We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,300

Open access books available

172,000

International authors and editors

190M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Cerebral Arterial Circulation: 3D Augmented Reality Models and 3D Printed Puzzle Models

*Prasanna Venkatesh Ramesh, Prajnya Ray,
Shruthy Vaishali Ramesh, Aji Kunnath Devadas,
Tensingh Joshua, Anugraha Balamurugan,
Meena Kumari Ramesh and Ramesh Rajasekaran*

Abstract

The field of augmented reality (AR) and three-dimensional (3D) printing are rapidly growing with many new potential applications in medical education and pedagogy. In this chapter, we have used 3D AR and 3D printed models of the cerebral arterial circulatory system, created by us to simplify concept learning. Various cerebral circulation diseases pertaining to ophthalmology can be explained in detail for immersive learning, with the help of various 3D models, for structures such as the circle of Willis, cavernous sinus, various cranial nerves, cerebrum, cerebellum and the eye. These models not only help in cognitive understanding of cerebral circulation diseases but also aid in diagnosing them with better conviction. Ophthalmologists, sometimes being the first responder, have a vigilant role to play with a heightened awareness of these cerebral arterial circulation diseases, which are not only vision-threatening but life-threatening too. This chapter summarizes the construction and holistic application of these 3D ophthalmology-related arterial cerebral circulation models in AR and 3D printing.

Keywords: cerebral circulation, 3D models, augmented reality learning, anatomy redefined, cognitive learning

1. Introduction

Cerebral circulation comprising of both arterial (**Figure 1**) and venous system (**Figure 2**), is a complex three-dimensional (3D) anatomical structure. Various textbooks and chapters have thrown light on the cerebral circulation system with multiple images and various sections of it. Despite that, neophytes may still find it difficult to mentally visualize the complex structures by cognitive 3D mapping. Hence, we have created a 3D model of the cerebral circulatory system and have provided it, both on an augmented reality (AR) platform as well as 3D printed models, to aid in the visual and tactile guide while learning and teaching.

Figure 1.
Image showing the circle of Willis and its parts.

Figure 2.
Image showing the cerebral venous system and its parts.

AR and 3D printed models help in academic-oriented learning of all the cerebral circulation disease conditions and their pathophysiologies [1–4]. We have created 3D models of the cerebral system comprising of various parts such as the cerebral nervous, venous and arterial system along with the brain, brainstem, and eyeball in fine detail (**Figure 3**). By creating these models with meticulous detailing and by incorporating them through AR (**Figures 4–6**), and by 3D printing these models (**Figures 7–9**), understanding of the disease process is made more serene and undemanding with gameful cognitive learning. Also, complex pathways such as the cranial nerve pathways (**Figure 10**) are traced in a three-dimensional manner for facilitating easy cognitive reading.

Figure 3.
Image showing the 3D model of the cerebral system comprising of various parts such as the cerebral nervous, venous and arterial system along with the eyeball and its components.

Figure 4.
Image showing the circle of Willis in the mobile screen over the AR template (red arrow).

Figure 5.
Image showing the cerebral venous system in the mobile screen over the AR template.

Ophthalmologist may be the first responder for detecting the cerebral pathologies earlier, thus helping in faster diagnosis and aiding in speedy treatment. In this chapter, we have discussed the anatomy of various ophthalmology-related cerebral arterial systems from a neophyte's point of view in detail, with the help of innovative

Figure 6.
Image showing the eyeball in the mobile screen over the AR template.

(a)

(b)

Figure 7.
(a) Image showing the 3D printed puzzle pieces of the circle of Willis. (b) Image showing the final assembled model of the circle of Willis, after the puzzle pieces are joined together.

(a)

(b)

Figure 8.
(a) Image showing the 3D printed puzzle pieces of the cerebral venous system. (b) Image showing the final assembled model of the cerebral venous system, after the puzzle pieces are joined together.

(a)

(b)

Figure 9.
(a) Image showing the 3D printed puzzle pieces of the eyeball. (b) Image showing the final assembled model of the eyeball, after the puzzle pieces are joined together.

