Xournals

Academic Journal of Anthropological Studies

ISSN: 2581-4966 | Volume 05 | Issue 01 | April-2022

Stereolithographic Printing - A Novelty in Forensic Odontology: A Review

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Available online at: www.xournals.com

Received 30th August 2021 | Revised 18th November 2021 | Accepted 14th March 2022

Abstract:

Forensic Odontology is a very interesting branch of the Forensic Sciences that involves the usage of dental sciences in identifying the dead individuals. Stereolithography is an evolving tool for finding the victims and deceased individuals in the branch of the forensic odontology. It's a type of the 3D printing procedure which is being aided for forming the models, patterns, etc., by using a photochemical process. In this process, light causes development of polymers. This review highlights the history, principle, and application, cases proven with stereolithographic printing in the field of forensics, its advantages and drawbacks.

Keywords: *Forensic Odontology, Stereolithography, 3D Printing, Victim Identification, Facial Reconstruction.*

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Introduction

Additive manufacturing is a technique wherein layer-by-layer fabrication of complex 3D structures with an extensive range of materials. SLA (Stereolithography) is one form of the additive manufacturing procedure that has the capability to create structures with advanced and complex geometry, composition, and functions **(Wallin *et al.*, 2018).** It is the developing tool for identifying victims and deceased individuals in the field of forensics. This type of technology is used for fabricating models, patterns, etc., by using a photochemical process, where the polymer is developed using light **(Martin *et al.*, 2015).** This article is hereby giving an overview of stereolithography, its history, parts, working, applications in forensic odontology, and its advantages and drawbacks.

History

In 1981, Dr. Hideo Kodama first developed SLA. He viewed it as a substitute for holographic techniques. It's a rapid and cheaper method of recreating models in 3D space **(Kodama, 1981).** In 1986, Charles W. Hull patented the first commercially available SLA printer, and it was known as the Second Generation Stereolithography. A 3D object is formed from a type of material that is capable of solidifying upon exposure to ultraviolet radiation. The formation is a layer-by-layer process. As an outcome of the natural adhesive property of the polymer, the non-transformed layers typically stick to the previously formed layer. With advancement, SLA has surpassed its own application of prototyping and now it can be used in manufacturing structures with highly complex geometries **(Hull, 1984).**

Tumbleston *et al*, (2015), developed third-generation stereolithography to overcome the shortcomings of second-generation SLA. The third generation SLA has a greater printing speed as compared to the previous approach.

Principle of Stereolithography

SLA works under the principle of photopolymerization. It's a technique by which the ultra-violet light activates the initiators in the liquid monomer and converts it into a solid polymer by the establishment of carbon bonds. It's an irreversible process and the solid polymer formed cannot be converted to a liquid monomer **(Hull, 1984).**

Parts of SLA

The parts of stereolithographic apparatus are as follows: (Figure No. 1)

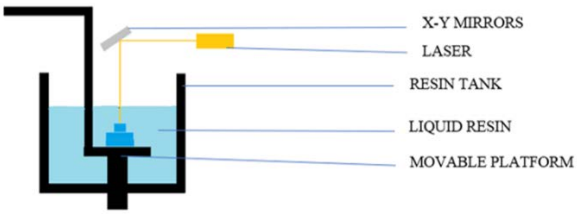

Figure No. 1: Schematic representation of Stereolithographic apparatus

1. Resin tank: houses the liquid photopolymer
2. Liquid resin: The liquid photopolymers used for stereolithography is of a wide variety. Recently, Epoxy-based resin hybrids and systems are used because of lower shrinkage, lower moisture absorption, higher temperature resistance, and higher strength.
3. High powered UV laser
4. Galvanometers (X-Y mirrors)
5. Movable Platform/ working surface
6. The computer controls the piston and the laser movements **(Haleem and Javaid, 2018).**

Working of SLA

The working of SLA has four main steps:

1. Image acquisition
2. Image segmentation
3. Image processing
4. 3D printing

Image Acquisition

For the image acquisition, the CT/MRI of the suspected victim acts as efficient and accurate data and plays a very significant role in the designing process. A piece of exact information about the bones and the inner organs are given by the CT/MRI scan **(Haleem and Javaid, 2018).**

Image Segmentation

This step improves the surface of replicas obtained from the image segmentation. The unwanted noises, ridges, and holes produced during image segmentation are removed during this process. This is later fed into the 3D slicing software responsible for generating G-code, the native language for the 3D printers **(Bücking *et al.*, 2017).**

Image Processing

This step improves the surface details of models obtained from image segmentation. The unwanted noises, ridges, and holes produced during image segmentation are removed during this process. **(Birbara *et al.*, 2018).**

3D Printing

In this step, the ultra-violet (UV) laser is activated to cure the liquid monomer to the solid polymer. The ultra-violet light falls on the X-Y scanning mirrors, which direct them onto the resin. The course is repeated until the complete desired structure is obtained.

