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Vector 3D Reconstruction of the Nerves of the Ventral Region of the Neck from Anatomical Sections of Korean Visible Human at the Laboratory of Digital Anatomy of Paris Descartes

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Abstract
Objective: To carry out a 3D vector reconstruction of the nerves of the ventral region of the neck from anatomical sections of the "Korean Visible Human" for educational purposes. Materials and Methods: The anatomical subject was a 33-year-old Korean man who died of leukemia. He was 164cm tall and weighed 55kgs. A cryomacrotome sectioned the frozen body into 5960 sections. Sections numbered 1500 to 2000 were used for this study. A segmentation by manual contouring of each nervous anatomical element of the ventral region of the neck was done using Winsurf version 3.5 software on a laptop PC running Windows 10 equipped with an 8 gigabyte RAM. Results: Our vector 3D model of nerves in the ventral neck region includes the brachial plexuses, vagus nerves, inferior and superior laryngeal nerves, glossopharyngeal nerves, hypoglossal nerves and spinal nerves. This vector model has been integrated into the Diva3d virtual dissection table. It was also uploaded to the Sketchfab website and 3D printed using an ENDER 3 printer. Conclusion: Our 3D reconstruction of the nerves of the ventral region of the neck is an educational tool for learning the nerves of the ventral region of the neck and can also serve as a 3D atlas for simulation purposes for training in therapeutic gestures.

Keywords: Nerves of the Ventral Region of the Neck, Korean Visible Human, 3D Vector Reconstruction, Diva3d Virtual Dissection Table, Teaching

1. Introduction

We have now entered the digital age. It is a real technological revolution which morphological science is no exception. Indeed, 3D modeling of human anatomy is a remarkable educational tool for teaching and understanding morphology. The future of surgery is also linked to this modeling to perform simulations, repeat surgeries or access augmented reality: modern surgery is surgery guided by the image and the 3D model. Training in human anatomy is essential at all stages of the practice of medicine: clinical examination, interpretation of medical images and surgery are based on knowledge of the anatomy of the human body. The acquisition of these skills is first theoretical and then practical with dissection. Admittedly, cadaveric dissection is the gold standard of knowledge in anatomy, on the other hand it has significant drawbacks: the lack of corpses which cannot meet the demand of medical schools, the limited location of the activity (theater anatomical) and the fact that the dissection is unique because it relies on a destructive and irreversible process on human tissue. For all these reasons, the 3D reconstruction of anatomical structures promotes new teaching methods widely used in the world, mainly successful for their new realistic and interactive interfaces. It is a wonderful tool for students keen to learn about the human body, but also for anatomy teachers and for interactive clinical simulation for practitioners (Ackerman 1999) and (Cho, Calamate, & Chi. 2012). Finally, it is a revolution for surgeons to help with preoperative planning, simulation and augmented reality when performing surgery. 3D digital anatomy opens up a new way of teaching anatomy thanks to the digital nature of data allowing quantitative morphological analysis in the context of computational anatomy (Chung, Shin, Brown. 2015). It also opens up a new way for young people to learn anatomy: by manually drawing the boundaries of anatomical structures on slices, they build 3D models that enhance deep learning, through the use of virtual reality techniques with their strong emotional impact on the learning process.

We initiated this study with the aim of performing a three-dimensional reconstruction of the nerves in the ventral region of the neck. 2.

