Producing a 3D Animation on Concussions

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"Seeing the Invisible Injury" provides an educational tool about concussion for the lay public, athletes, parents, coaches, and medical professionals. This four-minute video was designed to increase public awareness of the seriousness of concussions by communicating the effects of concussive injuries on the brain, at both the gross and cellular levels, using dynamic visual imagery. This paper describes the production process, with an emphasis on the integration of software tools.

Introduction

Concussion is a type of traumatic brain injury sustained by many recreational and professional athletes of all ages (Laker 2011). Although a large number of concussive injuries are likely not reported, it has been estimated by the Centers for Disease Control and Prevention (CDC) that approximately 135,000 individuals with sports-related concussion are seen at emergency departments in the United States each year (CDC 2012). Public awareness regarding the seriousness of concussions and the potentially negative side-effects has increased in recent years, especially since many professional athletes who have experienced numerous concussions have been featured in the media (Miller 2009, Alfonsi 2011, Malakoff 2013).

The dedication and perseverance required to succeed in sports often necessitates a defiant attitude towards pain and discomfort. For this reason, until very recently, concussions were viewed as an "insignificant injury" and the negative consequences of underestimating the seriousness of concussion were not considered (Gladwell 2009). Fortunately, educational materials have been shown to change this perception. For example, the CDC designed an information tool kit, consisting of printed material only, which was piloted with 333 athletic coaches in the United States. On follow-up, 50% of coaches using the tool kit reported that it "changed their views about the seriousness of the injury" (Sarmiento 2010). Although the study indicated that awareness of concussion was somewhat increased through education, more visual and easily accessible educational tools need to be developed, targeting coaches, athletes and the lay public, including parents.

The currently available visual resources for depicting concussion include: interview-style videos, colloquially known as "talking heads"; medical-legal illustrations, sometimes accompanied by animations; and print media.

Educational videos about concussion usually consist of interviews with medical and scientific experts, along with individuals who have suffered one or more concussions. These videos often include stock footage of athletes at play and may show a real or staged injury occurring (CDC 2008, NATA 2010, Evans 2011). Sometimes, still images of brain scans are included and may be the only illustrative component. Thatcher (2006) found that animations were superior to textbook learning −that is, printed material − in "improving comprehension and eliciting interest in the lessons".

Medical-legal visualizations are used as demonstrative evidence to highlight mechanisms of injury relative to a specific case. Since concussion can be a severe injury, resulting in permanent disability, it is frequently depicted visually for judges and juries. The range of medical-legal exhibits includes printed illustrations on boards, interactive displays or either 2D or 3D animations. Three-dimensional animations can be costly and are time-consuming to produce.

Print and electronic media are the most common forms of education related to concussion for the lay public. Print media can include brochures, information packets, and newspaper or magazine articles. In the present context, electronic resources are more widely available and consist of stock images, medical images and illustrations that accompany topical articles. These can be found online at medical, health, and news sites (Mayo Clinic 2011, CDC 2012).

Sarmiento et al. clearly demonstrated the need for more educational material directed to the lay public about the seriousness of concussion (Sarmiento 2010). In order to be effective, educational media needs to be current, captivating and informative (Tversky 2002). Therefore, the goal of this project was to create an animated video, "Seeing the Invisible Injury," about the events leading to brain injury during a concussion-level impact. There were two main objectives: (1) to communicate to a lay audience, through a short 3D animation, the current understanding of the physical response by the brain to high acceleration and deceleration forces; and (2) to depict the resultant diffuse axonal injury. The anticipated lay audience would include

