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Forensic facial reconstruction using CBCT: A systematic review

Jijin Mekkadath Jayakrishnan[1], Jagat Reddy[1], Vinod Kumar R. B.[2]

SUMMARY

Background. Forensic facial reconstruction is a technique to reconstruct human face from unidentified skull remains for human identification and facial recognition. Some of the methods of reconstruction is using 2D methods, 3D clay models and computerized craniofacial forensic reconstructions (CCFR). Although beneficial they are limited by meticulous and time consuming processiy. However, in 3D imaging cone beam computed tomography (CBCT) is an excellent alternative. Hence, this systematic review evaluated whether CBCT is a better diagnostic tool in facial forensic reconstruction compared to conventional 2D and 3D methods of facial reconstruction.

Results. Article selection and data extraction was done based on the inclusion and exclusion criteria devised for the study. The articles were screened from Pub Med, ProQuest, Google scholar, Science direct and Scopus.

Three hundred and thirty-nine articles were initially identified from which seven articles were full text reviewed and included in the review. All the articles included in this study suggest that the facial reconstruction done using CBCT are reliable.

Conclusion. The computerized 3D modeling method produces reliable facial reconstructions which involves the images scanned from CBCT and the combination method. The computerized 3D modeling method produces facial reconstruction which almost mimics the original resemblance.

Keywords: cone beam combuted tomography, facial reconstruction, facial soft tissue thickness.

INTRODUCTION

Forensic facial reconstruction is a technique to reconstruct human face from unidentified facial and skull remains for positive human identification and facial recognition (1). Facial reconstruction is often resorted to when positive identification cannot be achieved due to extensive damage to the facial bones and cranium to a point where it is not possible to identify facial features in the event of an animal attack, bomb blast or due natural disasters that is where Facial forensic reconstructions help to identify the person with little or no information. This positive identification is essential not only for legal purposes but also aids in the family's in overcoming their grief and bring a sense of closure to them (2). In such scenarios, an attempt is made to reconstruct the original facial appearanceof the individual which can be used tohelp in possible identification. However it cannot be used as a direct identification methodbut can be used as an adjunct to assist in identification. Scientific and artistic skills are essential in facial reconstruction. In order to recognize a non- identity person, the facial features are vaulable assets with anatomical landmarks of the soft tissue bbeing unique for each individual (3). Once it is reconstructed it would be easier to publish in Televisions and Newspaper for the relatives of the person to identify them.

Forensic facial reconstruction is a combination of employing both scientific methods and artistic skill. It can be used to reconstruct the soft tissues onto the skull in order to obtain the image of an

[1]*Department of Oral Medicine and Radiology, Indira Gandhi Institute of Dental Science, Sri Balaji Vidhyapeeth University, Pillaiyarkuppam, Puducherry, India*
[2]*Department of Oral Pathology and Microbiology, PSMDC, Thrissur, Kerala, India*

Address correspondence to Jijin Mekkadath Jayakrishnan, Department of Oral Medicine and Radiology, Indira Gandhi Institute of Dental Science, Sri Balaji Vidhyapeeth University, Pillaiyarkuppam, Puducherry, India.
E-mail address: drjijin@gmail.com

individual for his/her recognition and identification (4).

The methods which are used in the facial reconstruction are two-dimensional, three-dimensional clay models and three-dimensionalcomputerized modelling (5).The manual and the computerized technique are the two methods which are used in 3D forensic facial reconstruction. 3D computerized craniofacial forensic reconstructions (CCFR) has got various advantages over other techniques by use of computer which enhance the visualization of the tools that shows skin and bone together with adjustments (6).The other advantages of CCFR include easy assemble of the skull parts without damaging the skull and can easily replace the left out or empty areas (5).

But some disadvantages are also encountered that is, it is very time consuming and experience is necessary for the reconstruction.The various 3D manual methods which are in practice are the Anatomical (Russian), Anthropometrical (American) and Combination Manchester (British) methods which were developed by Gerasimov, Krogman and Neave respectively (7).

