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Araştırma Makalesi

Comparison of Two Different Software Programs For Three-Dimensional Analysis Of Carotid Atherosclerosis: A Retrospective CBCT Study

Karotis Aterosklerozunun Üç Boyutlu Analizinde İki Farklı Yazılım Programının Karşılaştırılması: Retrospektif KIBT Çalışması

Nagihan Koç

ABSTRACT

Aim: The present study aimed to compare two different CBCT software packages, Mimics Medical and 3D-DOCTOR, in performing the volume and areal measurements of extra-cranial carotid artery calcifications (ECACs).

Material and Methods: A total of 44 scans were evaluated. The calcifications were categorized as unilateral or bilateral. Volumetric and areal measurements of ECACs were done with the two software programs. Intraclass correlation coefficient (ICC) was used to evaluate the intra-observer reliability. The difference in measurements between two software groups was evaluated with the t-test.

Results: The ECACs were unilateral in 24 cases and bilateral in 20 cases. There were 25 females and 19 males and the mean age of the sample was 63.31 ± 10.21 years. The overall mean volume obtained with Mimics software was 52.97 ± 48.97 mm^3 while that obtained with 3D-DOCTOR software was 39.70 ± 34.40 mm^3 (P=0.001). Similarly, significant differences between Mimics (109.55 ± 85.40 mm^2) and 3D-DOCTOR (98.99 ± 75.34 mm^2) software programs were observed for areal measurements (P=0.001).

Conclusion: Although high agreement rates were observed in repeated measurements among two software programs, volumetric and areal measures of the ECACs obtained with Mimics Medical were higher than those obtained with 3D-DOCTOR.

Keywords: Atherosclerosis; Carotid artery; Cone-beam computed tomography

ÖZ

Amaç: Bu çalışmada, ekstrakraniyal karotis arter kalsifikasyonu (EKAK) hacim ve alan ölçümlerinde, iki farklı konik ışınlı bilgisayarlı tomografi (KIBT) yazılım paketinin, Mimics Medical ve 3D-DOCTOR'un, karşılaştırılması amaçlandı.

Gereç ve Yöntem: Toplam 44 hastaya ait görüntü değerlendirildi. Kalsifikasyonlar tek taraflı veya iki taraflı olarak sınıflandırıldı. EKAK'ların hacim ve alan ölçümleri iki yazılım programı ile gerçekleştirildi. Gözlemci içi güvenirliği değerlendirmek için sınıf içi korelasyon katsayısı (SKK) kullanıldı. İki yazılım grubu arasındaki ölçüm farkı t-testi ile değerlendirildi.

Bulgular: Kalsifikasyonlar, 24 vakada tek taraflı ve 20 vakada iki taraflıydı. 25 kadın ve 19 erkek hastadan oluşan örneklemin yaş ortalaması 63.31 ± 10.21 yıl idi. Mimics yazılımı ile elde edilen ölçümlerde ortalama hacim 52.97 ± 48.97 mm^3 iken 3D-DOCTOR yazılımı ile elde edilen hacim 39.70 ± 34.40 mm^3 olarak tespit edildi (P=0.001). Benzer şekilde Mimics (109.55 ± 85.40 mm^2) ve 3D-DOCTOR (98.99 ± 75.34 mm^2) yazılım programları arasında alansal ölçümler için önemli farklılıklar gözlendi (P=0.001).

Sonuç: İki yazılım programı arasında tekrarlanan ölçümlerde yüksek uyum oranları gözlemlenmesine rağmen, Mimics Medical ile elde edilen EKAK hacim ve alan ölçümleri, 3D-DOCTOR ile elde edilenlerden daha yüksekti.

Anahtar Kelimeler: Ateroskleroz; Karotis arter; Konik ışınlı bilgisayarlı tomografi

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INTRODUCTION

Carotid artery stenosis (CAS) is a significant risk factor for ischemic stroke, typically resulting from atherosclerotic plaque deposition in the arterial wall, which can lead to narrowing of the arterial lumen and consequent embolization.[1] Although carotid calcification is detected in the majority of cases with stenosis, its association with cerebrovascular events (CVE) is uncertain.[2] Stenosis of 50% or more in the arterial lumen is clinically significant and related to ophthalmic symptoms such as temporary or complete loss of vision, transient ischemic attack, and stroke due to impaired blood circulation.[3-5] However, there is evidence that unstable and vulnerable plaques are more prone to CVE regardless of the degree of stenosis.[6] Therefore, detection and quantification of plaque calcification are of great importance.

Imaging techniques for plaque characterization includes computed tomography (CT), magnetic resonance imaging (MRI), ultrasonography, angiography, and positron emission tomography (PET).[2,6] Recently, cone-beam CT (CBCT) has been a modality of choice to identify the carotid artery calcifications (CACs) especially in patients who referred for dental treatment.[7] Small voxel sizes, lower radiation doses, high-resolution images are the advantages of CBCT over CT.[8]

The cervical portion of the artery is a common location for calcified plaques and also named as the extra-cranial segment of the internal carotid artery (ICA).[9] These calcifications can often be detected on routine dental imaging.[10,11] Three-dimensional characteristics and the course of calcifications can adequately be visualized on CBCT scans.[12] Volume and surface area of the calcification can also be quantified on CBCT images by using third party software. The images obtained from CBCT scans can be exported to DICOM (Digital Imaging and Communications in Medicine) format, and with the help of three-dimensional analysis software, volumetric assessments can be done in addition to two-dimensional measurements.

The aim of this study was to compare two different CBCT software packages, Mimics Medical (Materialise, Leuven, Belgium) and 3D-DOCTOR (Able Software Corp., Lexington, USA), in performing the volume and areal measurements of extra-cranial CACs (ECACs).