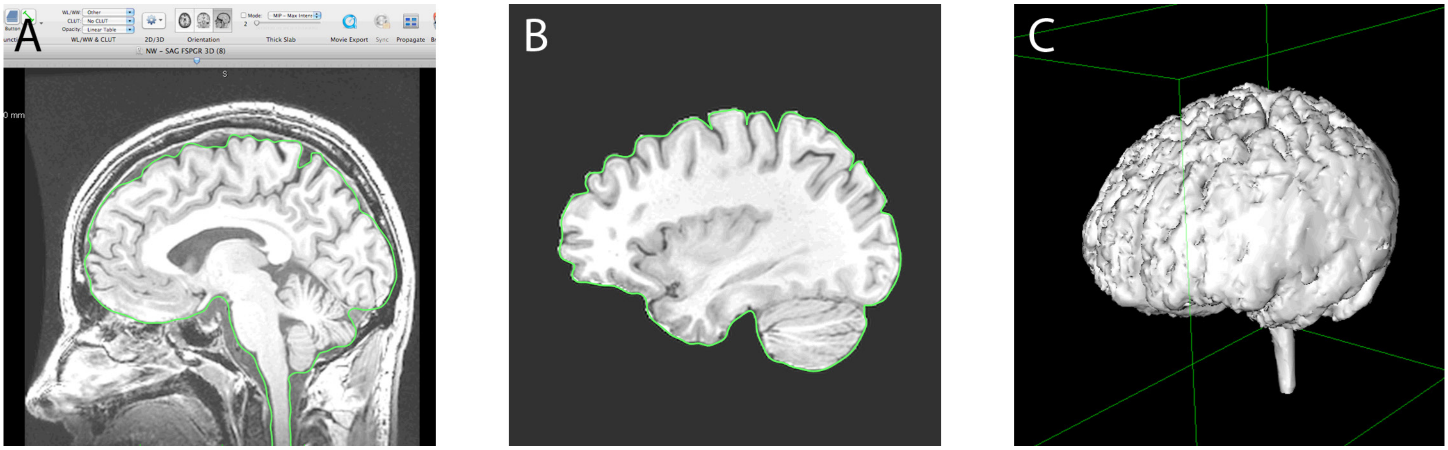

Figure 1. Reconstruction of brain from CT data using OsiriX*. A) Region of Interest (ROI) tools were used in OsiriX to isolate the brain from surrounding anatomy. B) Once isolated, the CT images could then be used to build a 3D model. C) OsiriX produces an exportable 3D surface rendering.*

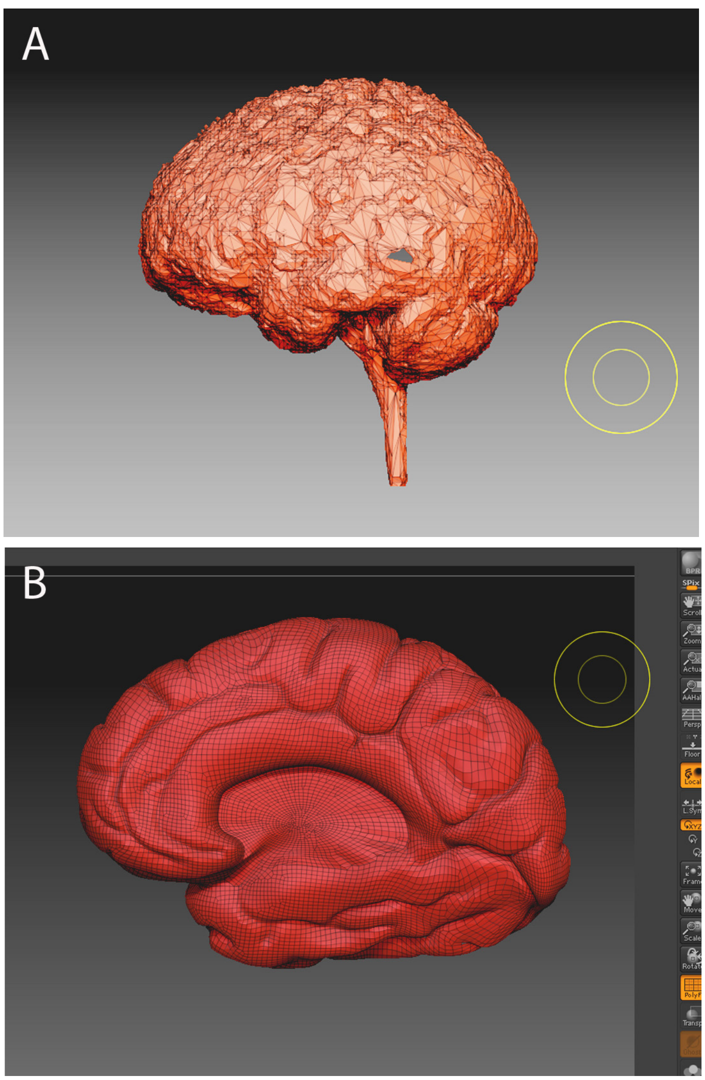

Figure 2. Retopology. *A) 3D reconstruction with disorganized triangular geometry. B) Clean geometry allows for sculpting fine surface details in ZBrush®.*

athletes, coaches, referees, sports officials, media personnel, and parents.