2. Methodology

Figure 1 measures the methodology of our 3D reconstruction of the nerves in the ventral region of the neck. We performed manual segmentation by contouring each nerve structure belonging to the ventral face of the neck on 500 anatomical sections of Korean Visible Human (Figure 2). These anatomical sections were taken from a 33-year-old Korean man who died of leukemia. This man had donated his body to science. A cryomacrotome (Figure 3) made it possible to make 0.2 mm thick sections on the frozen body, ie, 5960 sections. Sections numbered 1500 to 2000 were used for our study. Then we exported the 3D objects in cad format. And then we refined and improved the 3D objects with Blender version 2.7b. This required including the use of the "Skin" modifier to achieve a more realistic display of nerves. Then we classified the list of anatomical objects with Acrobat toolkit®. Finally, we built a 3Dpdf interface with the JavaScript language (Acrobat®).
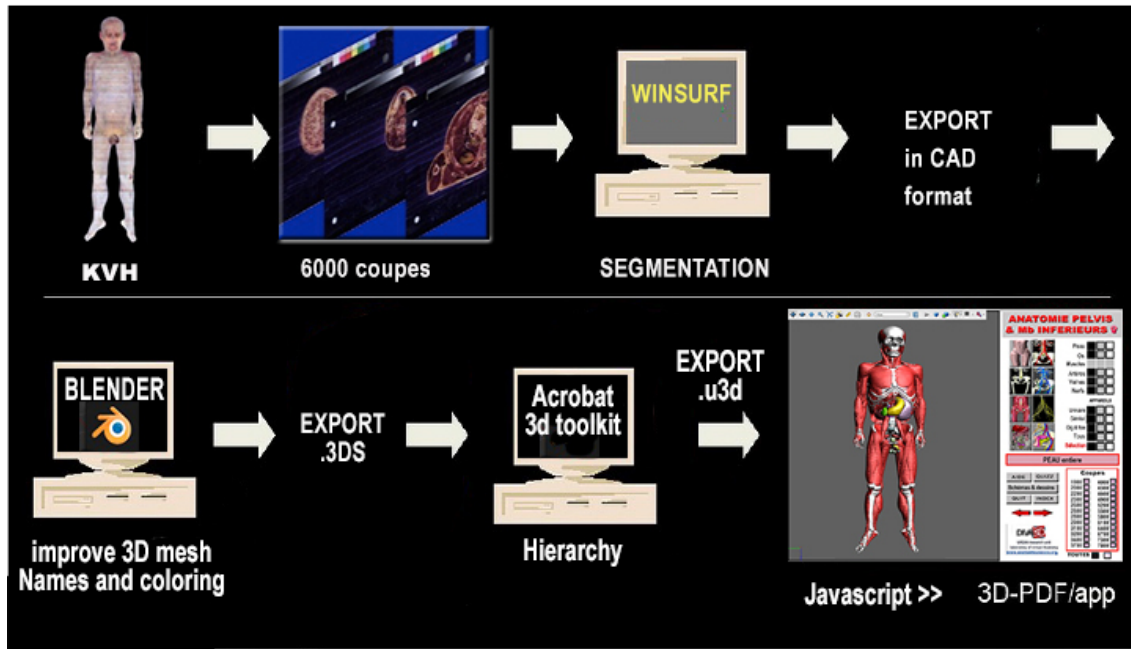
Figure 1: Methodology used to create the 3dpdf file from the anatomical sections.
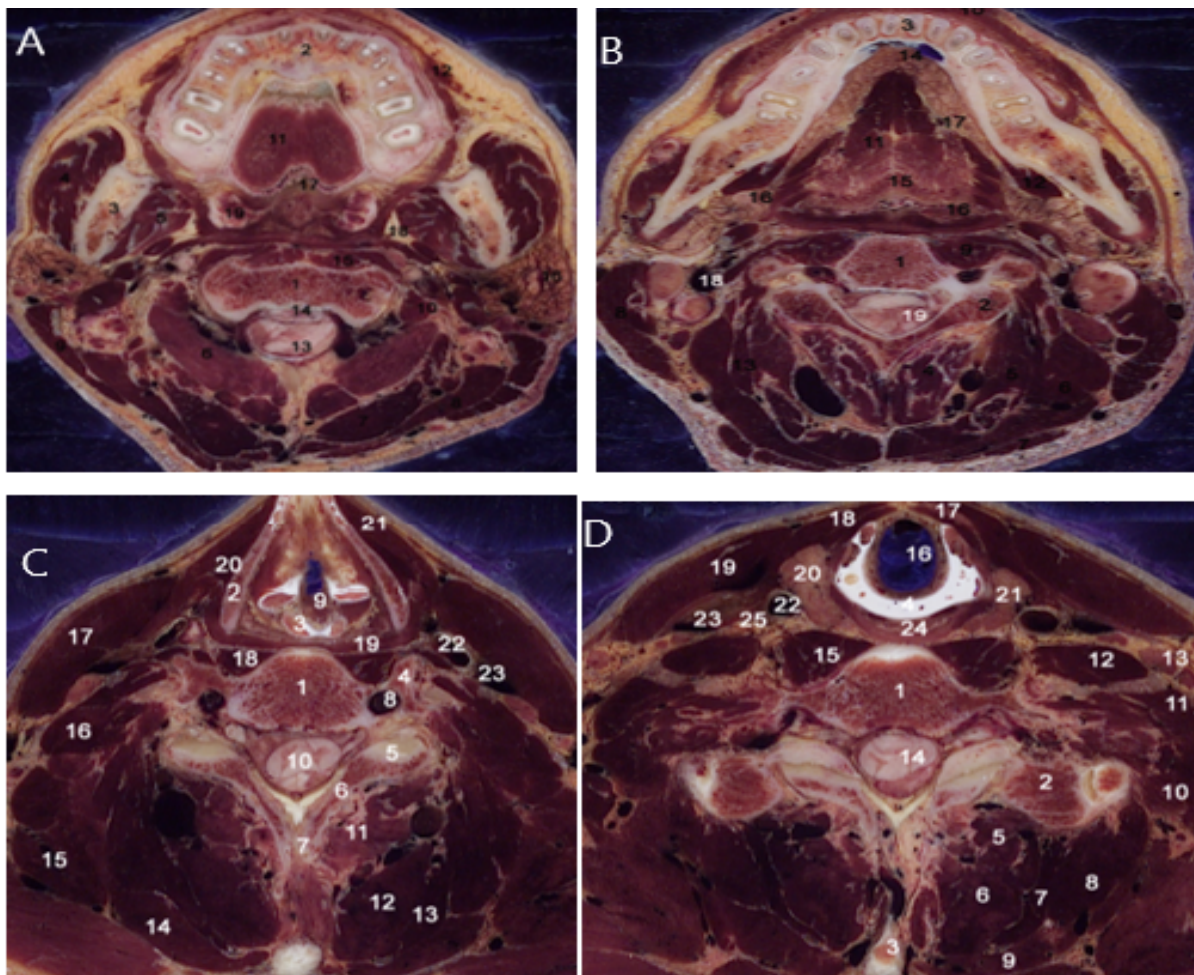

Figure 2: ABCD: Anatomical sections of KVH used for our study

A: Horizontal anatomical section of KVH passing through the axis

1. Axis body; 2. Mandible; 3. Rising branch of the mandible; 4. Masseter muscle 5. Stylopharyngeal muscle; 6. Rectus rectus posterior muscle of the head; 7. Semispinous muscle of the head; 8. Splenius muscle of the head; 9. Sternocleidomastoid muscle; 10. Long muscle of the neck; 11. Language; 12. Orbicular muscle of the lips; 13. Cerebellum; 14. Spinal cord; 15. Long muscle of the neck; 16. Thyroid gland; 17. Basis of the language; 18. Submandibular gland

B: Horizontal anatomical section of KVH passing through C3

1. Body of the third cervical vertebra; 2. C3 joint process; 3. Mandible; 4. Spiny transverse muscle of the neck; 5. Semispinous muscle of the head; 6. Splenius muscle of the head; 7. Trapezius muscle; 8. Sternocleidomastoid muscle; 9. Long neck muscle; 10. Depressor muscle of the lower lip; 11. Genioglossus muscle; 12. Mylohyoid muscle; 13. Elevator scapular muscle; 14. Lingual brake; 15. Epiglottis; 16. Piriform sinus; 17. Lingual artery; 18. Internal jugular vein; 19. Cervical spinal cord

C: horizontal anatomical section of KVH passing through C5

1. Vertebral body; 2. Thyroid cartilage; 3. Arytenoid cartilage; 4. Transversal process; 5. Joint process; 6. Blade; 7. Thorny process; 8. Transverse vasculo-nervous pedicle; 9. Larynx; 10. Cervical cord; 11. Transverse spinous muscle of the neck; 12. Semispinous muscle of the head; 13. Splenius muscle of the head; 14. Trapezius muscle; 15. Elevator scapular muscle; 16. Posterior scalene muscle; 17. Sternocleidomastoid muscle; 18. Long neck muscle; 19. Lower pharyngeal constrictor muscle; 20. Thyrohyoid muscle; 21. Sterno-cleido-hyoid muscle.

