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# The production of cost effective 3D models to enhance anatomy teaching in developing countries using Computer Numerical Control router machine

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## Abstract

The gold standard for teaching anatomy is cadaveric dissection but obtaining human cadavers these days is to a great extend difficult, expensive, and necessitates safety measures for employees and students handling embalming fluids that contain formalin. The current work objective is to produce 3D colored wooden engraved anatomical specimens with precise anatomical features that are affordable, clear, and accurate. This study combines three-dimensional (3D) wood engraving technology using a Computer Numerical Control (CNC) router machine to construct anatomical models that can be used as a supplement to human cadavers, especially in developing countries. MDF is a synthetic wood that was used to make anatomical models because its panels have excellent machinability, and a high surface quality. ZBrush is a type of software program that was selected for the digital representation of desired anatomical models. The produced models in the present work display the designated anatomical structures in a good manner. Anatomical models produced in the present work, may enhance anatomy learning by been used as adjuncts to traditional resources especially in developing countries.

**Keywords:** anatomy education; three-dimension; subtractive manufacturing; anatomical models.

## Introduction

All medical curricula must include anatomical knowledge, crucial to effective clinical practice across all disciplines, including interventional procedures and medical imaging interpretation [1]. Spatial visualization is essential for a comprehensive and precise understanding of anatomy [2]. Traditional methods of teaching anatomy include ultrasonography, surface anatomy, plastic made models, cadaveric tissues, and illustrated textbooks [3,4]. Concerns about the economy and ethno religion limit the availability of human cadavers. According to [5], in addition, the International Cancer Research Institute classified formaldehyde solutions used to preserve cadaveric tissues as Group 2A carcinogenic agents in 1995 as these solutions are carcinogenic to skin and respiratory system. Due to these hazardous, many universities were unable to use human cadavers [6], which resulted in improper anatomy teaching and consequent medical malpractice [7].

Although there are alternatives, such as potted, vacuum-sealed, or unmounted anatomical specimens, they are costly and human cadavers in nature [8]. In 2014, **McMenamin et al.** [9] created anatomical teaching specimens using three-dimensional (3D) printing technology. These 3D printed models can improve anatomy teaching process because being safe, affordable, and hard to handle, and they can accurately represent anatomical landmarks [10]. Additionally, each dissected specimen can be swiftly replicated in numerous copies using 3D printing technology without posing any ethical or social issues [9].

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The ability to produce 3D objects from 3D models, compatibility with STL and OBJ file types, and compliance with computer instructions are some of the fundamental parallels between CNC machining and 3D printing [12].

A CNC machine can create a wide range of items with precise different dimensions. However, the printing bed restricts the size of the produced model in 3D printing [12]. Strong pieces can be produced via CNC manufacturing from a variety of materials, including metal alloys, wood, acrylics, modeling foam, and thermoplastics [13].

MDF, a type of artificial wood its fibers formed of wax and synthetic resin binders. Panels made of MDF wood feature superior machinability, and a high-quality surface. MDF can be used for a variety of purposes because it is easily painted or coated [14]. Such low-cost, accurate, long-lasting, and ethically sound 3D anatomical models are needed in underdeveloped nations. The goal of the current work is to create inexpensive, transparent, and accurate 3D colored wooden engraved anatomical specimens with precise anatomical landmarks.

## Methods

### Stage I:

Digestive, respiratory, female genital systems, transverse and coronal sections of brain, transverse section of spinal cord and sagittal section of head and neck were chosen to be produced in the present work.

These anatomical structure images were from various resources including lecture notes, text books, multimedia teaching aids and three-dimensional medical imaging sourced as freeware on-line such as https://www.humanbodyhelp.com

Images resource for brain sections was the University of British Columbia Functional Neuroanatomy teaching site (https://www.neuroanatomy.ca) using the CC BY-NC-SA 4.0 license. Then the desired anatomical specimens were designated digitally.

For digital representation of desired anatomical specimens, a software program called ZBrush was chosen. ZBrush is a digitally sculpting technique.

The 3 dimensions height, width and thickness of the specimens were determined in STL (STereoLithography) file

### Stage II:

A computer numerical control (CNC) router was used for the present work. It has four main components bed, controller, motors and router [13]. A simplex CNC machine was used for this work.

After, an engineer makes 3D model using Computer Aided Design (CAD) program called ZBrush. The designed STL file is transmitted to the machine controller through a computer. The controller converts CAD to computer-aided manufacturing (CAM) program. CNC routers use specific commands called G-code that can drive a stepper motor or a servo motor powered signal (pulse train) to move producing precise movements. Then an array of rotating tools and sharp blades engrave the fixed wood board [15] **(Fig. 1)**.

