치의학석사 학위논문

Development of a Software Program for the Automatic Calculation of the Tooth-Pulp Volume Ratio on the Cone-Beam Computed Tomogram

Cone-beam 전산화단층 삼차원 영상 상의 치아-치수강 부피비율 계산을 위한 자동화 소프트웨어 개발

2015 년 2 월

서울대학교 치의학대학원

치의학과

이 훈 기

Abstract

Development of a Software Program for the Automatic Calculation of the Tooth-Pulp Volume Ratio on the Cone-Beam Computed Tomogram

Hoon-Ki Lee

Department of Dentistry

The graduate School

Seoul National University

Tooth is one of the most valuable tissues for the forensic purpose because of its mechanical, chemical and physiological stability over time comparing other forensic specimen. Its own physical and biological properties have been used for identification or age estimation in living individuals as well as dead bodies, while its hard tissue provides a protective shell for DNA inside of it in the body from harsh environment.

The decrease of pulp cavity of the tooth by deposition of secondary dentin with aging is one of the properties of the tooth tested the most frequently for age estimation. Various methods using tooth-pulp ratio have been developed and presented based on sectional specimen or two-dimensional or three-dimensional radiographic images. However the results are not consistent yet in its validity, reliability, and usability as an age-estimation method. In this study, we developed and introduced a software to extract the volume of tooth and pulp automatically from the cone-beam computed tomography (CBCT) that can guarantee the more objective, reproducible, and timesaving way to measure the tooth-pulp volume ratio.

Once the threshold density between the tooth, pulp cavity, and bone are defined using an automated tool integrated in the developed software on one cross-sectional CBCT image, regions of interest (ROI) are extracted automatically in the rest of the cross-sectional images to navigate the three dimensional volume of the tooth and pulp cavity and the tooth-pulp volume ratio is finally calculated. This process is done automatically by just indicating the center of the pulp cavity and the area where the tooth is located. The software tracks the change of density from the point pointed at the center of the pulp cavity to the boundary drown to indicate the area where the tooth is located so as to find the border of each structure, which can exclude the any possibility of subjective judgment by the examiner. Of course, the result can be corrected, if necessary, by the examiner as well as by changing the threshold of density of hard tissue.

In further studies based on a large-scale sample, the most proper threshold to present the most significant relationship between age and tooth/pulp volume ratio and the tooth correlated with age the most will be explored. If the software can be improved to use whole CBCT data set rather than just sectional images and to detect pulp canal in the original 3D images generated by CBCT software itself, it will be more promising in practical uses.

Keywords : Tooth-pulp volume ratio, Age estimation, 3D Image processing

Student Number : 2011-22479

목 차

그림 목차

Introduction

Tooth is one of the most valuable tissues for the forensic purpose because of its mechanical, chemical and physiological stability over time comparing other forensic specimen[1]. Its own physical and biological properties have been used for identification or age estimation in living individuals as well as dead bodies, while its hard tissue provides a protective shell for DNA inside of it in the body from harsh environment.

The decrease of pulp cavity of the tooth by deposition of secondary dentin with aging is one of the properties of the tooth tested the most frequently for age estimation. Various methods using tooth-pulp ratio have been developed and presented based on sectional specimen, two-dimensional or three-dimensional radiographic images[1-5]. Panoramic radiograph is one of the most commonly taken in dental practice, which allows it used very easily for age estimation. However its inevitable inborn image distortion is a limitation for exact measurement. Recently, cone-beam computed tomography (CBCT) is getting more common in dentistry along with the increased popularity of dental implant and lowered price of CBCT equipments. Moreover, the quality of the CBCT image has been improved gradually[6] to get over many limitations of two-dimensional images such as image distortion. Some of previous studies using CBCT reported promising results for age estimation based on the pulp/tooth ratio[2-5]. However the results are not consistent yet in its validity, reliability, and usability. It is mainly because the boundary of the tooth and pulp area on images were extracted in manual ways.

Therefore, the aim of this study was to develop an automated software to extract tooth and pulpal area from sectional CBCT images, which can guarantee more reproducible, objective and time-saving way to measure tooth-pulp volume ratio.

Materials and methods

Materials and methods

The software program was developed using MATLAB© (MathWorks, USA). To determine the optimal threshold for the region of interest (ROI) extraction, user interface to adjust the threshold for extraction algorithm was added. Default threshold was determined after several trials to make the outline of extracted ROI fitting to the tooth and pulpal outlines. To test the effect of starting point location selected initially in the pulpal area on the final result, tooth-pulp ratio was calculated 5 times with different 5 starting points, the center of pulpal area, mesially-, distally-, buccally-, and lingually-deviated points.