Figure 10.
(a) Image showing the various cranial nervous systems highlighting the (b) 3rd cranial nerve, (c) 4th cranial nerve, (d) 5th cranial nerve, (e) 6th cranial nerve, (f) 7th cranial nerve and (g) 8th cranial nerve respectively in green colour.

3D models and animative video created by us, to simplify the concept learning to aid in timely diagnosis and effective management.

2. Anatomy of the cerebral arterial circulation: Circle of Willis

The circle of Willis (**Figure 1**) is a ring of vessels that provides important colligative communications between the anterior and posterior circulations of the midbrain and hindbrain. The communications are established between the carotid and verte-brobasilar systems in conjunction around the optic chiasma and infundibulum of the pituitary stalk in the suprasellar cistern. It is named after Thomas Willis (1621–1675), an English physician [5]. The circle of Willis plays an important role, as it allows proper blood flow from the arteries to both the anterior and posterior hemispheres of the brain, and defends against ischemia in the incident of vessel disease or damage in one or more areas. In the event of arterial incompetency, it also provides collateral arterial flow to the affected brain regions [6–8].

Vessels comprising the circle of Willis include the following:

- Anterior circulation
- Posterior circulation

Video 1. Animated video depicting the anatomical structures of circle of Willis.
Available from (can be viewed at): <https://www.youtube.com/watch?v=yCM0Tq9JiFY>

2.1 Anterior circulation

When the right and left internal carotid artery (ICA) enter the cranial cavity, each one divides into two main branches:

- Anterior cerebral artery (ACA)
- Middle cerebral artery (MCA)

The ring is formed proximally by a single anterior communicating artery (AComA), which links the bilateral ACAs. Each ICA individually gives off an ophthalmic artery. At the junction between the ACA and the ICA, the lateral continuation of the ICA becomes the MCA.

2.2 Posterior circulation

The posterior communicating artery (PComA) arises from each ACA-ICA junction. The PComA connects the MCA with the posterior cerebral artery (PCA), to form the posteriormost aspect of the circle of Willis. The basilar artery (BA) forms from the fusion of the bilateral PCAs. The BA provides many branches, including the superior cerebellar arteries, pontine arteries, and the anterior inferior cerebellar artery (AICA). From the BA emerges bilateral vertebral artery (VA), which each gives off a posterior inferior cerebellar artery (PICA). The BA artery also contributes to the formation of a single anterior spinal artery [9, 10]. The combination of the AComA and the PComA makes up the circle of Willis, which permits collateral flow between the carotid and vertebrobasilar systems when there is vascular compromise.

2.3 Structures in detail

2.3.1 Internal carotid artery

The ICAs are part of the anterior circulation, which carries major blood supplies to the intracranial contents. There is a total of two ICA; originating from the carotid bifurcation, which runs cephalically through the neck and into the brain. It enters the skull through the carotid canal and reaches the cavernous sinus through the foramen lacerum after passing the parasellar area, and gives off the meningo-hypophyseal trunk that supplies the dura at the back of the cavernous sinus, as well as the oculomotor, trochlear, trigeminal, and abducens cranial nerves. The ICA makes a loop to reverse its direction under the anterior clinoid and the optic nerve at the anterior aspect of the cavernous sinus and passes through the two dural rings. After passing through the second dural ring, it becomes intradural and gives off the ophthalmic artery which is stemming out from the ophthalmic segment (C6) of the ICA. The ophthalmic artery enters into the orbit through the optic canal. It provides numerous collateral branches to supply the optic nerve. The ophthalmic artery's first major daughter branch is the central retinal artery which supplies the retina [11]. The ophthalmic artery provides oxygenated blood to the extraocular muscles, some facial muscles, as well as the intrinsic muscles of the eye [12]. Distal to the

origin of the ophthalmic artery, the intradural supraclinoid ICA gives rise to the anterior choroidal artery which supplies blood to the lateral geniculate body (LGB) distally and the optic tract proximally. Anterior choroidal artery anastomoses with the PCA through the PComA. The ICA gives off the ACA and ends as a branch of the MCA [13].