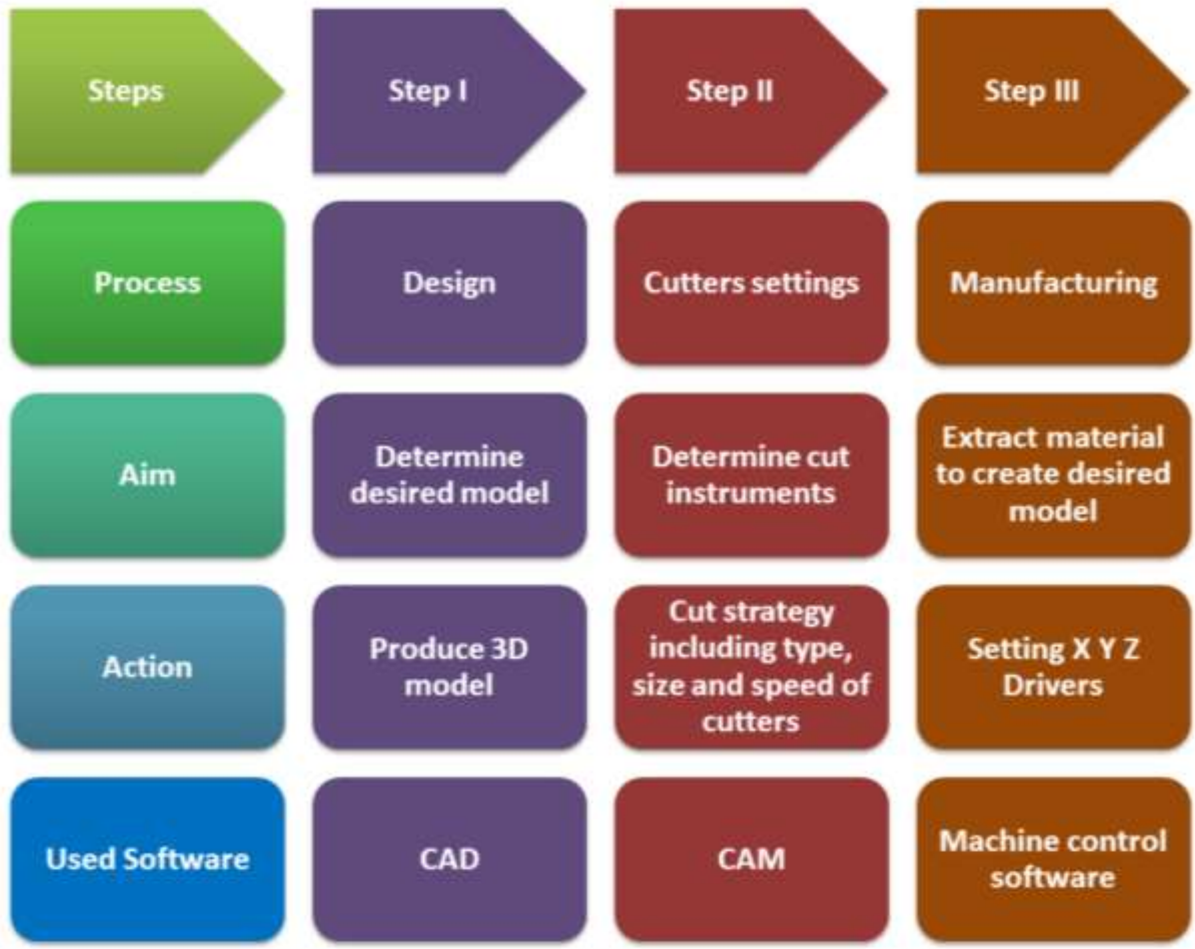


**Fig 1.** The CNC Routing steps; design, cutter settings and manufacturing

The used machine in the current work moves along three axes as the 3D CNC router operates along the X, Y, and Z axes. The 3D router tools usually move forward along the X and backward along the Y axis, and up and down along the Z axis. The CNC router tools are fixed in a vertical direction [12]. The wood board is fixed in CNC router machine bed by an attachment points during the cutting process to fix the wood panel [12].

All models were printed using Medium Density Fiberboard (MDF) panels. MDF is manufactured by transform soft wood into wood fibers then mixed with wax and a synthetic resin binder such as urea formaldehyde resins (UF) or other suitable bonding system. High temperature and pressure is applied to the mix to transform it to wood-based panels. For additional characteristics additives may be introduced during manufacturing process [16].