Algorithm

Main user experience (UX) concept is as followings. When the practitioner select one point of the pulpal area in the one axial section of CBCT images, the software extract tooth area automatically from the bone and pulpal area from the tooth area in sequence. Based on the result of this primary extraction, tooth and pulp area on the very next axial sections of CBCT images are automatically extracted in turn. In consequences, the tooth and pulpal areas extracted from all axial sections are reconstructed in 3D objects and tooth-pulp volume ratio is calculated automatically. In this whole procedure, the only human work is just one click to indicate the pulpal area on a axial section of CBCT images.

The first step of the algorithm is applying Otsu-thresholding, one of image processing techniques to discriminate the main object from the background[7]. By applying otsu-thresholding twice, the background are discriminated from the human body and removed from the image first, and then soft tissues other than hard tissue such as bone or tooth are discriminated and removed in the next step. In the following image processing, closing combined with opening is the basic workhorse of morphological noise removal. Opening is the process getting rid of small objects, while closing the process filling small holes[8]. By applying closing and opening, noise on the outline of filtered hard tissue area is reduced and turned in one linked area.

When the practitioner selects one point of the pulpal area, this point is regarded as a center of arbitrary circle. The black and white profiles on 360 lines of radius in the circle are measured. Each line profile is one-dimensional brightness value. To eliminate noise of the line profiles, low pass filter with mean filter of each profile is applied. The mean filter generally acts as a low pass frequency filter[8] and, therefore, reduces the high frequency noise intensity. By the differentiation of this value, dProfile, which means brightness change value, is calculated. The candidates of ROI (cROI) is determined by minus peak detection[9]. Among these cROIs, which are located on the bone area is excluded. If there are more than one cROI on a line profile, the nearest one from the center is selected only.

After all cROIs on the every 360 line profiles are determined, the closed curve that links every candidate is drawn. By applying low pass filter, the closed curve gets smoother. If the difference between the closed curve and filtered smoothen curve is more than 2 times of the standard deviation, the cROI point is regarded as mis-extracted and eliminated. This process makes the outline of tooth more smooth and natural[10]. By linking remained cROI points again, a closed curve is determined, resulting a tooth area extracted finally, in which the pulpal area is extracted by Otzu-thresholding. The extraction algorithm is shown in Figure 1.