2.3.2 Anterior communicating artery

The AComA connects the two ACAs across the starting point of the longitudinal fissure, organizing the anterior border of the cerebral arterial circle of Willis. Besides forming the conjugation channel between the anterior cerebral arteries, the AComA also contributes to supplying blood to certain parts of the brain via its anteromedial central branches. This artery supplies parts of the optic chiasma and intracranial optic nerves [14].

2.3.3 Anterior cerebral artery

The two ACAs are connected by the AComA. The ACA develops from a primitive anterior division of the ICA that initially supplies oxygenated blood to most midline portions of the frontal lobes, and superior, medial, and parietal lobes. The basal branch arising from the lenticulostriate branch of ACA supplies the posterior aspect of the optic chiasma. The cortical branch and orbitofrontal branch of ACA supply the olfactory cortex, gyrus rectus, and medial orbital gyrus [15].

2.3.4 Posterior communicating artery

The right and left PComAs form the dorsal part of the circle of Willis, at the base. Each PComA links the three cerebral arteries of the same side. Before the terminal bifurcation of the ICA into the ACA and MCA, the PComA connects to the ICA anteriorly. It links with the PCA posteriorly. The PComA supplies the rear part of the optic chiasma and optic tract [16].

2.3.5 Posterior cerebral artery

The left and right PCA is a terminal branch that arises from the bifurcation of the BA. The PCA moves around the cerebral peduncle and supplies the occipital lobe, the inferomedial surface of the temporal lobe, midbrain, thalamus, and choroidal plexus of the third and lateral ventricles after passing above the tentorium. The PCA gives off central branches and cortical branches which supplies the subcortical and cortical structures, respectively. The central branches of PCA include the thalamoperforating artery, thalamogeniculate artery, and posterior choroidal artery. The cortical branches of PCA include the temporal artery, occipital artery, parieto-occipital artery, and calcarine artery [17, 18].

2.3.5.1 Central posterior cerebral artery

The thalamoperforating arteries arise from the P1 segment of PCA and supplies parts of the thalamus, the third ventricles, and the midbrain. The thalamogeniculate artery arises from the P2 segment of PCA and supplies the medial and lateral

geniculate bodies and the pulvinar of the thalamus. The medial and lateral posterior choroidal arteries supply the dorsal portion of the thalamus and the choroidal plexus.

2.3.5.2 Cortical posterior cerebral artery

The temporal branches are given off from the P2 segment supply the uncus and the parahippocampal, medial, and lateral occipitotemporal gyri. The occipital branches supply the cuneus, lingual gyrus and posterolateral surface of the occipital lobe. The parieto-occipital artery arises from the P3 segment and supplies the cuneus and precuneus. The calcarine artery supplies the visual cortex, inferior cuneus, and part of the lingual gyrus, which arise indirectly from the occipital artery.

The visual cortex responsible for the contralateral field of vision lies in its domain. The macular part of the visual cortex often receives blood supply from both the PCA and MCA. It describes the “macular sparing” phenomenon in some patients following a PCA infarct.

2.3.6 Basilar artery

The right VA arises from the innominate artery, and the left VA begins as a branch of the proximal subclavian artery. The VA moves through a series of foramina in the lateral aspect of the cervical vertebral processes. After crossing the dura at the foramen magnum, the VA gives rise to the PICA before linking the other VA to form the BA. Along the course of the BA, small branches arise directly to supply parts of the pons and midbrain. The median branches of the BA supply the medial longitudinal fasciculus, paramedian pontine reticular formation (PPRF), and the medially located nuclei of the oculomotor, trochlear, and abducens nerve. The pontine branch of the BA also supplies the front portions of the cranial nerves (particularly the trigeminal nerve) at the point where they exit from the brainstem. Distally, the PICA supplies the inferior cerebellum, which is closely involved in eye movements. The AICA originates from the caudal BA and supplies the pontomedullary junction and the posterior part of the cerebellum. The internal auditory artery which is a large proximal branch of the AICA supplies the facial cranial nerve complex in the subarachnoid space and follows it into the internal auditory canal [19].