All models created were reviewed by author as an anatomical expert morphologically to ensure that all anatomical structures details are well recognized and similar to ZBrush designed files.

**Stage III:**

Wooden produced anatomical models do not contain colors that highlight different structures within the anatomical model, accurate and valuable colors were considered for certain specimens such as respiratory, digestive and genital systems. The wooden anatomical models were Hand-colored. The bright colors were chosen to produce a bright teaching model. The chosen painting material was resistant to water.

Institutional review board ethical committee approval was not required for the present work because the work did not involve animal experiment or human participants.

**Results**

In the present work chosen anatomical specimen were produced using (3D) wood Engraving Technology based on Z brush software data.

The chosen specimens to be produced were female genital system, digestive tract, respiratory system, transverse and coronal sections of brain, transverse section of spinal cord and sagittal section of head and neck. They all were successfully engraved in MDF wood panels.

The desired specimens were produced successfully with detailed anatomical landmarks that can be easily distinguished. The overall morphology was an exact copy of the digital representation of desired anatomical structures.

In addition, engraving of negative space such as frontal and sphenoidal air sinuses of sagittal section of head and neck was anatomically typical as data from STL file.

The cost of the models was composed of value of the software, MDF wood panels, and CNC machine time cost and coloration process. Duration time for engraving each model was registered (Table1,2).

Table1. Dimensions, weight, time to engrave and total cost of produced specimens

| Model | **Dimension in cm H ×W×T** | **Time to engrave** | **Weight Kg** | **Total cost EGP** |
|---|---|---|---|---|
| female genital system 1 | 20× 30×2 | 1:25 | 0.366 | 1000 |
| female genital system 2 | 30× 30× 2 | 1:35 | 0.498 | 1100 |
| female genital system 3 | 30× 30× 1 | 1:15 | 0.286 | 900 |
| digestive system | 70×30×2 | 4:10 | 1.946 | 1600 |
| respiratory system | 40×30×4 | 3:15 | 1.486 | 1300 |
| transverse section of spinal cord | 10×10×2 | 0:35 | 0.092 | 350 |
| sagittal section of head and neck | 30×15×4 | 2:50 | 0.824 | 950 |

H height, W width, T thickness, Kg kilogram, EGP Egyptian pounds

**Table 2. Dimensions, weight, time to engrave and total cost of both coronal and transverse sections through brain.**

| **Model** | **Dimension in cm H ×W×T** | **Time to engrave in minutes** | **Weight Kg** | **Total cost EGP** |
|---|---|---|---|---|
| **Coronal section 1** | 14× 18×2 | 25 | 0.190 | 350 |
| **Coronal section 2** | 16× 18× 2 | 30 | 0.196 | 350 |
| **Transverse section 1** | 15×18×2 | 35 | 0.180 | 400 |
| **Transverse section 2** | 16×22×2 | 38 | 0.254 | 400**$** |
| **Transverse section 3** | 17×24×2 | 40 | 0.276 | 400 |

H height, W width, T thickness, Kg kilogram, EGP Egyptian pounds

**Female genital system wood model (Fig. 2, 3)**.

Female genital system wood model is showing vagina, cervix of uterus, body of uterus with three colors for its three layers; endometrium, myometrium and perimetrium, uterus parts fundus, body and cervix, fallopian tube with its three parts isthmus, ampulla and infundibulum, Ovarian ligament.

Three models were created for Female genital system with different dimensions 20 ×20×2 cm, 30×30×2 cm and 30× 30× 1 cm.