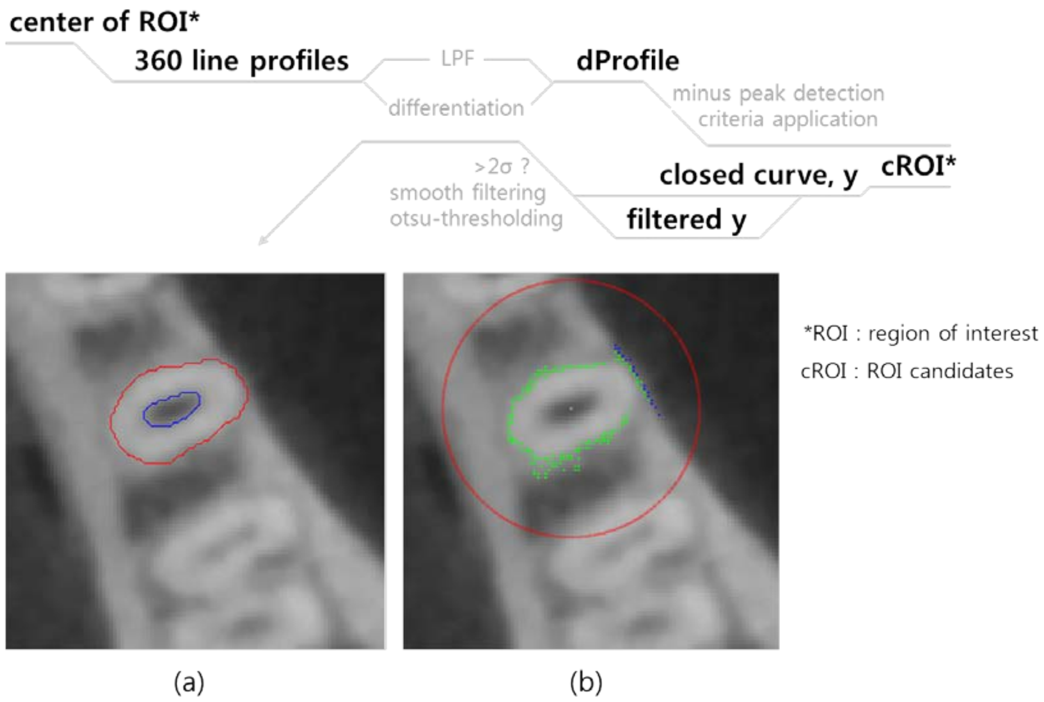

Figure 1 the concept diagram for ROI extraction algorithm

(a) final extraction result; red line is the extracted tooth border and blue line is the pulp border.

(b) candiates of tooth ROI is shown as green dots.; cortical bone outline, which can be easily mis-extracted as a tooth outline, is indicated as blue dots.; line profiles are determined on the each of 360 radiuses of the red circle.

From this extraction result of one axial section among the whole CBCT images, two-dimensional coordinate of center of pulpal area is calculated. From this coordinate, the tooth and pulp area of adjacent axial sections of the CBCT images are extracted by cascade using the same algorithm, as shown in Figure 2. Cascade process is terminated when the software fail to extract tooth area and then tooth and pulp cavity are reconstructed three-dimensionally and tooth-pulp volume ratio is calculated finally.

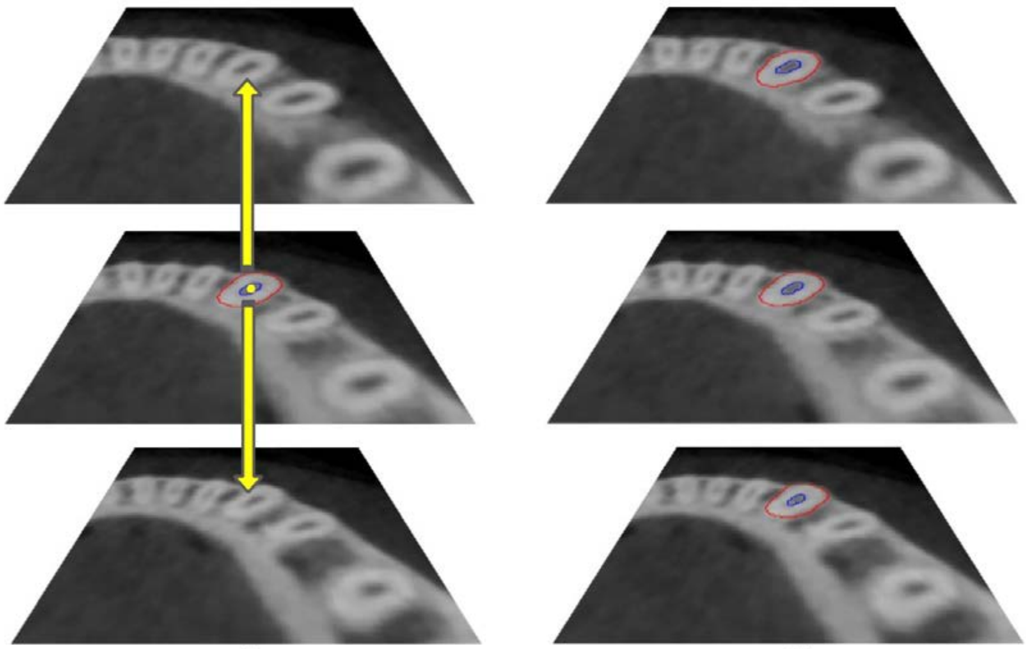

Figure 2 ROI extraction process in the adjacent slices by cascade

(a) the coordinate of two dimensional center of the extracted pulp outline is used for the starting point of the extraction process for adjacent axial sections.

(b) sample result of the ROI extraction for adjacent axial sections.

Results

The user interface and sample result of the developed software program is shown in Figure 3. Navigation interface is composed of image loading, zoom-in, zoom-out, and move tool. ROI extraction process, such as display of determined cROI and criteria application, can be shown by check in the option box. Default threshold is adjusted for the extracted tooth area to cover whole tooth including dentin, cementum, and enamel. Of course, the result can be corrected, if necessary, by the examiner as well as by changing the threshold of density of hard tissue. Extracted tooth and pulp area are reconstructed three-dimesionally and tooth-pulp volume ratio is calculated by voxel counting on reconstructed model.