3. Creation of the 3D models

3.1 Constructing the cerebral arterial system

The construction of the cerebral arterial system was done in Maya LT software [3, 20]. The reference image was first taken for the cerebral arterial system to e-trace it using the CV curve tool. Tracing of the different arteries was done using the three orthographic views, namely X-axis, Y-axis and Z-axis (**Figure 11**). This results in a cerebral arterial system, which is made up of lines and curves (**Figure 12a**). Next, a circle was extruded along every curve, thereby resulting in a cerebral arterial system made up of tubes (**Figure 12b**); and these tubes were tweaked in a way, that their ends are narrowed and closed (**Figure 12c**).

The other minor appendages and extensions of the circle of Willis were drawn on a plane, followed by deletion of the unnecessary ones and finally the face of the model

Figure 11. Image showing the traced cerebral arteries using the CV curve tool in the three different orthographic views namely, X-axis (bottom right), Y-axis (top left), and Z-axis (bottom left). The top right block shows us the default perspective view.

Figure 12. (a) Image showing the cerebral arterial system made up of lines and curves. (b) Image showing the cerebral arterial system made up of tubes. (c) Image showing the cerebral arterial system with narrowed and closed ends. (d) Image showing the cerebral arterial system with approximated artery colour given from default colour palette.

was extruded. Extrusion is mainly done to provide thickness, so that the thin line will transform into a vessel of appropriate thickness. The face extruded model was then applied to the retopologize function to clean up and smoothen the model. Finally, the circle of Willis was merged with its appendages through edge bridging and offset correction, resulting in the creation of the ‘cerebral arterial circulation system’ structure.

Similarly, the cerebral venous system, cranial nerves, cerebrum, cerebellum, brain stem (**Figure 3**) and the eyeball with TrueColor confocal images can be created.

3.2 Texturing the cerebral arterial system

The constructed model was given an approximated artery colour from the default colour palette (**Figure 12d**). This step can be done in Maya LT software or Blender software [21]. If Blender software is used, the 3D models have to be first exported from Maya LT software and imported into Blender software.

4. Augmented reality

The 3D models can be successfully launched in AR after UV unwrapping and lighting, followed by coding the models for the AR module in Unreal Engine software for a successful run.

Figure 13.
(a) Image showing the cerebral arterial system is appearing as black due to the absence of lightmap. (b) Image showing the cerebral arterial system is appearing in normal colour due to presence of lightmap.

4.1 UV unwrapping the cerebral arterial system model in Blender software

The 3D models have to be exported from Maya LT software and imported into Blender software for UV unwrapping. UV unwrapping is the process of cutting out a 3D model and placing it on a 2D plane. UV unwrapping is done so that the model can be lit in the absence of scene lights, which is very essential for a successful AR module.

4.2 Lighting the AR scene in Blender software for processing the models in Unreal Engine software

If there is no light in the AR scene, the 3D models inside the Unreal Engine software will appear black (**Figure 13a**). If we add light to the AR scene in the Unreal Engine software, the Android mobile phones will not be able to process it. But, processing the model by the mobile phone is of utmost importance, as the AR module innovated by us needs an Android mobile phone platform to operate. Hence, a lightmap has to be generated and applied to the 3D models to view the models correctly (**Figure 13b**), which cannot be done in Unreal Engine software. Hence, these lightmaps have to be generated in Blender software and then imported into the Unreal Engine.

4.3 Launching the Unreal Engine software for AR

The Unreal Engine is an integrated development environment (IDE) used to develop applications for various platforms [22–24]. The AR application is one such application that was coded in the Unreal Engine software [25]. The 3D models were exported from Blender software after UV unwrapping and imported into the Unreal Engine level file for the initiation of AR. Finally, the app (Eye MG AR) is built from the Unreal Engine for Android devices. The link for the app is given below:

https://play.google.com/store/apps/details?id=com.EyeMG_AR

Figure 14.
Image showing the coding/algorithm of the AR module.