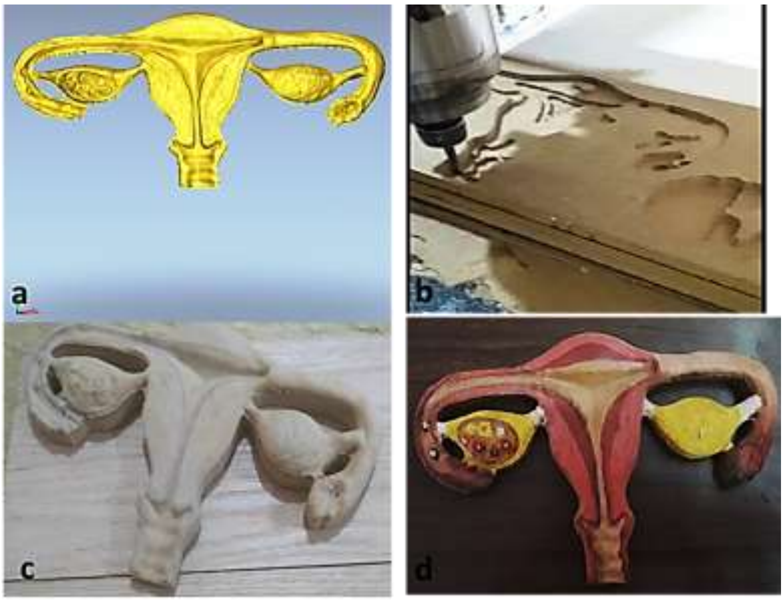


**Fig 2. a-** showing stl file format for production of genital system. b- showing CNC router during manufacturing genital systema- c- showing produced wood engraved genital system. d- showing genital system after coloration

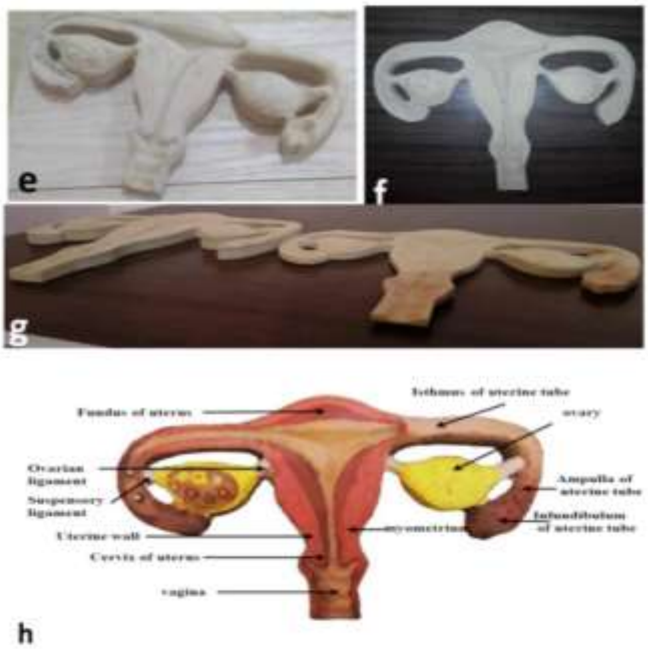


**Fig 3. e,f-** Examples of changing one of 3 dimensions of female genital system. (A) 20× 30×2 cm (B) 30× 30× 2cm (C) change in thickness from 30× 30× 2cm to 30× 30× 1cm, h-showing labeling of produced female genital system with important anatomical landmarks that are well demarcated on model

**Digestive tract wood model (Fig. 4)**.

Three-Dimensional wood engraved Model of digestive tract showing esophagus, stomach, small intestine and large intestine. In addition to transverse mesocolon

Structures such as stomach, pancreas, duodenum, cecum, rectum and anal canal were dissected to show their cavities

The engraved stomach is showing stomach parts; fundus, body and pylorus, the engraved pancreas is showing the pancreatic ducts, the mesocolon is well recognized, the engraved duodenum is showing the site of opening of hepato-pancreatic duct, the engraved terminal portion of the ileum and cecum shows the ileocecal valve and the engraved rectum and anal canal show internal and external anal sphincter muscles