D: Horizontal anatomical section of KVH passing through C6.

1. Vertebral body of C6; 2. Transversal process of C6; 3. Spinous process of C6; 4. Cricoid cartilage; 5. Transverse neck muscle; 6. Semispinous muscle of the neck; 7. Semispinous muscle of the head; 8. Muscle small complexus; 9. Trapezius muscle; 10. Dorsal scalene muscle; 11. Middle scalene muscle; 12. Long muscle of the head; 14. Cervical cord; 16. Cervical trachea; 18. Omohyoid muscle; 20. Left thyroid lobe; 21. Right thyroid lobe; 22. Common carotid artery; 23. Internal jugular vein; 24. Esophagus; 25. Vagus nerve
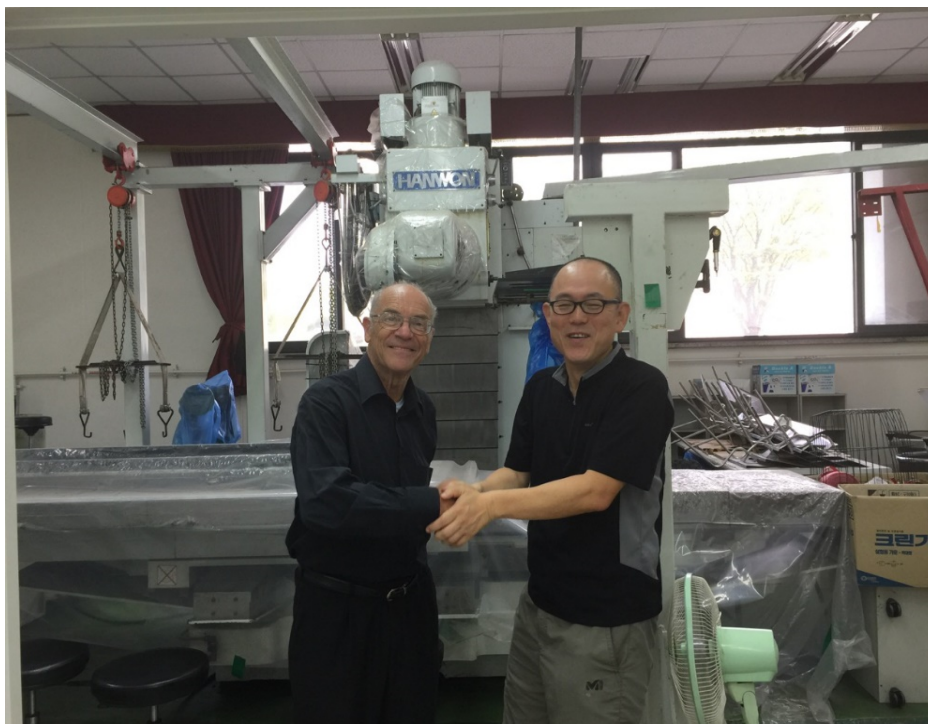

Figure 3: Cryomacrotome used to cut the body of Korean Visible Human with M. Uhl on the left and M. Chung on the right (Ajou University, Seoul, Korée)

3. Results

The applied methodology allowed us to obtain reconstruction of all the nerves in the ventral region of the neck.
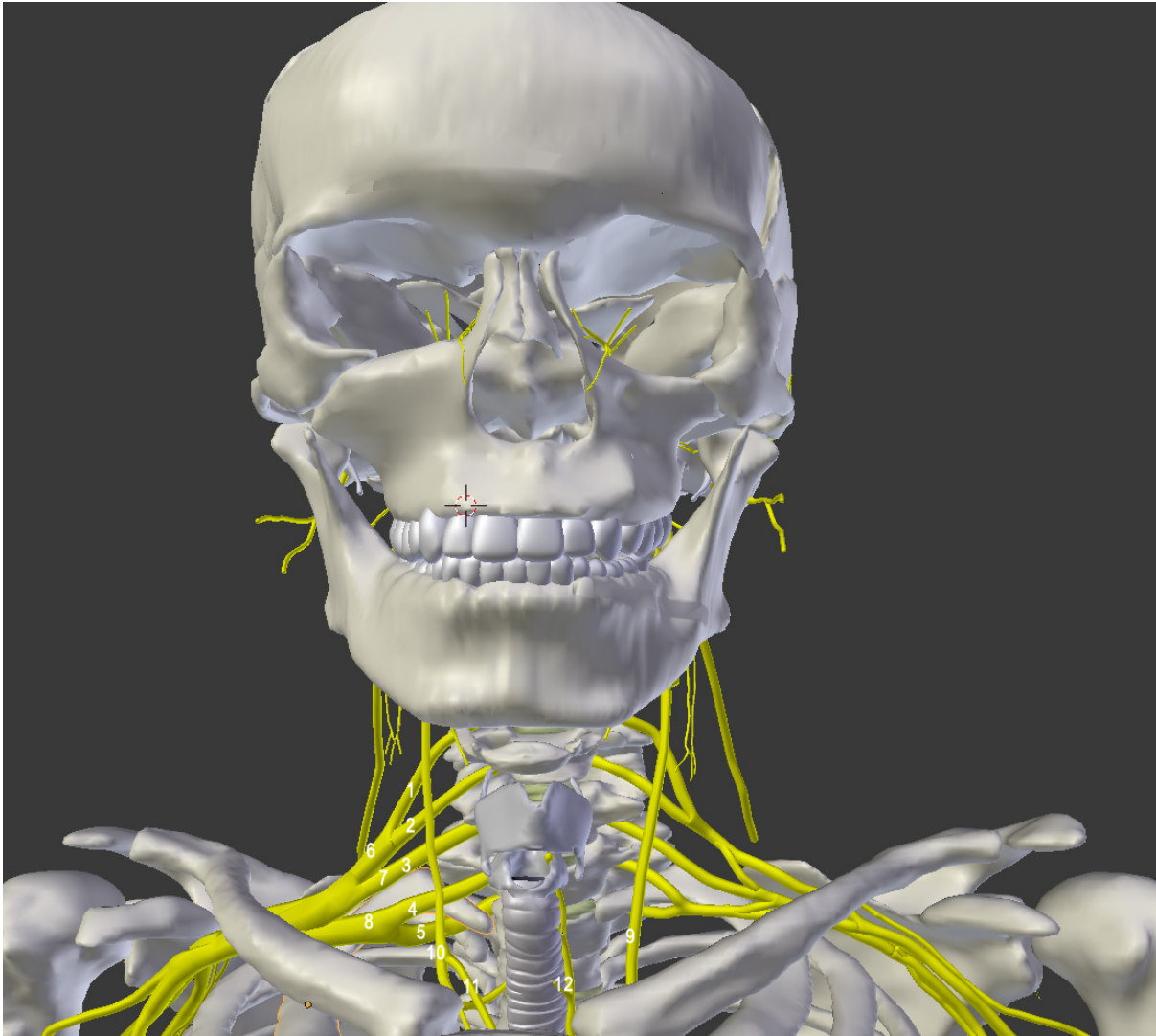