CBCT is the generation next that has emerged as a potentially low-dose volumetric imaging technique for visualizing maxillofacial structures. Sequential, single-image captures are stacked as multiple offset lateral cephalograms, corrected, assembled and reconstructed using filtered back projection algorithm (8). Further, secondary reconstructed images in the personal computer using dedicated software present the images to the radiologist in three orthogonal planes (axial, sagittal and coronal) and 3D reconstructions. The other methods using 3D techniques have their own advantages and limitations in such scenarios, CBCT can serve as a useful tool. Hence, The main aim of this systematic review is to evaluate whether CBCT is a better diagnostic tool in facial forensic reconstruction.

MATERIALS AND METHODS

Ethical approval from the Institutional review board was obtained. The substructure of the systematic review is based on PRISMA Statement. The focused question is "Is CBCT a better investigation tool for forensic facial reconstruction?"

Study design

This systematic review evaluated whether CBCT is a better diagnostic tool in facial forensic reconstruction.

Eligibility criteria

Inclusion criteria

Studies in which the primary objective was to evaluate the accuracy of a facial reconstruction technique using CBCT data. No language or time restriction were applied.

Exclusion criteria

Exclusion criteria included case reports, studies which included samples of facial anomalies and samples of orthognathic surgeries, studies done on two-dimensional facial approximation,reviews, letters, personal opinions, book chapters, conference abstracts and studies using animal models.

Information sources

The following databases were incorporated in the systematic search for relevant literature: PubMed, ProQuest, Google scholar, Science direct and Scopus. All searches were conducted from December 20 to January 10, 2021.

Search terms

Following search terms were used forensic facial reconstruction, CBCT and forensic facial reconstruction, facial approximation, craniofacial reconstruction, role of CBCT in facial reconstruction.

Study selection

In the 1st phase of selection, the titles and abstracts were screened and evaluated.

In the 2nd phase of selection full text were screened and study which have the inclusion and exclusion criteria were selected.

Collection process

For all the included studies, following descriptive characteristics were recorded Author, year of study, location, ancestry, sample size, mean age of the patients included in the study, 3D manual methods used in the study for facial construction, type of machine used, sample type- live or deceased patients and results of the included study. One reviewer collected all the required information for the systematic review and other reviewer verified its accuracy.

RESULTS

A total of 6754 articles were found in the various scientific database with search expressions relevant to this study, of these, 339 articles were selected for initial screening and from those 339 articles duplicates were excluded and the remaining was 159 articles. After abstract and text screening a