Methods

The storyboards and script for the animation were developed through a two-stage process consisting of: (1) a literature review; and (2) consultation with content experts, including clinicians and researchers in sports medicine, neurology, neurosurgery, and neuroscience.

The storyboarding stage is critical to the production process because the images depicted on the storyboard panels will identify the key frames of the animation, and the pacing of shots will be influenced by the duration of voice-over audio clips, as determined by the script.

Previsualization

In the literature review, papers in three main areas of concussion research were identified and reviewed. These were: (1) pathophysiology of concussion (Barkhoudarian et al. 2011, Meaney et al. 2011, Signoretti et al. 2011); (2) deformation of the brain induced by rapid acceleration forces (Bayly et al. 2005, Sabet et al. 2008, Feng et al. 2010); and (3) structural changes at the cellular level, including axonal and microtubule damage (Smith et al. 2003, Xu et al. 2007, Niogi et al. 2008, Sabet et al. 2008, Tang-Schomer et al. 2010).

The majority of existing visualizations that were identified focused on the coup/contrecoup theory of head injury. However, the current literature suggests that the major mechanism of injury is related to rapid acceleration forces and the resulting tissue deformation (Xu et al. 2007, Niogi et al. 2008, Sabet et al. 2008). The lay audience may not be aware of this new information, and all content experts agreed that this should form the basis of which the animation was designed.

Brain modeling

The 3D brain model that formed the basis of the animation

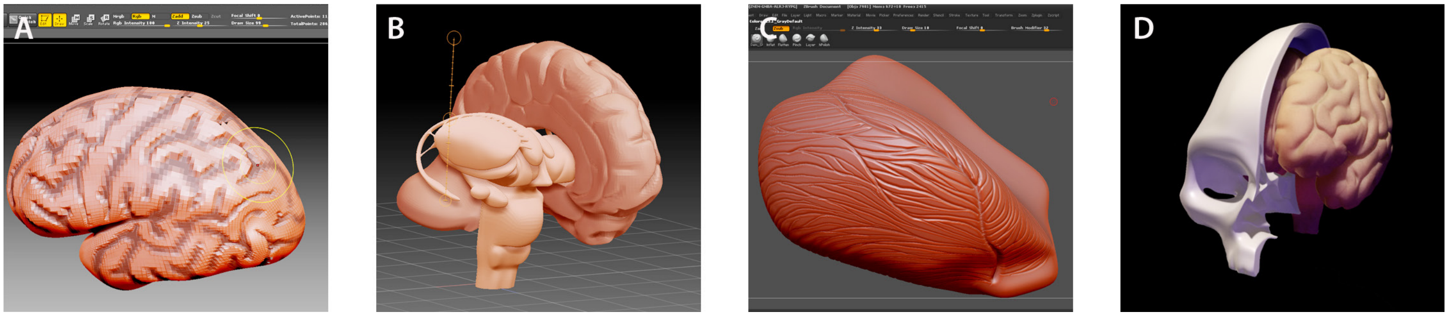

Figure 3. Modeling process. *A) Cerebral cortex: masking by depth in ZBrush®. B) Matching internal structures to cortex. C) Sculpting details of cerebellar cortex. D) Brain integrated with cranium, final rendering done in Autodesk® Maya®.*

was reconstructed from a series of transverse MRI scans. The images were converted from DICOM (Digital Imaging and Communications in Medicine) images to a volume representation using OsiriX (Rosset 2004), and region of interest (ROI) tools were used to isolate the structures to be modeled (Figure 1). The advantage of using OsiriX as a first step is that it provides an accurate representation of the overall form of the brain. OsiriX uses algorithms that can make an isosurface mesh, derived from a specified tissue density in the series. The resulting obj file (Figure 2), which is composed of triangular polygons, has artifacts that obscure the fine detail of the sulci and gyri. To produce a model with clean geometry, this template was imported into Maya® (Autodesk Inc., San Rafael, CA, USA) for retopologizing (the process of recreating the morphology of a 3D mesh, while reorganizing its' polygon structure) and then sculpted in ZBrush® (Pixologic.com).