Figure 4: Ventral view of the neck nerves (Blender® screen interface)

1.Ventral branch of the fifth cervical nerve or C5; 2. Ventral branch of the sixth cervical nerve or C6; 3. Ventral branch of the seventh cervical nerve or C7; 4. Ventral branch of the eighth cervical nerve or C8; 5. Ventral branch of the first thoracic nerve or T1; 6. Upper trunk; 7. Medium trunk; 8. Lower trunk; 9. Left vagus nerve; 10. Right vagus nerve; 11. Right caudal laryngeal nerve; 12. Left caudal laryngeal nerve.
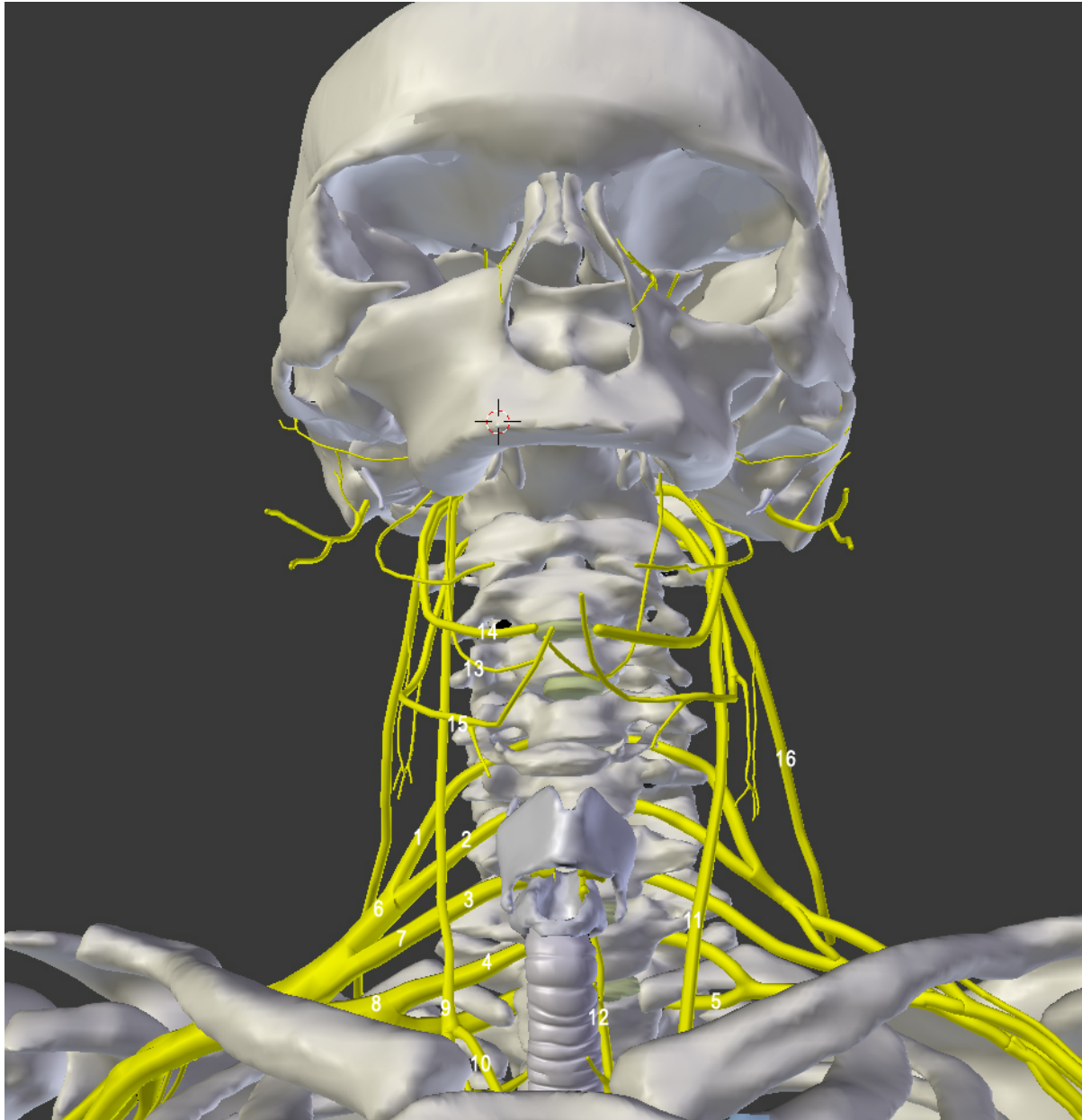
Figure 5: Inferior or caudal view of the nerves of the neck without the mandible