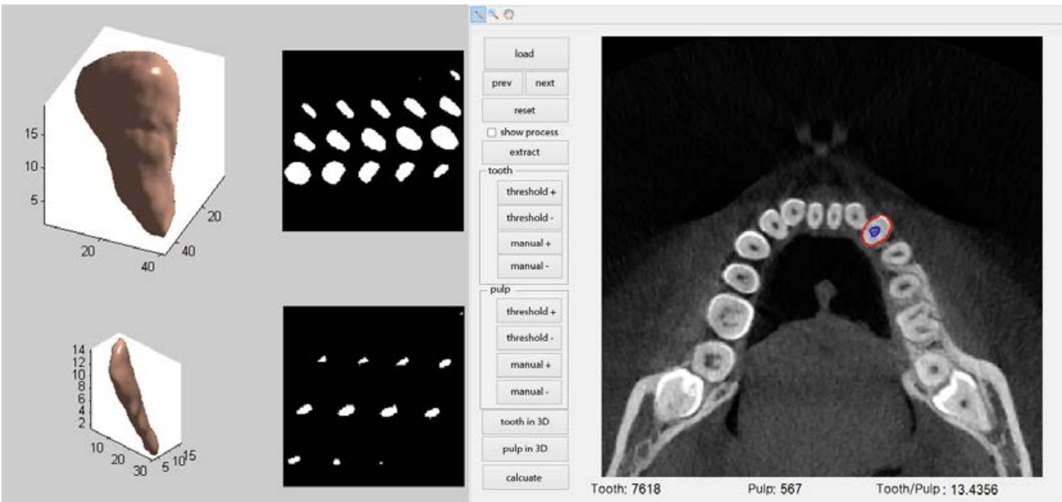

Figure 3 User interface and sample result of the developed software program

Differences by the ROI location

The difference between the tooth-pulp ratio results from the 5 different extraction starting points was not significant, as shown in Figure 4. The mean of pulp/tooth ratio, the difference between result from centered staring point and the others was 0.000829 and standard deviation was 0.003503 when this test on 5 points was repeated 3 times.

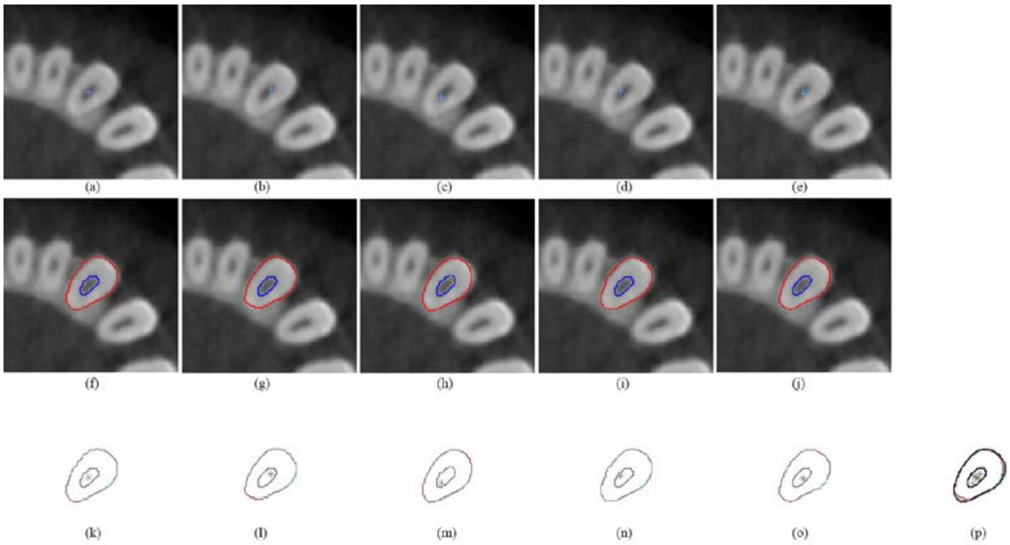

Figure 4. Reproducibility test for ROI extraction.

From (a) to (e) shows different starting points - centered, buccally, lingually, mesially, and distally deviated- for extraction process. From (f) to (o) shows the extraction results and there was not significant difference as shown in (j), duplicated view of (k) to (o).

Discussion

One of the main purposes of developed software program was minimization of practical errors by examiner. To calculate tooth-pulp volume ratio using developed software program, all the examiner has to do is just one mouse click on one of whole CBCT images. This minimized and automatized extraction process can guarantee more reproducible, objective and time-saving way to measure the tooth-pulp volume ratio.