The OsiriX model was exported and then brought into Maya to build a low-resolution polygon form. This low-resolution geometry was then exported to ZBrush for sculpting surface details (Figure 3). ZBrush has the ability to not only mask portions of the 3D mesh, but also to selectively mask areas based on their overall depth. By masking off only the cavities of the mesh, it is possible to isolate the gyri of the cerebral and cerebellar cortices. By inverting the mask, it is possible to selectively manipulate the sulci. The refined ZBrush model with clean geometry was then sent back to Maya for the addition of internal structures including the thalamus, hypothalamus, hippocampus, caudate nucleus, medial and lateral globus pallidus, and amygdala. These structures were reconstructed using the scan series as a reference.

Animation

The first step in animation is to determine the positioning of cameras (1-3 cameras may be used depending on the shot) using proxy models (Figure 4a). The composition of the shots, duration, and timing are determined by the script and storyboard. The animation and rendering of high-resolution models in professional 3D applications, such as Maya, require powerful computing infrastructure, involving the computation of millions of vertex points, and the floating-point intensive calculation of final images. The computation-intensive nature of these phases of the project, were accomplished on 8-core Mac Pros with 10GBs of RAM.

The lattice deformer tool in Maya was used to build a network of vertices around the 3D brain model (Figure 4b). By moving individual lattice points, corresponding deformations in the 3D mesh can be animated. To animate brain deformation during a concussive injury, the findings from an MRI study by Sabet et al. (2008) were used to model brain tissue movement within the skull.

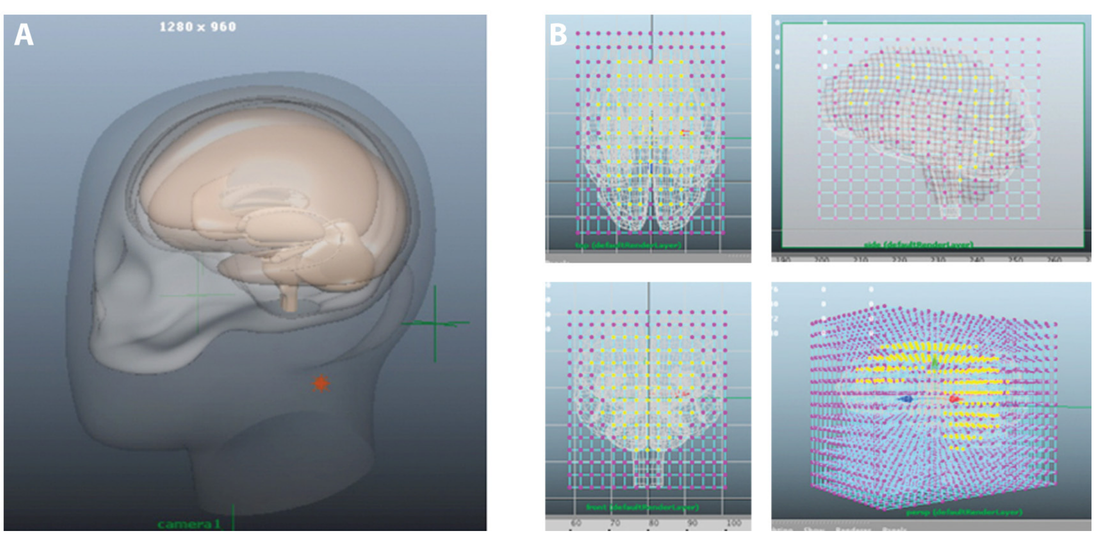

Figure 4. Animation process. *A) Timing and camera movement are developed with proxy models. B) Lattice deformer tool used to deform brain model.*

