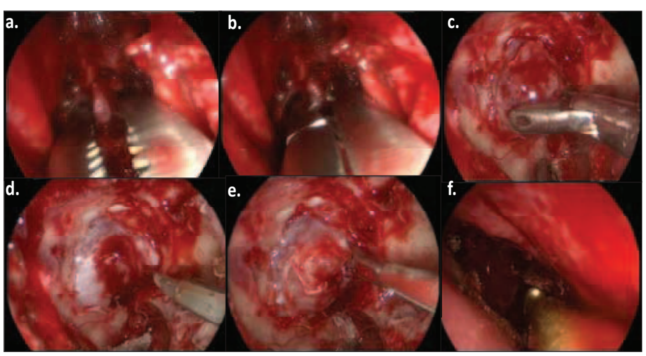

Fig. 1. Neuroendoscopic instruments used for (a) nibbling with crocodile jaw, (b) nibbling straight jaw, (c) Grasping, (d) Cutting (knife),(e) Cutting (scissors), (f) Backbiting

B. Blue Light Scanning

The surface data of all the instruments was acquired using Steinbichler Comet L3D 2 Megapixel blue light 3D scanner as shown in Figure 2. Tripod stand was used to fix the scanner. The scanner was calibrated using traceable calibration method prior to data collection. A thin layer of powdered chalk was sprayed on the instruments to prepare the even surface and mask their glossy finish.

Fig. 2. Blue light scanning data of microscopic and neuro-endoscopic instruments

Positional markers were placed on the instruments. Instruments were placed on the automatic rotary table and data was captured using a rotation angle of 60^0. Comet plus software was then used to merge the scans captured from different orientations. Noise reduction, filtering and gap filling operations were also applied to the merged data. STL file of the merged models was created.

C. Computer Aided Modeling

Unigraphics NX 6 CAD software (Unigraphic Solutions Inc, Plano, Texas, 2002) was used for reverse engineering of scanned instruments. STL file of blue light scanned data was imported. Data was aligned to the coordinate system of the software using datum plane made by two line method. Section curves were extracted from the scan data. B-splines and 3D curves were drawn from these extracted curves and then used to extract surfaces. B-spline is a spline function that is a linear combination of the control points and has minimal support for given degree and smoothness. This allows design of complex shapes with lower degree polynomials. These surfaces were then converted into 3D solid model by using features of solid modeling. Various design features like edge blend, chamfer were applied to smoothen the sharp edges and corners.

D. Motion Simulation

CAD models represent the dimensional details of the instruments. For demonstrating the functionality of the instruments in a more efficient way, motion simulations were developed. The CAD model was exported in 3DS MAX/MAYA software. The preprocessing was performed to smooth surfaces and hide the unnecessary features in the animations. The texturing of the stainless steel material was applied to the model. Then turntable Cameran of the instrument function was created.

E. Rapid Prototyping

Biopsy forceps an instrument used in neuro-endoscopy was fabricated in ABS plastic material using Fused Deposition Modeling (Stratasys dimension elite 3D printer). Micro-forceps an instrument used for performing fine micro-suturing was fabricated in stainless steel material using Direct Metal Laser Sintering (EOS Germany).

III. Results

A. Classification

The neurosurgical instruments were classified into various categories based on their function as shown in Table I.

TABLE I. FUNCTIONAL CLASSIFICATION OF INSTRUMENTS

S. No.	Function	Microscopy	Neuro-endoscopy
1	Cutting	Micro Scissors	Endo-scissors
2	Grasping	Forceps, Needle Holders	Biopsy Forceps
3	Clipping	Aneurysm Clips, Clip Applicators	-
4	Nibbling/ Punching	Ronguers	Up cutter/Back cutters
5	Scraping	Micro curettes	Endo curettes
6	Incising	Scalpels, Dissectors	Endo-knife
7	Retracting	Retractors, Hooks	-
8	Assist	Suction and irrigation	Endoscope Holder, Suction

B. Development of new designs and rapid prototyping

Micro-forceps is used under operating microscope at high magnification (17x). The existing micro-forceps have the inter-tip distance of 8 mm, which results in difficulty in holding the suture or needle. Hence, the design was modified using the virtual model from the repository. The inter-tip distance was reduced to 2.8 mm and the length of the tip was increased by 5mm to avoid occlusion in the microscope view (Figure 3).