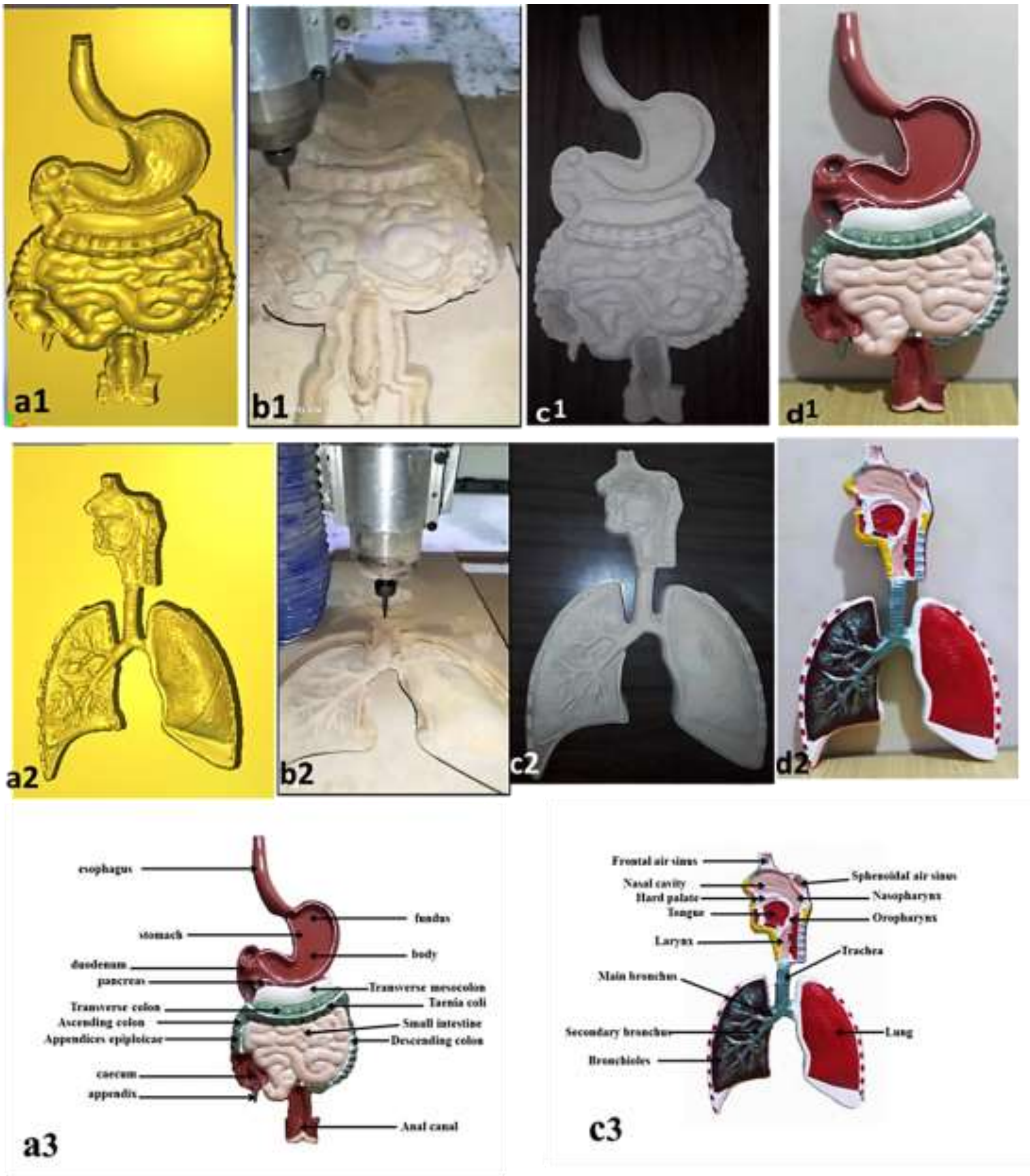


**Fig 4** a1,2- showing stl file format b1,2- showing CNC router during manufacturing, c1,2- showing produced wood engraved. d1,2- showing model after coloration for production of digestive tract and respiratory system. a 3, c3 showing labeling of produced digestive and respiratory system with important anatomical landmarks that are well demarcated on model.

**Respiratory system wood model (Fig. 4)**.

Three-Dimensional wood engraved Model of respiratory system showing frontal air sinus, sphenoidal air sinus, nasal cavity, pharynx, trachea, main bronchus, lobes of left lung, primary secondary and ribs.

Nasal cavity section is showing nasal concha, opening of Eustachian tube, nasopharynx

Oral cavity section is showing lips, hard palate, soft palate, tongue

**Sagittal section of head and neck (Fig. 5).**

Sagittal section of head and neck showing frontal air sinus, sphenoidal air sinus, nasal cavity, nasal concha, hard palate, tongue, pharynx, larynx.


**Fig 5.** a- showing stl file format for production of sagittal section of head and neck. b- Showing produced wood engraved sagittal section of head and neck.

**The structures that could be easily displayed by brain and spinal cord sections are as follow:**

**For transverse sections of brain (Fig. 6).**

The first transverse section is showing Caudate Nucleus – Body, Cingulate Gyrus, Corpus Callosum, and Lateral Ventricles – Body. The dimensions of this section are 15×18×2 cm.

The second transverse section is showing Caudate Nucleus – Head, Cingulate Gyrus, Forceps Major, Forceps Minor, Internal Capsule, Lateral Ventricles – Body, Putamen, and Septum Pellucidum. The dimensions of this section are 16×22×2cm.

The third transverse section is showing caudate Nucleus – Head, Cingulate Gyrus, Forceps Major, Forceps Minor, Fornix – Column, Insula, Internal Capsule, Lateral Ventricles – Body, Lateral

Ventricles - Posterior Horn, Optic Radiations, Putamen, Septum Pellucidum and Thalamus. The dimensions of this section are 17×24×2 cm.