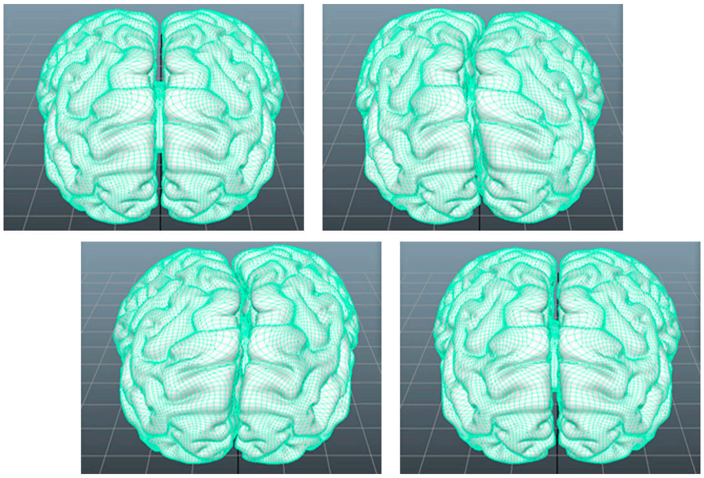

Figure 5. Blend shape tool used to animate brain deformation.

The authors investigated the movement of brain tissue during mild head accelerations using grids superimposed on axial MRI images, recorded in real-time, and multiplied the displacement by a factor of five for better visualization of tissue deformation. The blend-shape animation technique, which allows for keyframing between an unaltered model and a deformed model, was used to animate the shots (Figure 5).

Individual animated shots were composited together in Adobe After Effects® (Adobe Systems, Inc., San Jose, CA). Rendered animation from Maya was combined with narration, sound effects and labels (Figure 6). Music and sound effects were downloaded from freesfx.co.uk, under a Creative Commons license. This final stage of production allowed for smooth transitioning between segments, adjustment of shot duration, and appropriate script revisions.

Axonal Shearing and Microtubule Disruption

The axonal shearing and microtubule disruption animations were based on the papers identified in the literature review and discussions with content experts. Images in the papers were an excellent source of visual reference.

To model the nerve cell, photomicrographs from the literature and existing animations from the biomedical communications field were reviewed. As a prototype, one nerve cell including the dendrites, cell body, and axon, was modeled in Maya and duplicated to produce the cellular landscape (Figure 7a,b). The geometry of the prototype was animated to show axonal shearing using the lattice deformer and blend-shape tools. The animated nerve cell was multiplied with instance copies of the original model to create the grey matter and grey-white matter interface of the cerebral hemispheres. The cellular landscape showing the axonal shearing was then composited, as was predetermined in the storyboard (Figure 7c).

To simulate microtubule disruption within an axon, a new model with an increased number of vertices was produced to enable detailed dynamic simulation in Maya. This animation focused on the region of a node of Ranvier and included the myelin sheath, cell membrane of the axon and microtubules contained within the axonal cytoplasm (Figure 8a). The nCloth features of Maya were used to produce a convincing and realistic disruption. When using these features, attributes such as collision thickness and elasticity ensure that these dynamic objects interact with

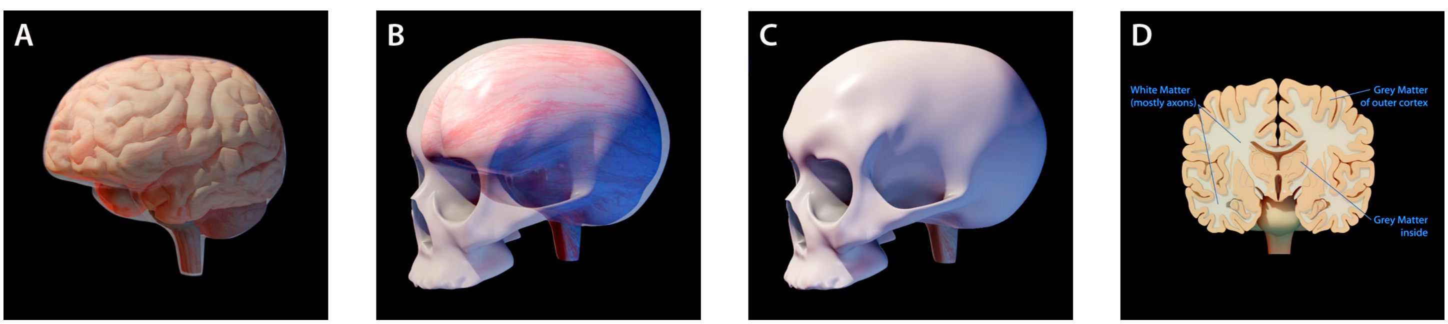

Figure 6. Compositing phase. *A) Brain with meninges partially faded showing outline of cerebral hemispheres. B) Transitioning from brain to cranium. C) Cranium with brain no longer visible. D) Labeling of key structures.*