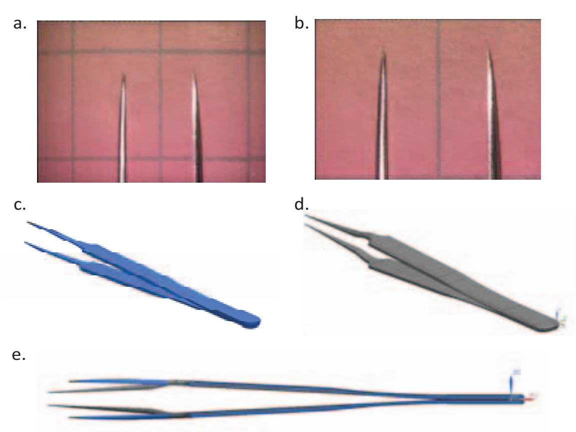

Fig. 3. Modification of existing micro forceps: (a) 15x magnification, (b) 17x magnification, (c) blue light scanning data, (d) modified micro-forceps, (e) superimposed scan data and CAD model to highlight the changes.

The modified micro-forceps was fabricated using fused deposition modeling and direct metal laser sintering. Several other instruments such as biopsy forceps and clip applicators were also fabricated for training.

C. Training: E-learning, Virtual simulations and navigation systems

The instruments from the virtual repository were used for creating a surgical animation of aneurysm clipping. The animation demonstrates the various steps involved in aneurysm clipping and functioning of the instruments that are used for performing specific tasks (Figure 4).

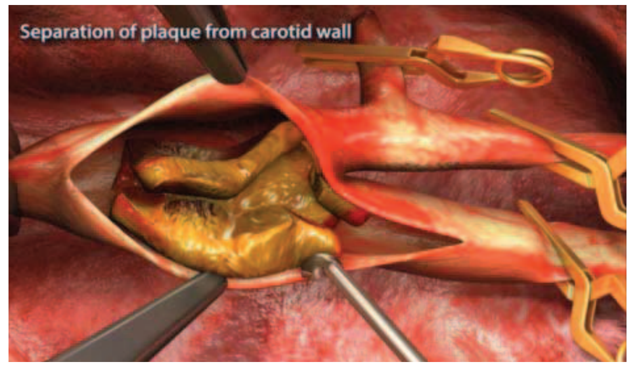

Fig. 4. Animation to demonstrate the procedure aneurysm clipping in micro-neurosurgery and function of instruments

Computer vision based analysis was also performed using the 3D models of instruments of the virtual repository. The model-fitting is performed on the video for appropriate positioning or registering of the instrument based on its pose as shown in Figure 5.

Fig. 5. Computer vision based tool matching for surgical skills evaluation

The change in pose is estimated from the videos and the instrument is mapped accordingly [17–19]. This is used for identifying the 3D position of the instruments for surgical skills evaluation.

IV. Discussion

Neurosurgery procedures involve optical devices for visualization: microscopes and neuro-endoscopes and surgical tasks are performed by various microscopic and endoscopic instruments. The instruments used in both the techniques vary according to the required maneuverability. The neuro-endoscopic instruments have long shafts and small end-effectors for the access to the site using smaller incisions. The design and modeling of instrumentation with such varied dimension are a challenging task. An attempt to functionally classify various instruments used in neurosurgery and development of a virtual repository has been the objective of the current study.