1. Ventral branch of the fifth cervical nerve or C5; 2. Ventral branch of the sixth cervical nerve or C6; 3. Ventral branch of the seventh cervical nerve or C7; 4. Ventral branch of the eighth cervical nerve or C8; 5. Ventral branch of the first thoracic nerve or T1; 6. Upper trunk; 7. Medium trunk; 8. Lower trunk; 9. Left vagus nerve; 10. Right vagus nerve; 11. Right caudal laryngeal nerve; 12. Left caudal laryngeal nerve. 13. Cranial laryngeal nerve; 14. Right glossopharyngeal nerve (IX); 15. Right hypoglossal nerve (XII); 16. Left spinal nerve (XI).
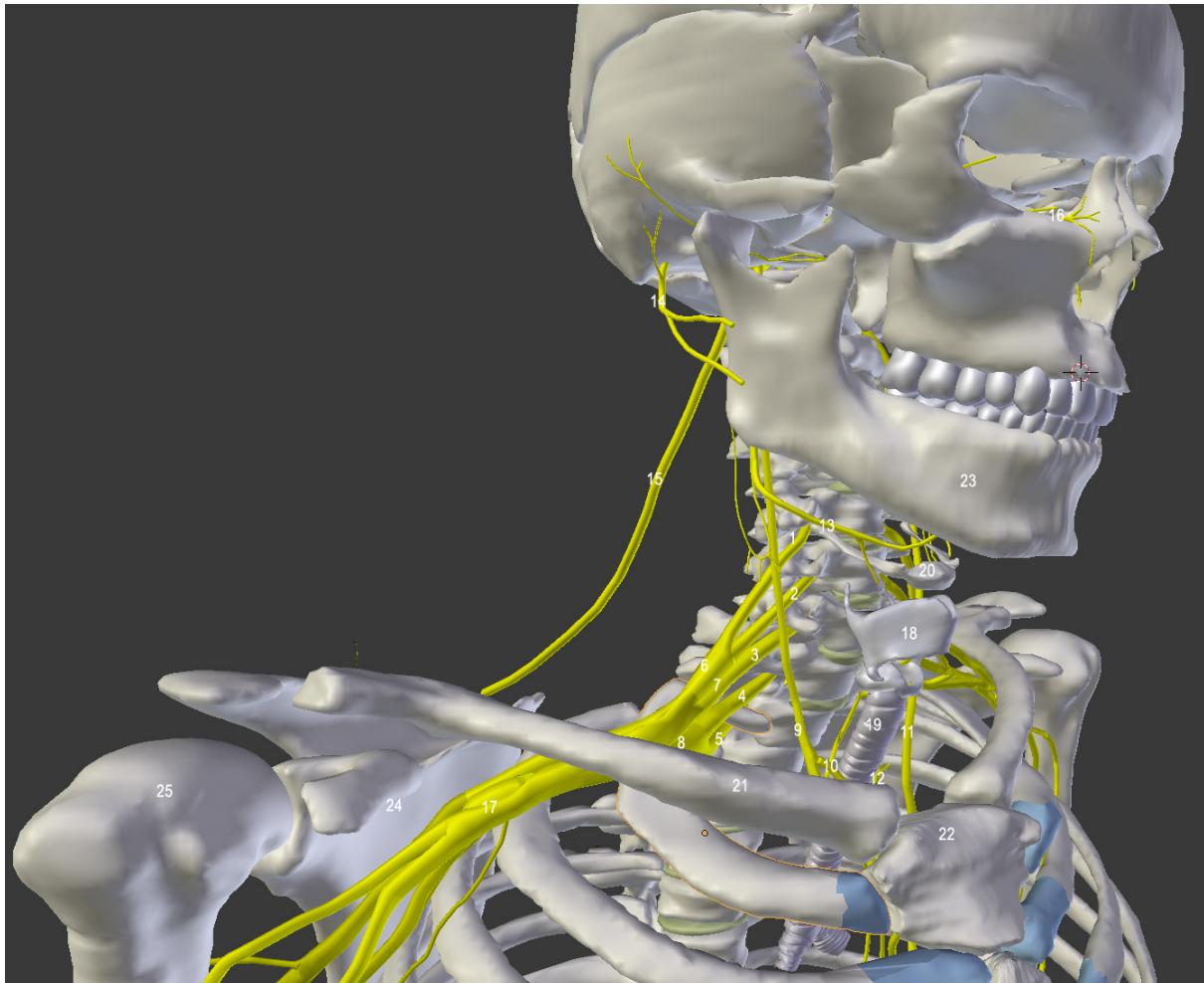
Figure 6: Left lateral view of the nerves of the neck

1. Ventral branch of the fifth cervical nerve or C5; 2. Ventral branch of the sixth cervical nerve or C6; 3. Ventral branch of the seventh cervical nerve or C7; 4. Ventral branch of the eighth cervical nerve or C8; 5. Ventral branch of the first thoracic nerve or T1; 6. Upper trunk; 7. Medium trunk; 8. Lower trunk; 9. Left vagus nerve; 10. Right vagus nerve; 11. Right caudal laryngeal nerve; 12. Left caudal laryngeal nerve. 13. Cranial laryngeal nerve 14. Right glossopharyngeal nerve (IX); 15. Right hypoglossal nerve (XII); 16. Left spinal nerve (XI); 17. Axillary region; 18. Thyroid cartilage; 19. Trachea; 20. Hyoid bone; 21. Right clavicle; 22. Manubrium sternal; 23. Mandible; 24. Scapula; 25. Humeral head
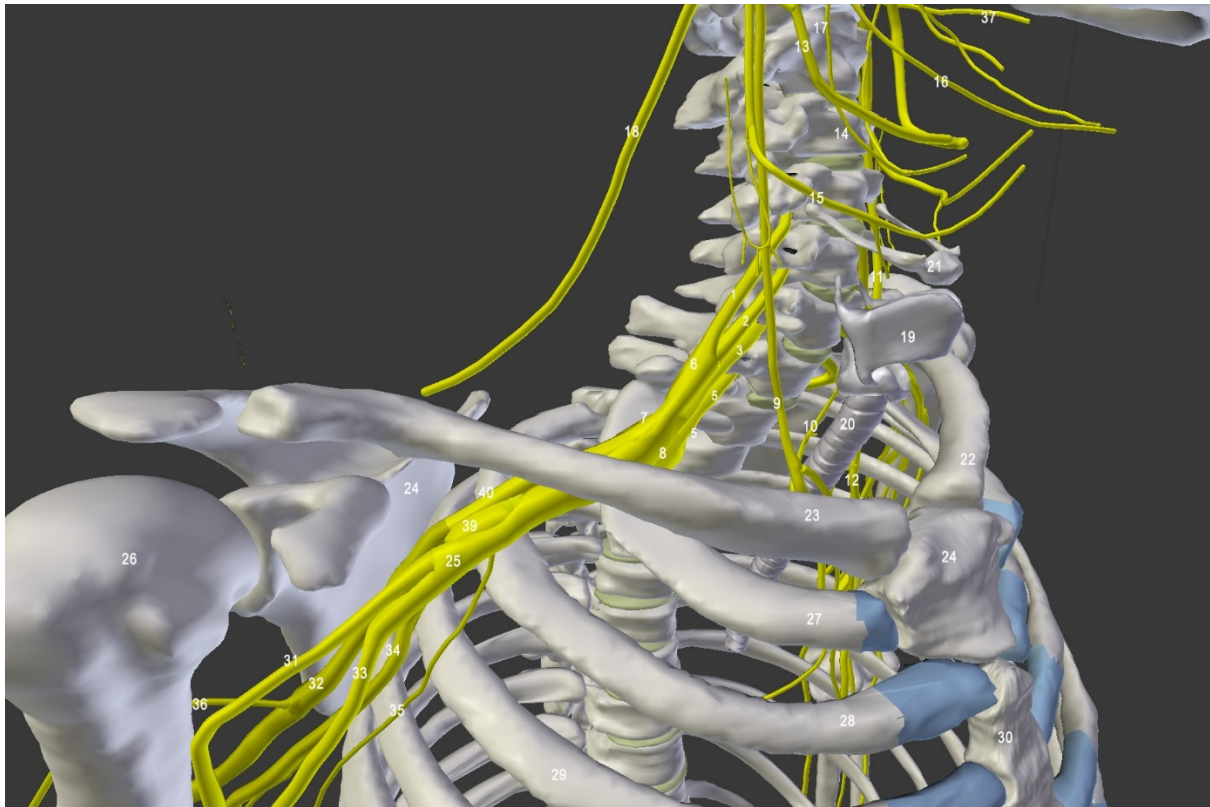
Figure 7: Left lateral view of the nerves of the neck (severed head)