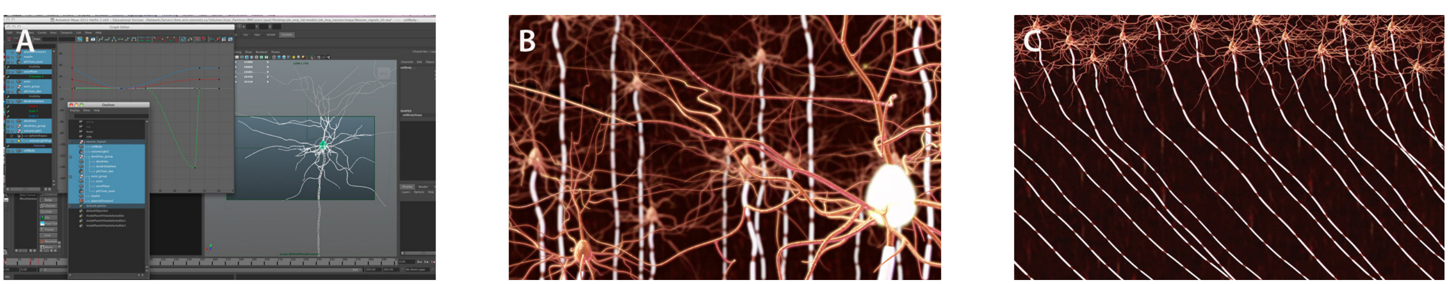

Figure 7. Nerve cell animation. *A) Nerve cell was modeled, UV mapped and animated in Maya®. B) Instance copying was used to produce the cellular landscapes. C) The same model was used to visualize axonal shearing.*

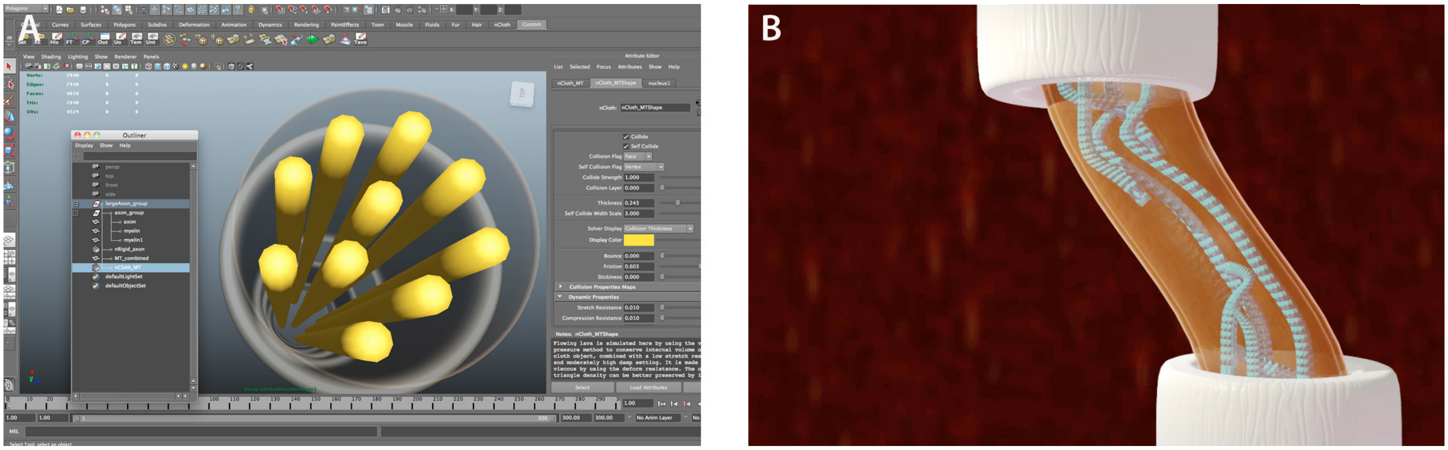

***Figure 8. Dynamics in Maya*®.** *A) Controls are provided to alter the physical properties of dynamic objects in Maya. B) Experimentation with dynamics attributes settings is required to produce a desired visual effect.*