The primary requirement for the creation of virtual models of neurosurgical instruments is the measurement of dimensions with high accuracy. Blue light scanning is a suitable technique for acquiring dimensions as it saves time and also provide exact dimensions and curvatures, whereas manual measurement requires specified manpower, long time and also results in errors in measurement. However, minimum resolution of 5 megapixels is required to obtain data of the fine tips of the instruments. For long instruments, the scan has to be performed in parts and then the model is finished by merging the scans.

The virtual repository is an efficient starting aid for the development of new designs of the instrumentation [20–22]. The 3D models in the repository are specimens that can be easily modified to obtain a new design like changing the dimensions, angle of the tip or adding new features. The 3D models can be exported to the standard stereolithography format and used directly used for rapid prototyping. The already existing instruments can be printed in plastic and can be used for training tasks in surgical simulation labs on physical and synthetic simulators. The direct metal laser sintering of the instrument model is also suitable for clinical validation of new designs. The prototyping cost per unit of a new design for validation studies is much lesser with the help of advanced rapid prototyping techniques as compared to the traditional subtractive manufacturing methods [20].

3D virtual models can be used as teaching tools for e-learning modules. The e-learning in Neurosurgery includes a demonstration of various surgical approaches and use of related instruments. It involves demonstration of how expert neurosurgeons perform surgery and do's and don'ts during surgery. These can be explained virtually with animations and simulations without the requirement of cadavers. Animations of the tool assembly, the positioning of the patient, appropriate usage of instruments and surgical step description requires 3D models of the existing instruments[23, 24]. Hence, the developed Virtual repository plays a vital role as a database for development of e-learning platform.

Another way of imparting training includes virtual reality simulators. The development of virtual reality simulators also includes the use of 3D models of the instruments. The virtual models of various instruments and their interaction with the virtual models of tissues need to be mathematically modeled for virtual reality simulators [25, 26]. The appropriate selection of the instruments is another cognitive skill required for the surgeon and various instrument models available in the repository helps the designing of the virtual training setup.

The current virtual reality simulation based procedural training for neurosurgery requires various instruments in the simulation platform for realistic rendering and feedback. The force feedback can be modeled according to user interaction with the real or haptic system and the corresponding output is delivered with the virtual interaction of the instrument with the type of tissue [27, 28]. This requires technical expertise regarding the mechanical properties of the instrument as well as the interacting tissues. 3D simulations with appropriate force calculations, auditory, and visual feedback provide high state of realism and helps the trainee get involved in the training procedure and can learn better.

Apart from the applications demonstrated for the virtual repository, it can also be used for simulation of electronic designs [29, 30]. The electronic components can also be modeled and the force, pressure and load of the instrument with and without electronic components can be studied with the help of finite element analysis. The 3D models can also be used to create 2D drawings for understanding the mechanisms [31]. It is an integral part of new design development and also for force modeling and tissue interaction. The virtual repository can be made available online as open source content for research related to neurosurgical instruments.

V. Conclusion

A virtual repository of the existing microscopic and neuro-endoscopic instruments has been created. The developed virtual models were used for various applications such as design modification, additive manufacturing, training and evaluation of surgical skills. Such a repository has a high potential for conducting research related to neurosurgical instruments.

Acknowledgment

We would like to acknowledge the efforts of scientific, technical and application specialist from Neurosurgery Skills Training Facility, Neurosurgery Education and Training School, All India Institute of Medical Sciences, New Delhi, India.

References

[1] K. Uluç, G. C. Kujoth, and M. K. Başkaya, "Operating microscopes: past, present, and future", Neurosurg. Focus, vol. 27, no. 3, p. E4, Sep. 2009.

[2] V. Siomin and S. Constantini, "Basic principles and equipment in neuroendoscopy", Neurosurg. Clin. N. Am., vol. 15, no. 1, pp. 19–31, Jan. 2004.

[3] D. Catapano, C. a Sloffer, G. Frank, E. Pasquini, V. a D'Angelo, and G. Lanzino, "Comparison between the microscope and endoscope in the direct endonasal extended transsphenoidal approach: anatomical study", J. Neurosurg., vol. 104, no. 3, pp. 419–25, Mar. 2006.