Comparing the pulp area extraction, it is more complicated and difficult to extract tooth area from the adjacent anatomical structures such as alveolar bone and jaw bone. To obtain more natural outline of tooth area, candidates of tooth outline was determined by detection of sudden changes on 360 line profiles. Bone area was determined at first to exclude cortical bone of the jaw and several noise filters were applied. The pulp area was more feasible to extract by applying Otzu-thresholding method on the extracted tooth area. In image processing, Otzu-thresholding method is used to automatically perform clustering-based image thresholding, or the reduction of a gray-scale image to a binary image. The algorithm assumes that the image contains two classes of pixels, foreground pixels and background pixels, and then calculates the optimal threshold separating the two classes so that their combined spread is minimal[11]. The gray level of tooth area and pulpal area on radiographic images can depend on many conditions, such as calcification level of the tooth, state of the pulp, amount of the radiation emission, and level adjustment of the clinician. Because the threshold is not a constant value, using Oztu-thresholding method, it is possible to get a feasible extraction results from the interested area regardless of the absolute gray level of it.

The mean of the difference between the calculated tooth-pulp ratio from centered starting point and the others, deviated mesially, distally, buccally, and lingually, was 0.00196. It has reported that pulp/tooth ratio had a tendency to decrease about 0.01267 to 0.02142 by aging in decade [2-5]. So it can be concluded that the location of the starting point in the pulpal area does not affect the calculation of the tooth/pulp volume ratio for age estimation. In other words, the only human work in the whole calculation process does not affect the result, which means that automatizing process will guarantee higher reliability to measure the tooth/pulp ratio for age estimation than the methods before by minimizing the chance of human error. Moreover, this result also supports that it is logical to determine automatically the starting point on the next axial section in terms of location of the starting point on the first axial section, because the starting point determined automatically by the software does not have to be located exactly in the center of the pulpal area.

This development of the software program is the first step of the study on the age estimation based on the tooth-pulp volume ratio calculated automatically in CBCT images. In further studies based on a large-scale sample should be done to provide the most proper threshold reflecting the relationship between age and tooth/pulp volume ratio the best and investigate the most proper tooth to use. If the software can be improved to use whole CBCT data set rather than just sectional images and to detect pulp canal in the original 3D images generated by

CBCT software itself, it will be more promising in practical uses. Moreover, once the resolution of the CBCT images is improved enough, this automatic 3D reconstruction of the pulp will give great benefits in endodontic field.

References

1. Roberto Cameiere, Stefano De Luca, Inmaculada Alema, Luigi Ferrante, Mariano Cingolani: Age estimation by pulp/tooth ratio in lower premolars by orthopantomography, Forensic science international, 2012;214:105-112
2. Fan Yang, Reinhilde Jacobs, Guy Willems: Dental age estimation through volume matching of teeth imaged by cone-beam CT, Forensic science international, 2006;159:78-83
3. Frieda M. Vandervoort, Lars Bergmans, Johan Van Cleynenbreugel, Didier J. Bielen, Paul Lambrechts, Martine Wevers, Ann Piers, and Guy Willems, Age Calculation Using X-ray Microfocus Comput∗ed Tomographical Scanning of Teeth: A Pilot Study: J. Forensic Sci, 2004;49;787-90
4. Hazha Star, Patrick Thevissen, Reinhilde Jacobs, Steffen Fieuws, Tore Solheim, Guy Willems, Human Dental Age Estimation by Calculation of Pulp–Tooth Volume Ratios Yielded on Clinically Acquired Cone Beam Computed Tomography Images of Monoradicular Teeth: J. Forensic Sci, 2011;56:77-82
5. F. Fritsch, B. Willershausen, C. Gleissner: Human dental age estimation by cone beam computed tomography - an in vitro study, Journal of forensic odonto-stomatology, 2013;31 suppl 1:149-151
6. CA Lascala, J Panella, MM Marques: Analysis of the accuracy of linear

measurements obtained by cone beam computed tomography(CBCT-NewTom), Dentomaillofacial radiology, 2004;33:291-294