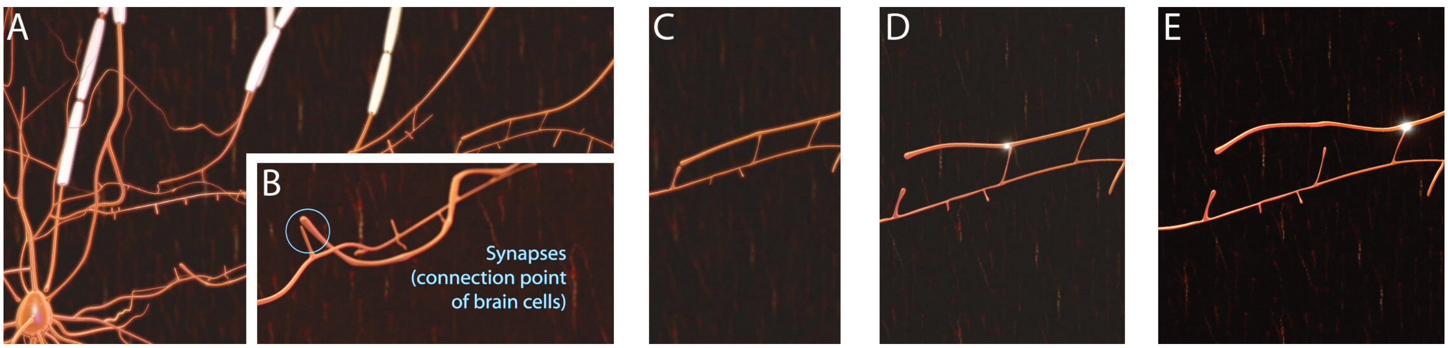

Figure 9. Synapse disconnection. *The terminal end of an incoming axon disconnects from the dendrites of the featured brain cell, a sequential view from left to right.*

each other in a realistic way. Since dynamic simulations leave the animator with little control of the outcome, apart from setting the initial conditions, many iterations of microtubule disruption were run in order to produce an animation that would effectively communicate microtubule damage (Figure 8b).

Synapse Disengagement

To show synapse disengagement, another model showing the synapse between an axon and dendrite of two nerve cells was created in Maya. To visualize the separation of the axon from the dendrite, only one component needed to be animated; in this case, the axon was chosen (Figure 9). The animation was achieved, as with the microtubule disruption, using the dynamic features of nCloth. The level of detail incorporated into the animation was tailored to the target audience, as outlined on the storyboard.

Discussion

This animated video provides an educational tool for the lay public, athletes, parents, coaches, and medical professionals. Because of its four-minute running time, the video is compact enough to be easily incorporated into educational materials. It is anticipated that this video will help to increase public awareness of the seriousness of concussions by communicating the effects of concussive injuries on the brain, using dynamic visual depictions of damage at the cellular level.

Concussion research has advanced rapidly in recent years, and there is scope for even more extended and complex depictions of the science. Time constraints limited the number of anatomical models and dynamic animation sequences that could be included in the present project. For example, the number of anatomical structures depicted in the model could be increased and brain tissue deformation and microtubule dynamics could be simulated using more robust, yet time-consuming, methods. Given a greater time budget, a more detailed and realistic depiction of brain tissue deformation, using the anatomical surface model, could be achieved by utilizing the nCloth dynamics engine, which was employed for the microtubule visualization. A more traditional 3D animation technique—Maya's blend shape tool—was used to deform the brain model in this project. Maya's nCloth dynamics was not used due to time constraints; since simulating a polygon-dense model requires extensive experimentation and adequate processing power. A dynamics-based approach would also require the inclusion of tissue properties and the effects of multiple restraining and supportive cranial structures.

Conclusion

"Seeing the Invisible Injury" is a four-minute animated video produced to educate the lay audience about the physical response of the brain to concussive forces, and to provide an overview of the mechanism of diffuse axonal injury. This animated video, as reported by anecdotal evidence, has been well received by the targeted audience and medical professionals. The video is available online for educational purposes to the lay public and students, and has been viewed over 2,000 times at the time of writing. It can be accessed at pkvisualization.com and offline access can be licensed for medical-legal uses, clinical training programs, and other commercial purposes.

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