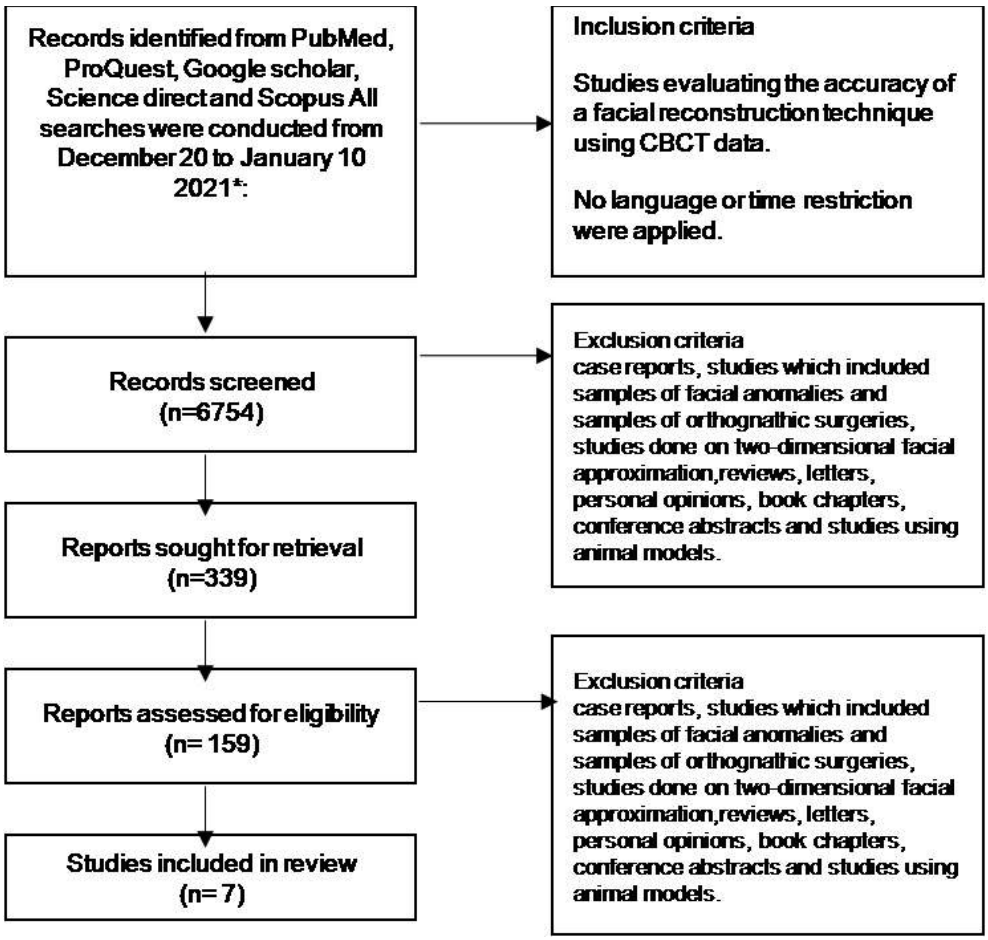

Fig. Study selection process

total of 7 articles were finally selected for the study with the inclusion and exclusion criteria of the systematic review (Table). The selection process of the included studies is shown in Figure.

Out of 7 studies which were included in the systematic review, in 5 of the published studies, 3D computerized craniofacial forensic reconstruction tool was used, one study had used the combination method in facial reconstruction (the british / the Manchester method) and one study used Region fusion strategy as the main tool for facial reconstruction. The sample size of each study ranged from 1 to 200. The facial reconstruction in the included studies was done in live patients, existing CT data and cadavers.

The studies that were systematically reviewed had analyzed various measurements which ranging from skull digitization, geometric measurements, sex classification and computerized CFR, Facial soft tissue thickness at different sites and the deviation errors between the reconstructed and target faces were measured. Majority of included studies analyzed facial soft tissue landmarks.

The result of the included studies indicates that the facial features of the reconstructions using CBCT data demonstrated good levels of accuracy.

DISCUSSION

Facial soft tissue reconstruction plays a main role in identifying a deformed person with little or no information. It is very essential to know the average values of the facial soft tissue thickness of certain sites of the face to reconstruct the skull to some extent (9). Various studies on facial reconstruction have generated data base of soft tissue thickness related to BMI, gender, race and ethnicity. With the help of the database available on various ethnicities and productive use of CBCT, facial reconstruction is more reliable in individual identification and also can be used for archeological research (10, 11). CBCT produces feasible 3D craniofacial reconstructions, with a minimal radiation exposure. It is mainly appertaining to maxillofacial region. Its different field of views (FOV) produces excellent images of the skull and also the landmarks used in cephalometric analysis along with a 3D volumetric of external facial surface (12). The various advantages of CBCT are as follows, can obtain the images in upright positions, lower radiation dose compared to CT, maximum tissue depth, can repeat the scans, editing of the images can be done on the go such as rotation and zoom views.

There are different types of methods in facial reconstruction, which is manual and computerized 3D method (13). The manual method of facial reconstruction includes:

1. Anthropometerical American Method/ Tissue Depth Method.

   Krogman in 1946 developed Tissue Depth Method. The law enforcement agencies most commonly use this method of facial reconstruction. The needles, X-rays and/or ultrasound are used for taking the measurements. Highly trained personnel is needed for this technique to record the

facial muscles in correct anatomic position, hence this technique is not preferred now a days (14).