4.4 Coding for AR module in Unreal Engine

A dataset array is set up in Unreal Engine software which contains the image of the AR template (**Figure 4**). When the program starts running, all the images in the camera view will be tracked. If any of the tracked images match with the AR template from the data set array, the 3D models will be spawned, with transform values matching the centre of the AR template. If the 3D model is already spawned, then the transform value is updated to the centre of the AR template and will go to the next frame. This is the algorithm for the AR module (**Figure 14**), and it is made to run on a loop at multiple frames per second (FPS) depending on the device.

5. 3D printing anatomy puzzle models

The 3D printing of ophthalmology related models has been proposed first by Ramesh et al. for enhancing learning through the concept of puzzle assembly (**Figures 7-9**) [26]. The concept of puzzle assembly can serve as a comprehensive self-learning tactile tool kit for neophytes [26–31]. 3D printing models can overcome the limitations of the theoretical framework of textbooks used for studying [32–35]. Practical sessions facilitate teaching and 3D printing anatomical puzzle models perfectly augment it cost-effectively.

The software used to create the 3D models was Maya LT. Cura software was used for printing the models in sliced layers. Cura software gives the output in an STL format, which is the standard tessellation language format for 3D printing. FabX XL printer was used to print the Circle of Willis model and the eye. FabX Plus printer was used to print cerebral venous system model. Polylactic acid (PLA) material which is a biodegradable plastic, manufactured from corn starch, cassava and sugar cane waste was used for 3D printing all anatomical structures except the retina. For the retina, thermoplastic polyurethane (TPU) material was used for 3D printing.

The 3D models created by us are currently available for free download from the website (mcmi.in).

5.1 Economics

The PLA plastic costs approximately 13.43 USD for 1 kg weight. TPU costs approximately 40.28 USD for 1 kg weight.

The economics involved in 3D printing models is as follows:

- Circle of Willis model costs approximately 6.71 USD for 400 g sample
- Cerebral venous system model costs approximately 6.71 USD for 400 g sample
- Eyeball model costs approximately 26.85 USD for 1 kg sample

5.2 Duration of printing

The duration of printing the 3D models is as follows:

- 10 hours to print: The circle of Willis

- 5 hours to print: The cerebral venous system
- 48 hours to print: The eyeball

6. Conclusions

Cerebral arterial circulation and other allied anatomical structures are best understood with sound knowledge of their complex anatomy. In this chapter, we have simplified the anatomical learning of these complex anatomical structures with 3D AR models (in the free Android app Eye MG AR) and 3D printed models for better concept learning. This cognitive learning module of the cerebral circulation will aid in concept building for neophyte ophthalmologists, neurosurgeons, intensivists, physicians, and paramedics thus aiding in faster diagnosis, speedy treatment and effective rehabilitation.

Acknowledgements

We are grateful to Mr. Pragash Michael Raj (Department of Multimedia), and Mrs. Priyadharshini of Mahathma Eye Hospital Private Limited, Trichy, Tamil Nadu, India for their technical support throughout the making of this chapter and its illustrations. We sincerely express our thanks to Ms. Banasmita Mohanty for her support for the proofreading of this chapter. We are also grateful to Dr. Sabin Malik for his support and help with references for the anatomy of the cerebral models used for animation in this chapter.

Conflict of interest

The authors declare no conflict of interest.

Notes/thanks/other declarations

I (Dr. Prasanna Venkatesh Ramesh) owe a deep sense of gratitude to my daughters (Pranu and Hasanna) and family (in-laws) for all their prayers, support, and encouragement. Above all, I extend my heartfelt gratitude to all the patients who consented to the images which are utilized for this chapter.

I (Dr. Shruthy Vaishali Ramesh) want to thank my partner (Arul) for his constant support and encouragement during the process of creating this chapter.