1.Ventral branch of the fifth cervical nerve or C5; 2. Ventral branch of the sixth cervical nerve or C6; 3. Ventral branch of the seventh cervical nerve or C7; 4. Ventral branch of the eighth cervical nerve or C8; 5. Ventral branch of the first thoracic nerve or T1; 6. Upper trunk; 7. Medium trunk; 8. Lower trunk; 9. Right vagus nerve; 10. Right caudal laryngeal nerve; 11. Left vagus nerve; 12. Left caudal laryngeal nerve; 13 Right trigeminal nerve (branch ..) 14. Right trigeminal nerve (mandibular branch); 15. Right hypoglossal nerve (XII); 16. Right trigeminal nerve (maxillary branch) 17 Left trigeminal nerve (ophthalmic branch.) 18 Left spinal nerve (XI); 19. Thyroid cartilage; 20.Trachea; 21. Hyoid bone; 22. Left clavicle; 23. Right clavicle; 24. Manubrium sternal; 25. Side beam; 26. Humeral head; 27. Ventral arch of the 1st Coast; 28. Ventral arch of the 2nd Coast; 29. Ventral arch of the 3rd Coast; 30. Sternal body; 31.Musculo-cutaneous nerve; 32. Radial nerve; 33.Median nerve; 34. Ulnar nerve; 35.Long thoracic nerve; 36. Axillary nerve; 37. 38.Scapula; 39. Medial bundle; 40. Dorsal or posterior bundle our 3D reconstruction was inserted into the DIVA3D virtual dissection table (Figure 88) and was emitted on the Sketchfab® (Figure 9).
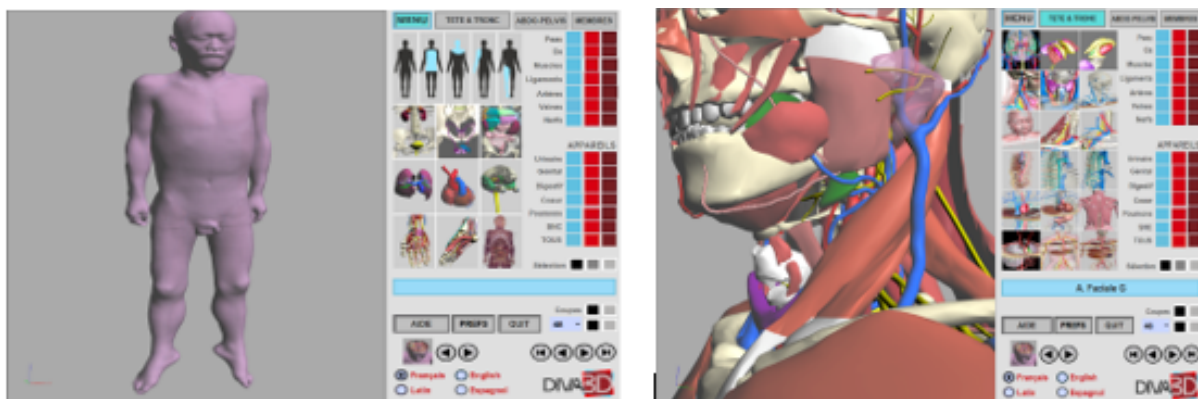