**For coronal sections of brain (Fig. 7)**.

The first coronal section is showing body of caudate, body of corpus callosum and anterior horn of lateral, Cingulate Gyrus, Putamen, Sagittal Fissure. The dimensions of this section are 14× 18×2 cm

The second coronal section is showing Caudate Nucleus, Cingulate Gyrus, Corpus Callosum, Lateral Fissure, Lateral Ventricles - Anterior Horn, Putamen, Sagittal Fissure and Temporal Lobes. The dimensions of this section are 16× 18× 2 cm

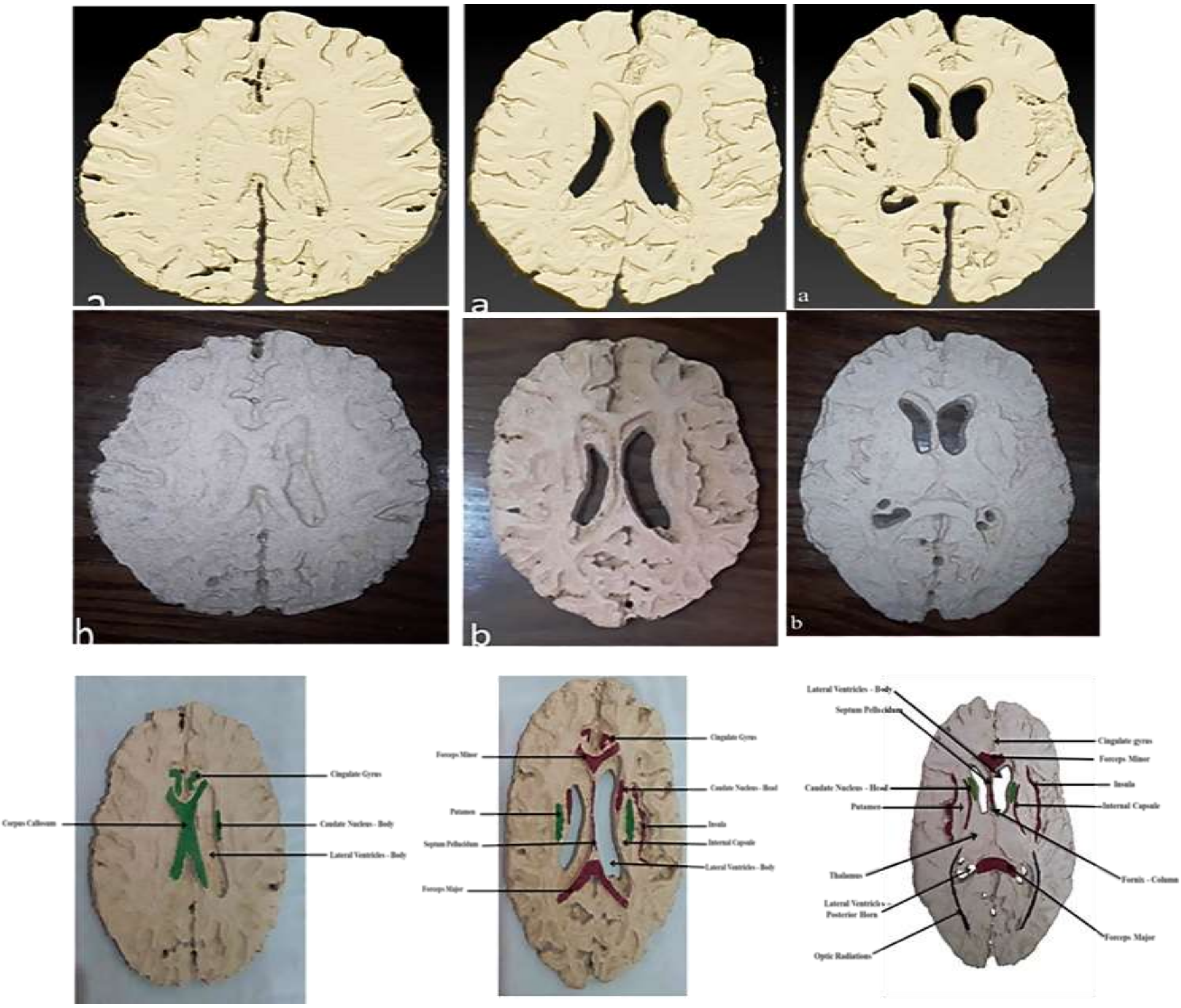


**Fig 6.** a- is showing stl file digital format of transverse section of brain b- is showing produced wooden transverse section, C-is showing labeling of colored anatomical landmarks of wood engraved brain section