Declaration of patient consent

In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the chapter. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Appendix and nomenclature

3D models were created and used in animations by us in this chapter. This includes the human eyeball with TrueColor confocal fundus image, cranial nervous system, the cerebral venous system, cerebral arterial system (comprising of the circle of Willis), brain stem nuclei, extraocular muscle, meninges etc. These models help in better understanding and can be used in various fields of medicine. We have created models which are related to ophthalmology, which allows us to explain a disease or a condition with its pathophysiology, pathway, clinical features, tests, treatment and prognosis.

These models can be 3D printed, used for augmented reality simulations, used for virtual reality and can also be used for advanced mixed reality with Microsoft HoloLens. 3D models when used for real-time teaching, especially with the help of multimodal fundus images, microscopic structures like the trabecular meshwork, angles, diseases of lens etc., can pave the way for new-age pedagogy. We have created apps using these models like the Eye MG AR (https://play.google.com/store/apps/details?id=com.EyeMG_AR) and Eye MG 3D (https://play.google.com/store/apps/details?id=com.EyeMG_3D) which are based on augmented reality model of the eye and multimodal fundus imaging atlas, respectively. These are available for Android users and are free to download from Google Play Store. An app for iPhone users, named Eye MG Max is currently available in App Store. In this application, eyeball with TrueColor confocal fundus images, and all structures related to ophthalmology are provided with a user-friendly interface. In Eye MG Max, multiple views with transparency for viewing the structures passing through another model, free camera mode, annotated modes, customised zoomed views and videos related to any ophthalmic pathology are provided; thus, providing a 3D atlas at the user's fingertip for comprehensive learning.

Nomenclature

3D	three-dimensional
ACA	anterior cerebral artery
ACoM	anterior communicating artery
AICA	anterior inferior cerebral artery
BA	basilar artery
CN	cranial nerve
ECA	external carotid artery
FPS	frames per second
ICA	internal carotid artery
IDE	integrated development environment
LGB	lateral geniculate body
MCA	medial cerebral artery
MLF	medial longitudinal fasciculus
PCA	posterior cerebral artery
PCoM	posterior communicating artery
PICA	posterior inferior cerebellar artery
PLA	polylactic acid
PPRF	paramedian pontine reticular formation
TPU	thermoplastic polyurethane
VA	vertebral artery

IntechOpen

Author details

Prasanna Venkatesh Ramesh^{1*}, Prajnya Ray², Shruthy Vaishali Ramesh³,
Aji Kunnath Devadas², Tensingh Joshua⁴, Anugraha Balamurugan⁵,
Meena Kumari Ramesh³ and Ramesh Rajasekaran⁶