2. Anatomical Russian Method.

   Gerasimov in 1971 introduced this method of facial approximation. The soft tissue depth data is not necessary for this technique. The approximation is performed by shaping the muscles, glands and cartilage onto the skull layer by layer. This method is not used now a days since it requires deeper anatomical acknowledge on performing the facial construction. Reconstruction of fossilized skulls can be done using this method (15).

3. Combination Manchester Method/ British Method.

   This method was introduced by Neave in 1977. This is the most accepted method and most widely used than the other two. It uses both the tissue depth and muscles (16).

Computerized 3D facial reconstruction

The 3D computerized models can be fabricated using both the manual clay and 3D animation software techniques and virtual sculpture system can also be used. 3D facial reconstruction relies on the principle of building a "face" onto the skull based on the application of mean tissue thicknesses for given anatomical landmarks. In this method multiple images of the same face can be created most effectively (17).

The included studies in this systematic review used either the manual or computerized 3D facial reconstruction, but majority of the included studies opted computerized 3D forensic facial reconstruction method. The included studies in this systematic review suggest that the facial construction using CBCT are reliable.

CBCT has proved as a reliable tool as it leaves reduced physical footprint, a low radiation dose and its low cost have been responsible for the rapid uptake of CBCT in the dental health-care systems (18). Apart from volumetric imaging, CBCT allows various nonaxial 2D images and synthesizes cephalograms comparable with the conventional ones (19). Several such advantages have made CBCT useful in the diagnostic assessment of bony and dental pathologies including fractures, maxillofacial deformities, temporomandibular joint imaging and implant treatment planning; it also facilitates image-guided surgery (20). In olden days, CBCT scanners were exclusively used for imaging of the hard tissues of the oro-facial complex as they have a limited ability to differentiate the soft tissues. It was rectified when Januario et al., developed a soft tissue CBCT that scanned the maxilla using an i-CAT™ scanner (Imaging Sciences International, Hatfield, PA, USA) for 40 seconds with a focal spot of 0.5 mm, voxel size of 0.2 mm, and grayscale 14-bit resolution. As this technique reconstructs the images in all 3 orthogonal planes (axial, sagittal, and coronal), it improved the image quality of the soft tissue. (21). Nunes et al., reported that prevalence of soft tissue calcifications was found higher on CBCT images when compared to conventional 2D images as they tend to produce more ghost images the exact location cannot be identified (22).

To our knowledge, this systematic review is the first of its kind to study the efficacy of CBCT for the purpose of forensic craniofacial reconstruction. Meundi M et al described that CBCT is a valuable and a precise tool in detailing the facial soft tissue thickness dataset which is useful in forensic facial reconstructions of South Indian population as well as in maxillofacial and plastic reconstructive surgeries (23).

Jon-Lee W et al utilized CBCT in computerized facial reconstructions produced using skull models from live adult Korean subjects to assess facial morphology prediction accuracy. The facial features of the reconstructions demonstrated good levels of accuracy compared to the target faces (4).

Hwang et al in their study indicate that CBCT images can be used to measure ST thickness with high reproducibility. However, some landmarks need to be redefined to reliably measure ST thickness on CBCT images (24). In addition to CBCT, we also found that combination method produced reliable results in facial reconstruction for forensic purposes.

Sforza et al reviewed various imaging technologies to study three dimensional facial morphology useful in facial reconstruction found that there was a decrease in the error rate in various studies on facial reconstruction after the use of CBCT from 2000 to 2006 (25). By reducing the restoration-related artifacts, CBCT further improves accuracy of facial reconstruction for that individual by recording the site and type of the restorations. Dental fillings provide useful identification to that particular person and can be very helpful in identification on comparison with antemortem records available (26, 27). Dental CBCT can readily confirm the presence of restorations and prostheses, root canal filling materials, and denture clasps and wires for enforcement in both dry- and soft-tissue-attached skulls during their forensic analysis and are thus useful in reconstruction of face.