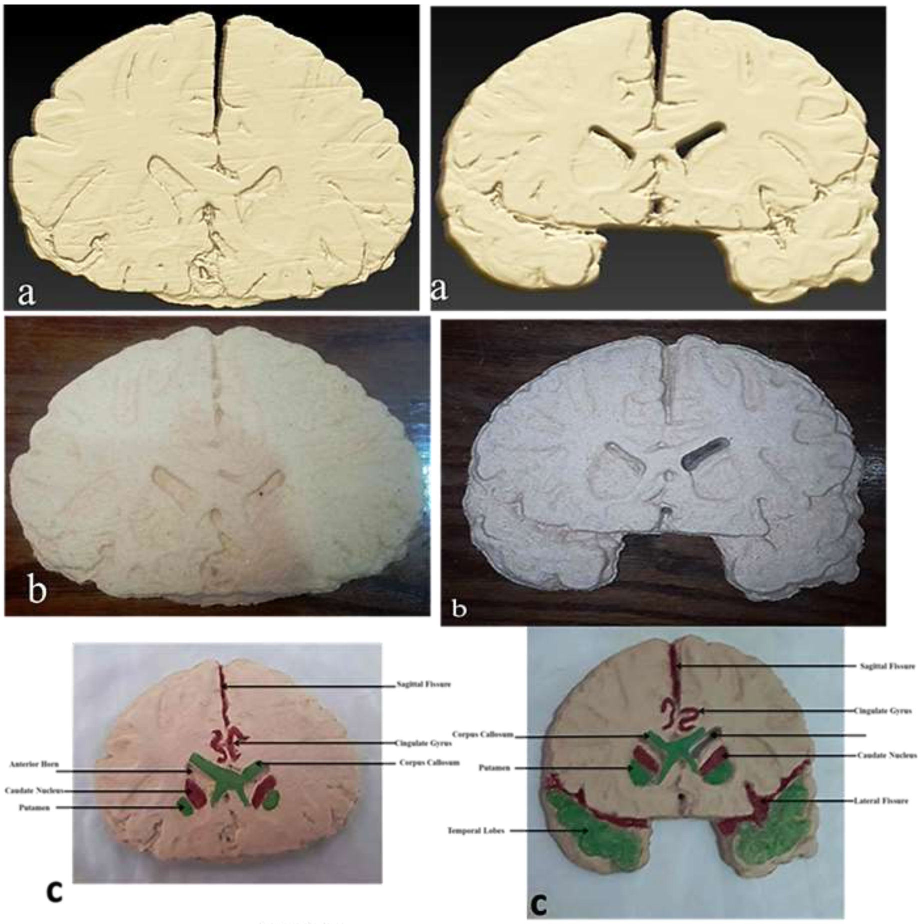


**Fig 7:** a- showing Two coronal section of brain were chosen. Images resource was the University of British Columbia Functional Neuroanatomy teaching site (https://www.neuroanatomy.ca) using the CC BY-NC-SA 4.0 license. The dimensions of each section were determined, b - is showing stl file digital format of coronal section of brain c- is showing produced colored wooden coronal section.

**Cross section of spinal cord (Fig. 8).**

The anterior midline of cross section is marked by the anterior median fissure, and the posterior midline is marked by the posterior median sulcus. The interior of section is showing anterior horn, posterior horn and lateral horn.

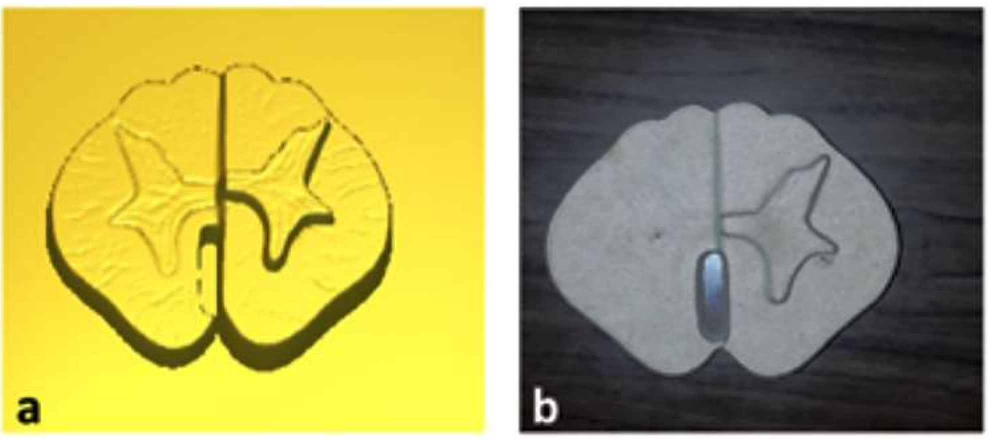


**Fig 8.** a- showing stl file format for production of transverse section of spinal cord.
b- showing produced wood engraved transverse section of spinal cord.