At end of the process, the model is removed from the working surface, cleaned, and then kept for final curing in a UV oven **(Birbara *et al.*, 2018), (Haleem and Javaid, 2018)**

Different Types of the 3D Printing

There are seven different groups of additive manufacturing technology which are as follows:

- Vat photopolymerization
- Material jetting
- Binder jetting
- Material extrusion
- Powder bed fusion
- Sheet lamination
- Directed energy deposition **(Chaudhary *et al.*, 2018).**

Application of Stereolithography in Forensics and Forensic Odontology

a) **Presentation of the Evidence in Court:** In forensic science, though human remains help in providing a piece of conclusive evidence, the judicial system relies on the scanned copies and the photographs of remains of a human in court. The main reason involved in presenting the remains of a human in court is attributable to legal and ethical issues. Hence, stereolithography helps to duplicate the remains of humans for presenting them in court **(Naru and Dykes, 1996).**

b) **Bite Mark Analysis:** The major applications will be to collect and display bite mark evidence. First, the forensic expert should identify if a bite mark was produced by a tool, instrument, animal, or human. The bite mark can be then related to the suspect's dentition for identification. This technology is more useful because it can prevent the distortion of the bite marks with time **(Mertz and Stimson, 1997).**

c) **Chelioscopy, Palatoscopy, Tongue Prints, and Fingerprints:** Stereolithography is of great use to record lip prints, tongue prints, etc. as they are more prone to distortion with time and it's enormously difficult to count on conventional impressions **(Scott, 2016).**

d) **To illustrate bone loss pattern in bone pathology:** 3D models in case of bone pathology like bone fracture gives evidence about the process that caused the injury and also about the bone loss pattern associated with a lesion **(Forrest *et al*, 2012).**

e) **Age Estimation:** An accurate 3D dentition model is very essential in the event of age estimation. 3D replica of the lower jaw (mandible) also helps in the age estimation with gonial angle **(Cuperus *et al.*, 2012).**

f) **Sex Estimation:** SLA also helps in sex determination with the 3D dentition models and bone models. The 3D dentition models created from stereolithography didn't present any kind of significant difference in crown height, root height, crown width, and root width when compared with tooth sizes of the suspect/victim **(Keating *et al*, 2008).**

g) **3D Facial Reconstructions:** It's a method of reconstruction of a person's face with the help of tissue markers and materials such as clay from the remains of their skeletal **(Schuh *et al,* 2013).**

h) **Planning post-traumatic reconstruction surgery**

i) **In Forensic Archaeology:** Digitization of the mass graves and the archaeological sites are more common in forensic archaeology. SLA may also help in duplicating the archaeological site; however, no such research has been done in this field to date **(Baier and Rando, 2016).**

j) **Disaster Victim Identification:** SLA is of great use in the case of the DVI though the victim's body is completely charred. The CT scan of teeth from severely charred remains helps in duplicating the tooth model which will be easy to handle and also to present in court **(Biggs and Marsden, 2019).**

k) **Ballistic Reconstruction:** Helps in identifying and in reconstructing the weapons used **(Carew, and Errickson, 2019).**

l) **As an Anatomical Model:** To analyze the crime, the Presentation of evidence helps as a training aid, functions as a test piece and investigative tools **(Chaudhary *et al*., 2018).**

m) **Dental and Forensic Anthropology**: In the case of dental anthropology, SLA is of great use as it can duplicate the accurate details of dental non-metric traits like Carabello cusp, shovelling, hypocone, etc. These details aid in improving the assessment of the population. In forensic anthropology, SLA helps in forming skeletal remains which further aids in the assessment of the sex and age of an individual **(Carew and Errickson *et al,* 2019).**

n) **Crime Scene Reconstruction:** Crime scene or accident scene reconstruction helps in determining the difficulty of the incident scene. It also helps to assess the relationship amongst the collided vehicles in any case of an accident **(Komar *et al.,* 2011).**

o) **Forensic Medicine:** It helps in creating models of fractured bone and ruptured organs which help in teaching purposes to demonstrate the pathological and anatomical structures **(Ebert *et al.,* 2011).**

Proven Cases with SLA in Forensics

Given below are a few examples of this technology that helped in solving the cases –

a) Hong Kong police used this technology to recreate the scene of a crime and to present the evidence in court.
b) Birmingham's "suit-case killing" case where the 3D printing was used to accuse the killer.
c) Case of Ellie Butler, a 6 years old girl where 3D printing was used to create a replica of her extremely damaged skull
d) A murder case of a 47 years old unidentified victim, where the New York Police along with the State University of New York attempted to recreate the victim's face using a 3D-printed replica of the victim's skull **(Chaudhary et al, 2018).**

Advantages of Stereolithography

a) The chief benefit of stereolithography is its high speed in manufacturing a 3D object.
b) The accuracy of the model obtained is high and precise.
c) It also has a high-quality finish with a smooth surface.
d) It also has high built volumes and therefore, there is no sacrifice in surface details and precision.
e) Any object with greater geometric complexity can be obtained
f) Rapid turnover time **(Puri *et al*., 2012).**

Disadvantages of Stereolithography

a) The major drawback of stereolithography is its high printing cost.
b) The photopolymer resin used is extremely sticky in nature and is messy to handle.
c) It also has an extensive range of limitations on the materials that can be employed.
d) In the case of forensics, the bone replica does not match the exact density of bone and hence, should be presented with the CT scan.
e) Few built-in lines are present in the prototype which gives a false representation of the actual object **(Sharma *et al*., 2019).**

Conclusion

Stereolithography is one of the oldest technology which was established for rapid prototyping still remains an attractive solution for creating prototypes with high accuracy and durability. It's still in the genesis stage and needs to be researched. Stereolithography has the potential of creating more robust shreds of evidence in the branch of forensics. Hence, can be considered as an accurate, useful, and novel tool in the field of forensics.

Acknowledgement
Nil

Conflict Of Interest
Nil

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