1 Department of Glaucoma and Research, Mahathma Eye Hospital Private Limited,
Trichy, Tamil Nadu, India

2 Department of Optometry and Visual Science, Mahathma Eye Hospital Private
Limited, Trichy, Tamil Nadu, India

3 Department of Cataract and Refractive Surgery, Mahathma Eye Hospital Private
Limited, Trichy, Tamil Nadu, India

4 Mahathma Centre of Moving Images, Mahathma Eye Hospital Private Limited,
Trichy, Tamil Nadu, India

5 Department of Vitreo-Retinal Surgery, Mahathma Eye Hospital Private Limited,
Trichy, Tamil Nadu, India

6 Department of Paediatric and Strabismus, Mahathma Eye Hospital Private Limited,
Trichy, Tamil Nadu, India

*Address all correspondence to: email2prajann@gmail.com

IntechOpen

© 2022 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

- [1] Gopalakrishnan S, Chouhan Suwalal S, Bhaskaran G, Raman R. Use of augmented reality technology for improving visual acuity of individuals with low vision. *Indian Journal of Ophthalmology*. 2020;**68**:1136-1142
- [2] Iskander M, Ogunsola T, Ramachandran R, McGowan R, AlAswad LA. Virtual reality and augmented reality in ophthalmology: A contemporary prospective. *Asia-Pacific Journal of Ophthalmology*. 2021;**10**:244-252
- [3] Karakas AB, Govsa F, Ozer MA, Eraslan C. 3D brain imaging in vascular segmentation of cerebral venous sinuses. *Journal of Digital Imaging*. 2019;**32**:314-321
- [4] Cabrilo I, Bijlenga P, Schaller K. Augmented reality in the surgery of cerebral arteriovenous malformations: Technique assessment and considerations. *Acta Neurochirurgica*. 2014;**156**:1769-1774
- [5] Uston C. NEUROwords Dr. Thomas Willis' famous eponym: The circle of Willis. *Journal of the History of the Neurosciences*. 2005;**14**(1):16-21
- [6] Menshawi K, Mohr JP, Gutierrez J. A functional perspective on the embryology and anatomy of the cerebral blood supply. *Journal of Stroke*. 2015;**17**(2):144-158
- [7] Rosner J, Reddy V, Lui F. Neuroanatomy, Circle of Willis. In: StatPearls [Internet]. Treasure Island, FL: StatPearls Publishing; 2021. Available from: <http://www.ncbi.nlm.nih.gov/books/NBK534861/> [Cited: 25 December 2021]
- [8] Circle of Willis [Internet]. Kenhub. Available from: <https://www.kenhub.com/en/library/anatomy/circle-of-willis> [Cited: 25 December 2021]
- [9] Prince EA, Ahn SH. Basic vascular neuroanatomy of the brain and spine: What the general interventional radiologist needs to know. *Seminars in Interventional Radiology*. 2013;**30**(3): 234-239
- [10] Robben D, Türetken E, Sunaert S, Thijs V, Wilms G, Fua P, et al. Simultaneous segmentation and anatomical labeling of the cerebral vasculature. *Medical Image Analysis*. 2016;**32**:201-215
- [11] Hendrix P, Griessenauer CJ, Foreman P, Shoja MM, Loukas M, Tubbs RS. Arterial supply of the upper cranial nerves: A comprehensive review. *Clinical Anatomy*. 2014;**27**(8):1159-1166
- [12] Ludwig PE, Aslam S, Czyz CN. Anatomy, Head and Neck, Eye Muscles [Internet]. In: StatPearls. Treasure Island, FL: StatPearls Publishing; 2021. Available from: <http://www.ncbi.nlm.nih.gov/books/NBK470534/> [Cited: 15 November 2021]
- [13] Internal Carotid Artery [Internet]. Kenhub. Available from: <https://www.kenhub.com/en/library/anatomy/internal-carotid-artery> [Cited: 25 December 2021]
- [14] Gaillard F. Anterior Communicating Artery | Radiology Reference Article | Radiopaedia.org [Internet]. Radiopaedia. Available from: <https://radiopaedia.org/articles/anterior-communicating-artery> [Cited: 25 December 2021]
- [15] Tahir RA, Haider S, Kole M, Griffith B, Marin H. Anterior cerebral artery: Variant anatomy and pathology. *Journal of Vascular and Interventional Neurology*. 2019;**10**(3):16-22