## DISCUSSION

The primary goal of the current work is to increase the availability of physical teaching anatomical models with high accuracy and the lowest cost, particularly in developing nations. The novelty of the current work is the application of 3D engraving technology by using a CNC machine. The produced anatomical models may enable better learning of anatomy by developing an accurate, safe, hard, and inexpensive anatomical model; additionally, multiple copies of the anatomical specimens with varying dimensions can be produced. The benefits of the 3D engraved anatomical specimens produced in the current work include firmness, accuracy, ease of reproduction, cost effectiveness, and the avoidance of safety concerns associated with human cadaveric tissues or plastinated specimens.

Students can handle anatomical models made by CNC machine for very long periods as they are safe, hard and doesn’t need preservative solutions on the other hand cadavers are to some extend fragile and need preservation.

Students can get important tactile feedback from the 3D anatomical model that isn’t attainable from lecture notes, illustrations and textbooks. Hands-on models and visual learning aids can enhance comprehension and memory of knowledge through tactile learning approaches [17]. One kind of engraving machine is a 3D CNC router, which can engrave three-dimensional sheet materials including metal, plasterboard, and wood. It functions by combining machining and computing technologies. The CNC machines offer a quick and efficient way to create numerous identical models in a range of sizes [11].

The 3D (CNC) routers are flexible fully automated devices with a cutting tool that rotates quickly. It works by inputting numerical data into the computer system. Sawing, drilling, and routing make up its duties [13]. Because it cuts materials with such precision, CNC machining is known for its accuracy. As a result, models created with router CNC machining will be consistently accurate and uniform in size [12].

Size of the 3D engraved model can be adult life-size, increased or decreased according to need. This flexibility allows satisfactory productions. **Yang et al.** [18] in their study of effects of model size on anatomy learning reported that participants who studied from models with a diameter greater than 10 cm had a significant better leaning score than those who used models less than 10 cm. As a 3D models with size more than life size can achieve more visibility and subsequent better learning of anatomy.

In addition, in the present work engraving of negative space such as frontal and sphenoidal air sinuses of sagittal section of head and neck was successfully done with accuracy.

Many neuro-anatomists reported that 3 dimensions models allow better understanding of brain internal structures and their relations [19]. In 1940s wax and plaster casts were used to create brain sections models [20] to aid in teaching brain internal structures.

The produced models in the present work display the internal anatomical structures of cerebrum in a good manner and can be used as supplementary modalities for teaching of Neuroanatomy for medical schools’ students especially in developing countries. The models produced in the present work are easy to reproduce, and time and cost efficient. It relies on 3D engraving process which is a type of subtractive manufacturing.

MDF panels were used for engraving each model in present work. MDF has numerous benefits, including superior machinability, exceptional mechanical qualities, and a high-quality surface. MDF has a wide range of applications because to its ease of patterning, painting, and coating [14]. The bacteriostatic properties of wooden boards have long been known.

In order to raise awareness of the value of color use in orientation and education, symbolic color was employed in this work. It has long been known that color can be used symbolically in anatomical illustrations. As they demonstrate anatomical linkages and assist students in visualizing and differentiating various tissues (such as the layers of the uterine wall) [21]. The used CNC router in the present work incorporates engineering technologies for new teaching methodologies. The 3D models produced in the present work, may enhance learning by been used as adjuncts to traditional resources especially in developing countries.

**Limitation:**

The general limitations of CNC Milling are prototype size, axis movement, and drill bit size. The size and shape limitations will vary by the machine used.

**Future perspective:**

To the best of our knowledge this study is the first study which documents the production of 3D engraving models using CNC router machine. We hope to develop a new generation of 3D models that incorporate this technology enabling students to attain information by visual and tactile learning about various components of the anatomical structures.

## CONCLUSION

Treating Early sweet grapevines three times with Micromix at 0.1% and salicylic acid at 50ppm was responsible for improving yield quantitively and qualitatively.

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