[4] M. Mihara, Y. Hayashi, T. Iida, M. Narushima, and I. Koshima, "Instruments for super microsurgery in Japan", Plast. Reconstr. Surg., vol. 129, no. 2, p. 404e–406e, Feb. 2012.

[5] M. R. Gaab, “Instrumentation: endoscopes and equipment”, World Neurosurg., vol. 79, no. 2 Suppl, pp. S14.e11–21, Feb. 2013.

[6] J. Tuomi, K. S. Paloheimo, J. Vehviläinen, R. Björkstrand, M. Salmi, E. Huotilainen, R. Kontio, S. Rouse, I. Gibson, AA. Mäkitie, “ A novel classification and online platform for planning and documentation of medical applications of additive manufacturing”, Surgical innovation, vol. 21, no. 6, pp. 553-9, Dec 2014.

[7] M. Vankipuram, K. Kahol, A. McLaren, and S. Panchanathan, “A virtual reality simulator for orthopedic basic skills: A design and validation study”, J. Biomed. Inform., vol. 43, no. 5, pp. 661–668, Oct 2010.

[8] A. P. Mitha, M. a Almekhlafi, M. J. J. Janjua, F. C. Albuquerque, and C. G. McDougall, “Simulation and augmented reality in endovascular neurosurgery: lessons from aviation”, Neurosurgery, vol. 72 Suppl 1, no. January, pp. 107–14, Jan. 2013.

[9] L. M. Galantucci, G. Percoco, G. Angelelli, C. Lopez, F. Introna, C. Liuzzi, and a De Donno, “Reverse engineering techniques applied to a human skull, for CAD 3D reconstruction and physical replication by rapid prototyping”, J. Med. Eng. Technol., vol. 30, no. 2, pp. 102–111, March. 2006.

[10] L. Li, N. Schemenauer, X. Peng, Y. Zeng, and P. Gu, “A reverse engineering system for rapid manufacturing of complex objects”, Robotics and Computer-Integrated Manufacturing” vol. 18, pp. 53–67, Feb 2002.

[11] M. J. Milroy, D. J. Weir, C. Bradley, and G. W. Vickers, “Reverse engineering employing a 3D laser scanner: a case study”, Int. J. Adv. Manuf. Technol., vol. 12, pp. 111–121, March 1996.

[12] L. Ma, T. Xu, and J. Lin, “Validation of a three-dimensional facial scanning system based on structured light techniques”, Comput. Methods Programs Biomed., vol. 94, no. 3, pp. 290–298, Jun. 2009.

[13] C. Bernal, B. De Agustina, M. M. Marín, and a. M. Camacho, “Performance evaluation of optical scanner based on blue LED structured light”, Procedia Eng., vol. 63, no. Cmm, pp. 591–598, Dec. 2013.

[14] J. Y. Choi, J. H. Choi, N. K. Kim, Y. Kim, J. K. Lee, M. K. Kim, J. H. Lee, and M. J. Kim, “Analysis of errors in medical rapid prototyping models”, Int. J. Oral Maxillofac. Surg., vol. 31, no. 1, pp. 23–32, Feb. 2002.

[15] D. Manfredi, F. Calignano, M. Krishnan, and R. Canali, “From Powders to Dense Metal Parts: Characterization of a Commercial AlSiMg Alloy Processed through Direct Metal Laser Sintering”, Materials, pp. 856–869, Mar. 2013.

[16] J. Y. Wong and A. C. Pfahnl, “3D Printing of Surgical Instruments for Long-Duration Space Missions”, Aviat. Space. Environ. Med., vol. 85, no. 7, pp. 758–763, Jul 2014.

[17] R. Poppe, “Vision-based human motion analysis: An overview,” Comput. Vis. Image Underst., vol. 108, pp. 4–18, Nov. 2007.

[18] H. Azizpour and I. Laptev, “Object Detection Using Strongly-Supervised Deformable Part Models,” Eur. Conf. Comput. Vis., pp. 836–849, Jan 2012.