Table. Main characteristics of included studies

No	Author	Year of study	Location	Ancestry	Sample size	Mean age	Method	CBCT ma-chine	Sample type	Measurements ana-lyzed in the study	Result
1	Hwang et al..,	2010	Korea	Korean	20	28.1	Computerized 3D CT imag-es	Alphard Vega; Asahi Roentgen Co., Kyoto, Japan	Department data base	31 landmarks (10 midline and 21bilat-eral) were identified according to De Greef et al..,	The reproduci-bility of the fa-cial ST thick-ness was relia-ble but some showed low reproducibility. The landmarks of the 3D im-ages can be re-produced.
2	Zacharias Fourie et al.,	2010	Nether-lands	Nether-lands	7	-	Computerized 3D CT imag-es	KaVo 3D exam (Ka-Vo Dental GmbH, Bisma-bring, Germany) CBCT scanner	Cadaver	Facial soft tis-sue thickness at 11 differ-ent sites (soft tis-sue landmarks were meas-ured)	Overall, the re-sult of this study con-firmed that the measurements can be used to create soft tis-sue database thickness.
3	Won-Joon Lee	2012	Korea	Korea	3	28.4	Combination methods	Alphard Vega; Asahi Roentgen Co., Kyoto, Japan	3 student volunteers	the deviation errors between the recon-structed and target faces were measured.	Reconstructions of the facial features were reliable when compared with the faces
4	Wuyang-Shui	2019	China	Han Chi-nese	140	-	Computerized 3D CT imag-es	A Konica Minolta VIVID 910 laser scan-ner	140 living individuals (70 females and 70 males)	skull digitiza-tion, geometric measure-ments, sex classifica-tion and com-puter-ized CFR	Reconstructions of the unidenti-fied face can be reproduced.
5	Yang Wen et al..,	2020	China	Han Chi-nese	200	17-75	Region fusion strategy	CT scanner	Volunteers	-	The results showed the re-construction of the facial thick-ness were relia-ble
6	Clemente Maia S. Fer-nandes	2012	Brazil	Brazilian female	1	-	Computerized 3D CT imag-es	-	Volunteer	10 midline points and 11 bilateral points	The results of this study show that this a use-ful tool in facial recon-struction, mentioned with the parameters used in the study.
7	Geraldo Eli-as Miranda et al..,	2017	Brazil	Brazilian Caucasian	4	21-49	Computerized 3D CT imag-es	-	4 volun-teers do-nated exist-ing CT Da-ta	Geometric comparison of the CCFR to the subject 3D face model (obtained from the CT data)	The two CCFRs were matched cor-rectly and the accuracy levels of the free software pro-grams produce 3D CCFRs and can be used in forensic appli-cations.

IV – intravenously; * – three times higher rate of postoperative infections; ** no statistically significant difference.

The craniofacial face is one of the most complex geometric objects in the natural world.

Even though, soft tissue measurement with CBCT gives more accurate pictures, some postural errors may raise differences in measurements. A study conducted by Munn and Stephan with 62 patients, demonstrated that postural variation affects the overall average facial soft tissue thickness measurements, especially in the cheeks, eyes and nasolabial fold area (28).

As the contrast resolution of CBCT is limited by high scatter radiation during image acquisition, the divergence of the x-ray beam, and built-in flat panel detector related artifacts it tends to produce images with a relatively less contrast resolution (29)

Even with the above limitations, the image quality produced by CBCT is still decisively higher than the regular 2D modeling method at a cheaper price in forensic face reconstruction.

CONCLUSION

The computerized 3D modeling method produces reliable facial reconstructions which involves the images scanned from CBCT and the combination method. The computerized 3D modeling method produces facial reconstruction which almost mimics the original resemblance.

LIST OF ABBREVIATIONS

CBCT – cone-beam computed tomography.

CCFR – computerized craniofacial reconstruction.

PRISMA – preferred reporting item for systematic-review and meta-analysis.

3D – three dimensional.

FOV – field of view.

CT – computed tomography.

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