- [16] Posterior Communicating Artery [Internet]. Kenhub. Available from: <https://www.kenhub.com/en/library/anatomy/posterior-communicating-artery> [Cited: 25 December 2021]
- [17] Javed K, Reddy V, Das JM. Neuroanatomy, Posterior Cerebral Arteries. In: StatPearls [Internet]. Treasure Island, FL: StatPearls Publishing; 2021. Available from: <http://www.ncbi.nlm.nih.gov/books/NBK538474/> [Cited: 25 December 2021]
- [18] Posterior Cerebral Artery [Internet]. Kenhub. Available from: <https://www.kenhub.com/en/library/anatomy/posterior-cerebral-artery> [Cited: 25 December 2021]
- [19] Adigun OO, Reddy V, Sevensma KE. Anatomy, Head and Neck, Basilar Artery. In: StatPearls [Internet]. Treasure Island, FL: StatPearls Publishing; 2021. Available from: <http://www.ncbi.nlm.nih.gov/books/NBK459137/> [Cited: 25 December 2021]
- [20] Abdul Ghani D, Naim Bin Supian M, Zulhilmi Bin Abdul 'Alim L. The research of 3D modeling between visual & creativity. International Journal of Innovative Technology and Exploring Engineering. 2019;8(11S2):180-186
- [21] 3D Texturing in Animation; Step by Step Workflow + Techniques & Video [Internet]. Available from: <https://dreamfarmstudios.com/blog/getting-to-know-3d-texturing-in-animation-production/> [Cited: 25 December 2021]
- [22] Ramesh PV, Aji K, Joshua T, Ramesh SV, Ray P, Raj PM, et al. Immersive photoreal new-age innovative gameful pedagogy for e-ophthalmology with 3D augmented reality. Indian Journal of Ophthalmology. 2022;70(1):275-280
- [23] Ramesh PV, Aji K, Ray P, et al. Combating anti-glaucoma medication compliance issues among literate urban Indian population—Has this fallen in our blind spot? Journal of Clinical Ophthalmology. 2021;5(S5):472-475
- [24] Aydınoğlu G, Kavaklı K, Şahin A, Artal P, Ürey H. Applications of augmented reality in ophthalmology. Biomedical Optics Express. 2020;12:511-538
- [25] Eye MG AR—Apps on Google Play [Internet]. Available from: https://play.google.com/store/apps/details?id=com.EyeMG_AR&hl=en&gl=IN [Cited: 26 November 2021]
- [26] 3D Printing. In: Wikipedia [Internet]. 2021. Available from: https://en.wikipedia.org/w/index.php?title=3D_printing&oldid=1045923488 [Cited: 5 October 2021]
- [27] Sehnnonimo. 3D Jigsaw Puzzles and Their Benefits [Internet]. HubPages. Available from: <https://discover.hubpages.com/games-hobbies/3D-Puzzle> [Cited: 5 October 2021]
- [28] Akkara JD, Kuriakose A. The magic of three-dimensional printing in ophthalmology. Kerala Journal of Ophthalmology. 2018;30:209-215
- [29] Adams JW, Paxton L, Dawes K, Burlak K, Quayle M, McMenamin PG. 3D printed reproductions of orbital dissections: A novel mode of visualising anatomy for trainees in ophthalmology or optometry. The British Journal of Ophthalmology. 2015;99(9):1162-1167
- [30] Dave TV, Tiple S, Vempati S, Palo M, Ali MJ, Kaliki S, et al. Low-cost three-dimensional printed orbital template-assisted patient-specific implants for the correction of spherical orbital implant migration. Indian Journal of Ophthalmology. 2018;66(11):1600-1607

[31] Harrington Z. 7 Spectacular Benefits of Puzzles (Hint: They're Not What You'd Think!) | Melissa & Doug Blog [Internet]. Available from: https://www.melissaanddoug.com/on/demandware.store/Sites-melissaanddoug-Site/en_US/Blog-PostView?postId=7-spectacular-benefits-of-puzzles-hint-theyre-not-what-youd-think [Cited: 5 October 2021]

[32] Sommer AC, Blumenthal EZ. Implementations of 3D printing in ophthalmology. *Graefes Archive for Clinical and Experimental Ophthalmology*. 2019;257(9):1815-1822

[33] 3-D Printing for Ophthalmic Surgery [Internet]. American Academy of Ophthalmology; 2019. Available from: <https://www.aao.org/eyenet/academy-live/detail/3-d-printing-ophthalmic-surgery> [Cited: 25 December 2021]

[34] Implications of 3D Printing in Ophthalmology [Internet]. Available from: <https://www.longdom.org/proceedings/implications-of-3d-printing-in-ophthalmology-54045.html> [Cited: 25 December 2021]

[35] The Application of 3D Printing in Ophthalmology [Internet]. CJEO Journal. 2020. Available from: <https://cjeo-journal.org/the-application-of-3d-printing-in-ophthalmology/> [Cited: 25 December 2021]