Figure 8: Virtual dissection table interface screen. On the left the 3D window. On the right, the function buttons to choose the display and the mode to be selected by zone, device, system, organ and / or unit.
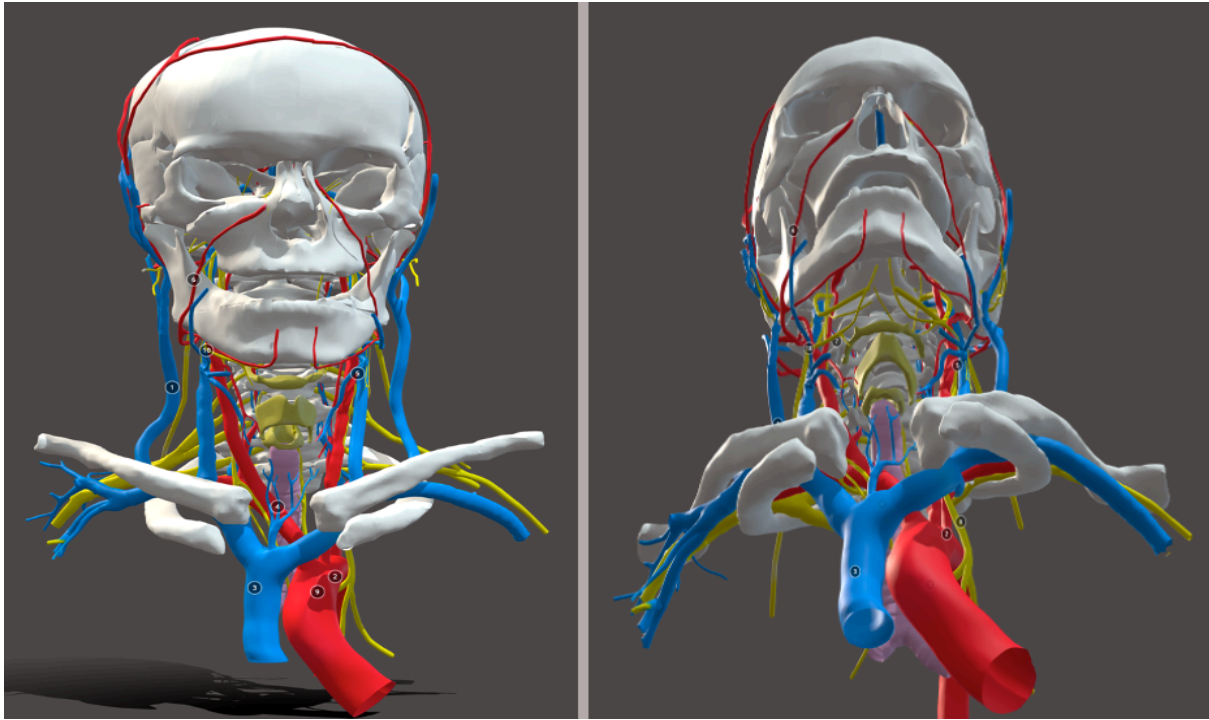
Figure 9: 3D model of KVH's neck and head displayed with Sketchfab® software Available at:
https://skfb.ly/6QYxZ (Right ventral view and left caudal view)

We printed our model with a cheaper printer and painted it with acrylic paint (Figure 10).

Figure 10: Left: our 3D model of the ventral neck and head region being printed (with printing supports). Right:
3D printing of our model painted manually with acrylic paint (ventral view - manual colorization)

4. Discussion

Certainly the Korean team and we have all worked on real anatomical sections unlike the other authors. However, our methodologies are different. The Korean methodolo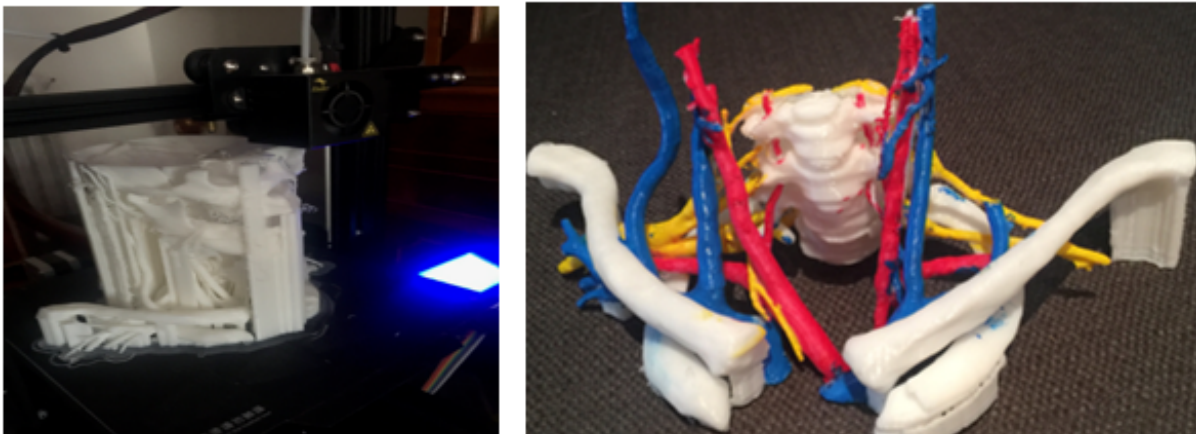gy used four steps for their modeling. The first step was to segment the anatomical sections using Photoshop® software using the magic tub (Figure 11). This stage lasted 8 years. The second step was to automatically model the anatomical sections using Mimics® software and the third step was to enhance and simplify the drill bits using Maya®. The fourth step was to export the 3D models to Acrobat Pro as a 3DPDF file. The downside of this methodology is that it segments only one in five cuts and uses three high-cost paid software that requires a long learning time. Indeed, Photoshop® is the most expensive 2D image software. Mimics® is modeling software that costs 3000 euros and MAYA® is reconstruction and animation software at 2000 euros.
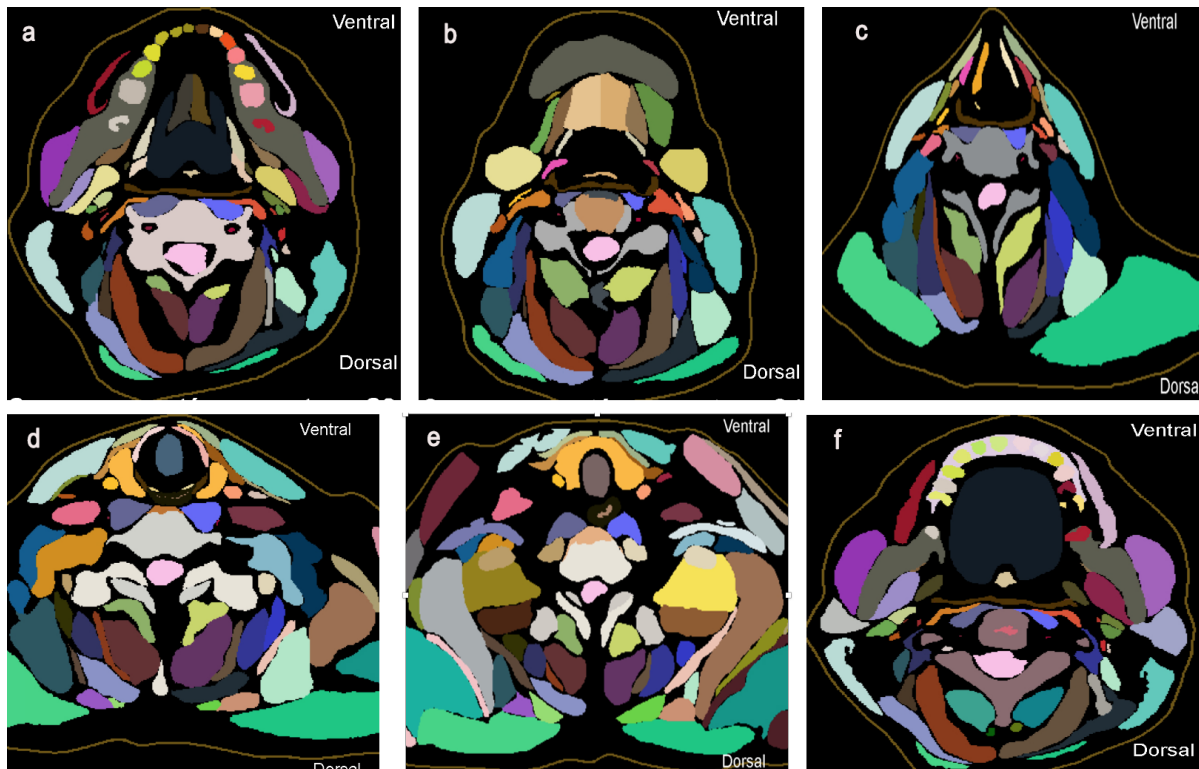