[19] R. S. Sidhu, D. Tompa, R. Jang, E. D. Grober, K. W. Johnston, R. K. Reznick, and S. J. Hamstra, “Interpretation of three-dimensional structure from two-dimensional endovascular images: implications for educators in vascular surgery.,” J. Vasc. Surg., vol. 39, no. 6, pp. 1305–11, Jun. 2004.

[20] R. Kontio, R. Björkstrand, M. Salmi, M. Paloheimo, K. Paloheimo, J. Tuomi, and A. A. Mäkitie, “Designing and Additive Manufacturing A Prototype for A Novel Instrument for Mandible Fracture Reduction,” pp. 2–4, Jan 2012.

[21] A. Meining, D. Roppenecker, A. Schneider, and T. Lüth, “A new instrument for endoscopic submucosal dissection: The ‘EndoDissector,”, Gastrointestinal Endoscopy, vol. 44, no. 4, 2012.

[22] S. Jayaraman, a L. Trejos, M. D. Naish, a Lyle, R. V Patel, and C. M. Schlachta, “Toward construct validity for a novel sensorized instrument-based minimally invasive surgery simulation system”, Surg. Endosc., vol. 25, no. 5, pp. 1439–45, May 2011.

[23] P. Jotwani, V. Srivastav, M. Tripathi, R. C. Deo, B. Baby, N. Damodaran, R. Singh, A. Suri, M. Bettag, T. S. Roy, C. Busert, M. Mehlitz, S. Lalwani, K. Garg, K. Paul, S. Prasad, S. Banerjee, P. Kalra, S. Kumar, B. S. Sharma, and A. K. Mahapatra, “Free-access open-source e-learning in comprehensive neurosurgery skills training”, Neurol. India, vol. 62, no. 4, pp. 352–61, Jul 2014.

[24] S. Thomson, “Ebrain: the Electronic Learning Platform for Clinical Neuroscience”, Br. J. Neurosurg., vol. 27, no. 5, pp. 577–9, Oct. 2013.

[25] R. Källström, “Construction, Validation and Application of a Virtual Reality Simulator for the Training of Transurethral Resection of the Prostate”, no. 1167. 2010.

[26] J. Gasco, A. Patel, C. Luciano, T. Holbrook, J. Ortega-Barnett, Y.-F. Kuo, S. Rizzi, P. Kania, P. Banerjee, and B. Z. Roitberg, “A novel virtual reality simulation for hemostasis in a brain surgical cavity: perceived utility for visuomotor skills in current and aspiring neurosurgery residents”, World Neurosurg., vol. 80, no. 6, pp. 732–7, Dec. 2013.

[27] N. Galoppo, S. Tekin, M. A. Otaduy, M. Gross, and M. C. Lin, “Interactive Haptic Rendering of High-Resolution Deformable Objects”, Virtual Reality. Springer Berlin Heidelberg, pp. 215-223, Jan 2007.

[28] H. Iqbal and T. Aized, “Workspace analysis and optimization of 4-links of an 8-DOF haptic master device”, Rob. Auton. Syst., vol. 62, no. 8, pp. 1220–1227, Aug. 2014.

[29] K. Takemura, S. Park, and T. Maeno, “Control of multi-dof ultrasonic actuator for dexterous surgical instrument”, J. Sound Vib., vol. 311, pp. 652–666, Apr 2008.

[30] H.-C. Chang, J. M.-L. Tsai, H.-C. Tsai, and W. Fang, “Design, fabrication, and testing of a 3-DOF HARM micromanipulator on (111) silicon substrate,” Sensors Actuators A Phys., vol. 125, no. 2, pp. 438–445, Jan. 2006.

[31] J. J. B. Lim and A. G. Erdman, “A review of mechanism used in laparoscopic surgical instruments,” Mech. Mach. Theory, vol. 38, pp. 1133–1147, Nov 2003.