7. Liu Jianzhuang, Li Wenqing, Tian Yupeng, Automatic thresholding of gray-level pictures using two-dimension Otsu method: IEEE Circuits and Systems, 1991; 1;325-327
8. Joyce Farrell, Microsoft Visul C# 2008: An Introduction to Object-Oriented Programming, Course Technology, 2009
9. Domingo Mery, Crossing Line Profile: A New Approach to Detecting Defects in Aluminium Die Casting: Lecture Notes in Computer Science, 2003;2749;725-732
10. Tomasi, C., Manduchi, R., Bilateral filtering for gray and color images, IEEE, 1998: Computer Vision, 1998. Sixth International Conference on; 839-846
11. Nobuyuki Otsu, A threshold selection method from gray-level histograms, IEEE Trans. Sys., Man., Cyber. 1979;9 (1); 62–66
12. JS Lee, Digital Image Enhancement and Noise Filtering by Use of Local Statistics: Pattern Analysis and Machine Intelligence, IEEE Transactions, 1980;2;165-168
13. D Bradley, G Roth: Adaptive threshloding using the internal image, Journal of graphics, GPU, and game tools, 2007:12,2;13-21
14. Chan, F. H. Y., Lam, F. K., and Zhu, H.: Adaptive thresholding by

variational method, IEEE Transactions on image processing, 1998;7,3:468-473

15. Canny, John: A compuational approach to edge detection, Pattern analysis and machine intelligence, IEEE transactions PAMI-8, 2009;6:679-698

국문초록

연령추정은 대상의 생사여부와 관계없이 법의학적으로 중요한 정보를 제공한다. 그 중 치아는 특유의 강한 기계적, 화학적, 생리적 충격이나 시간에 대한 저항성 때문에 법의학적 정보를 제공할 수 있는 기회나 정보의 정확성이 훌륭하다. 그 간 많은 법치의학적 연령추정 방법이 보고되어 왔으며, 치아와 치수강의 비율을 이용한 연령추정의 유의성도 기존의 연구에 의해 보고된 바 있다.

치수강의 크기는 증령에 따라 이차상아질의 침착으로 인해 점차 줄어드는 경향을 보이므로 이를 통한 연령추정이 가능하다. 치수강의 크기는 개개인의 치아 형태나 크기에 따라 달라질 수 있으므로, 치수강/치아 비율을 통해 연령추정을 함으로써 이러한 개인적 편차를 감소시킬 수 있다. 파노라마 방사선 사진은 치과적 방사선 영상 중 매우 일상적으로 촬영되는 기본적인 방사선 영상이므로 접근성 측면에서 큰 장점을 가진다. 반면에 이차원 영상이 가지는 근본적인 상의 왜곡에 의한 한계가 있다. 점차로 정확도 및 해상도, 가격접근성이 좋아지고 있는 cone-beam computed tomography(CBCT)의 경우 이러한 점을 보완하기에 적합하다고 할 수 있다. 기존의 치수강/치아 비율을 이용한 연령추정 방법은 치수강의 치아의 면적 혹은 부피를 수작업을 통해 직접 외형을 추출하므로, 정확성이나 재현성, 작업시간 등에서 한계를 가진다.

본 연구는 이러한 단점을 보완하기 위해 CBCT 영상으로부터 치아와 치수강에 해당하는 영역을 자동화된 영상처리를 통해 추출하고, 이를 통해 계산된 치수강/치아 비율을 이용하여 더 정확하고, 재현 가능한, 그리고 짧은 작업시간을 가지는 연령추정 시스템을 개발하기 위한 것이다. 사용자가 전체 단층영상 중 하나에서 치수강 영역에 대해 한번의 마우스 클릭을 하면, 치아와 치수강 영역을 개발된 소프트웨어 프로그램이 자동으로 추출하고, 이를 바탕으로 인접 단층영상에서의 추출을 자동 연계하여 최종적으로 치수강/치아의 삼차원적 부피비율을 계산하는 소프트웨어를 개발하였다. 주변 해부학적 구조물로부터 자연스러운 치아 외형을 자동 추출하기 위한 영상처리 알고리즘을 제안하였으며, 연령추정에 적합한 추출 결과를 위한 최적의 추출 알고리즘 임계값을 조절할 수 있도록 하였다.

향후 연구에서는 다수의 환자 데이터를 바탕으로 치수강/치아 부피비율과 연령추정에 최적의 임계값을 분석하고, 이를 이용한 소프트웨어 프로그램의 고도화의 진행이 필요할 것이다.

주요어 : 치수강/치아 부피비, 연령추정, 3 차원 영상처리

학 번 : 2011-22479