Figure 11: Segmented cuts using Photoshop® To. Segmented cut through C3; b. Segmented cut passing through C4; vs. Segmented cut passing through C5; d. Axial section passing through C5; e. Segmented cut passing through C7; f. Segmented sections passing through C7-T1;

Our methodology uses the same cuts with the following five steps: (Figure 1) • Segmentation and 3D vector modeling of the nervous elements of the ventral region of the neck with Winsurf® software version 3.5 (Moody and Lozanoff 1997) from anatomical sections. • Export of the Winsurf® mesh in cad format • Refinement, cleaning and arrangement of the mesh with Blender® • Classification of anatomical elements with Acrobat 3D toolkit® • Construction of the final user interface with Acrobat pro® Unlike the Korean methodology, we used the free and easy to learn Winsurf® software. In fact, the very easy-to-use Winsurf® software allows real-time control of the 3D result during 2D contouring, and therefore makes it possible to correct errors made. Although the Winsurf ® software has allowed us to reproduce the nerves in the ventral region of the neck fairly faithfully, it still has some flaws. The main disadvantage of this software is the length of work required to achieve the desired result. Indeed, this is a tedious contouring job. Unfortunately, there is no perfect solution to reduce this working time if it is not for great motivation and an unprecedented personal investment. The second drawback relates to the contouring work itself: Indeed, the 3D reproduction of certain low-caliber anatomical entities was particularly complicated. The only possible solution would then be to embark on a cut-by-cut contouring in order to be sure not to "lose your nerves along the way." It was also very difficult to get the final resolution as presented in the "Results" section. Indeed, when contouring is cut by the nerves of the neck, for example, or when the number of points

allocated to the object of interest is too large, the end result may be disappointing. Indeed, the anatomical entities will look like a "stack of plates," which decreases the final resolution and would therefore call into question our objective of creating a 3D atlas for application in the academic and surgical fields. There is a feature on Winsurf®, called "Smooth Object" which significantly smoothes the end result without affecting the shape of the organ. However, this process should not be abused as it could greatly accentuate any defects present in the reconstruction.

If despite everything the smoothed result is not satisfactory, it is recommended to restart the contouring of this object, avoiding repeating the same errors: always contour in the same direction (clockwise) starting at the same place from one cut to another, find the right balance in the choice of the number of points per object (neither too large because of poor precision, nor too small because there is a risk of a stack of trim in the end) ... In addition, we encountered a very great difficulty in the contouring of certain nerves. In fact, as mentioned in the "Methodology" section, these cuts were made in an axial plane; therefore longitudinal (or sagittal) structures are particularly difficult to reproduce. Thus, we used the Blender software to perfect the reconstruction obtained by Winsurf. Our 3D reconstruction of the nerves in the ventral region of the neck was redone using Blender® with "skin" technology due to the poor cosmetic quality of the result obtained on Winsurf®. Thus we carried out a detailed and explicit reconstruction of the cervical nerves.

Therefore our 3D model of the cervical nerves represents a real educational tool. Figure 10 shows the impression of our 3D model of the ventral neck region. It was done with a cheaper printer and lasted three days. We painted the anatomical structures with acrylic paint. Our printed model is an educational tool that can be used during tutorials and student practice. Our 3D reconstruction of the nerves in the ventral neck region was inserted into the DIVA3D virtual dissection table (Figures 8-9). Our DIVA3D virtual dissection table is a powerful teaching tool and constitutes an educational innovation. Indeed, it revolutionizes the teaching and learning of human anatomy. It offers full-body 3D anatomy and teaches anatomy on a 3-finger touch screen. Students can visualize anatomical structures just like on a cadaver. It therefore allows the learning of human anatomy beyond what a real body could provide. The richness of the content and the level of detail have aroused the interest of Masters in Anatomy and students of the Faculty of Medicine of Bamako. It is mainly used in our tutorials and practicals because it allows students to manipulate young and well-preserved virtual tissues instead of aged and damaged corpses. Thus, our students are impressed with the quality and visual impact of the fabrics. Figures 8-9 show the interface screen of our virtual dissection table. On the left the 3D window. On the right, the function buttons to choose the display and the mode to be selected by zone, device, system, organ and / or unit. Were it not for the absence of segmentation of certain organs, it would be comparable to the Anatomage table which represents the first virtual dissection table in the world and the most advanced on the market with an operating table design combined with a powerful radiology software. Conclusion: Our 3D modeling of the nerves of the ventral neck region is an original educational tool that easily teaches the nerves of the neck and can also be used as a 3D atlas for simulation purposes for training in medical procedures.

Acknowledgments

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