MATERIALS AND METHODS

This study was conducted following the approval of the Research Ethics Board of Hacettepe University in Ankara, Turkey (ID: 2020/01-13, Date: 07.01.2020). CBCT images of the patients 40 years of age or older were retrieved from the computer database of Department of Dentomaxillofacial Radiology between January and March 2020. CBCT examinations were requested for different diagnostic tasks based on diagnosis and dental treatment planning. The scans including C2 to C4 vertebral levels were screened.[13] Following the exclusion of the scans with inadequate field of view and motion or metal artefacts, the final sample of 44 images were obtained and selected for evaluation.

All CBCT examinations were obtained using an i-Cat Next Generation device (Imaging Sciences Interna-

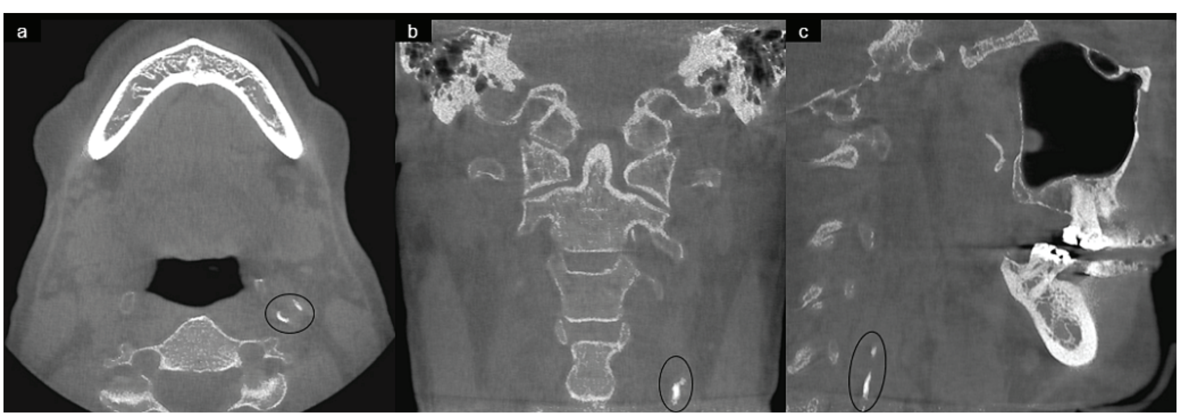

Figure 1. Axial (a), coronal (b), and sagittal (c) cone-beam computed tomography images showing calcification on the left extra-cranial carotid artery

tional, Hatfield, PA, USA) with the same protocol: 120 kVp, 3–8 mA, 16 x 13 cm field-of-view, 0.20-mm voxel size, and 26.9-s scan time.

The image analysis was performed by evaluating the axial, coronal, and sagittal multiplanar reconstructions (MPR) and the ECACs were identified as described previously in the literature.[7,14,15] The slice thickness was set at 0.2 mm. The presence of calcification was confirmed when it was detected in at least three sequential slices (Figure 1). The calcifications were categorized as unilateral (right or left) or bilateral.

CBCT data were exported as DICOM files and then imported to 3D-DOCTOR and Mimics softwares. The 3D-DOCTOR software is a commercial software that allows anatomical segmentation on consecutive axial slices, enabling visualization of the calcification at each level craniocaudally. The semi-automatic segmentation method that used in this study included manual selection of the region of interest (ROI), generating boundaries of the calcification in the axial sections by changing threshold ranges interactively, automatically segmentation of the calcified area, and finally, complex surface rendering (Figure 2).

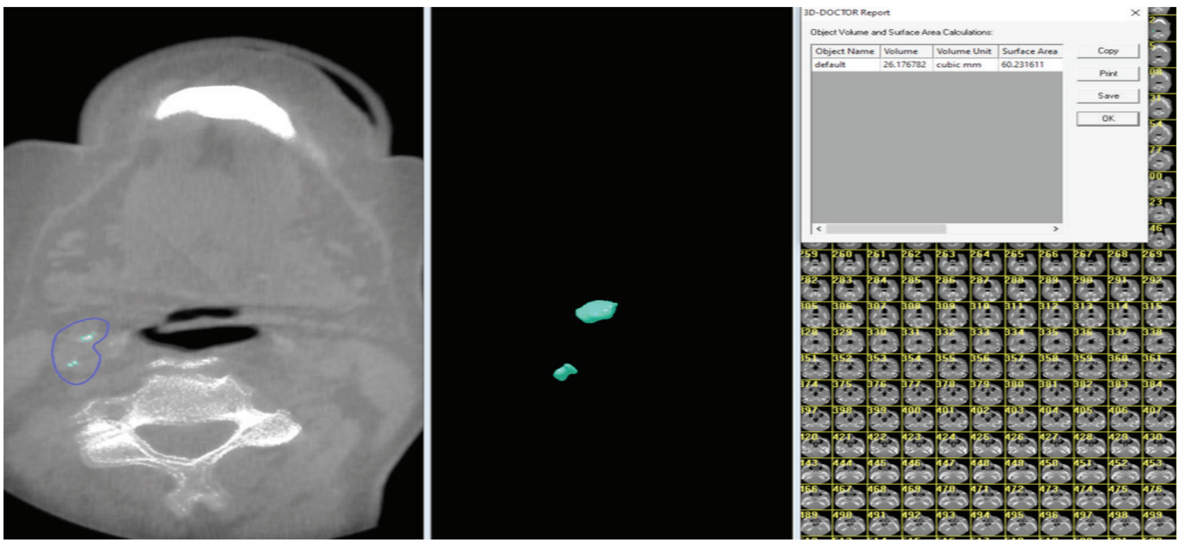

Figure 2. An example of volumetric measurement of the right extra-cranial carotid artery calcification on the 3D-DOCTOR software.

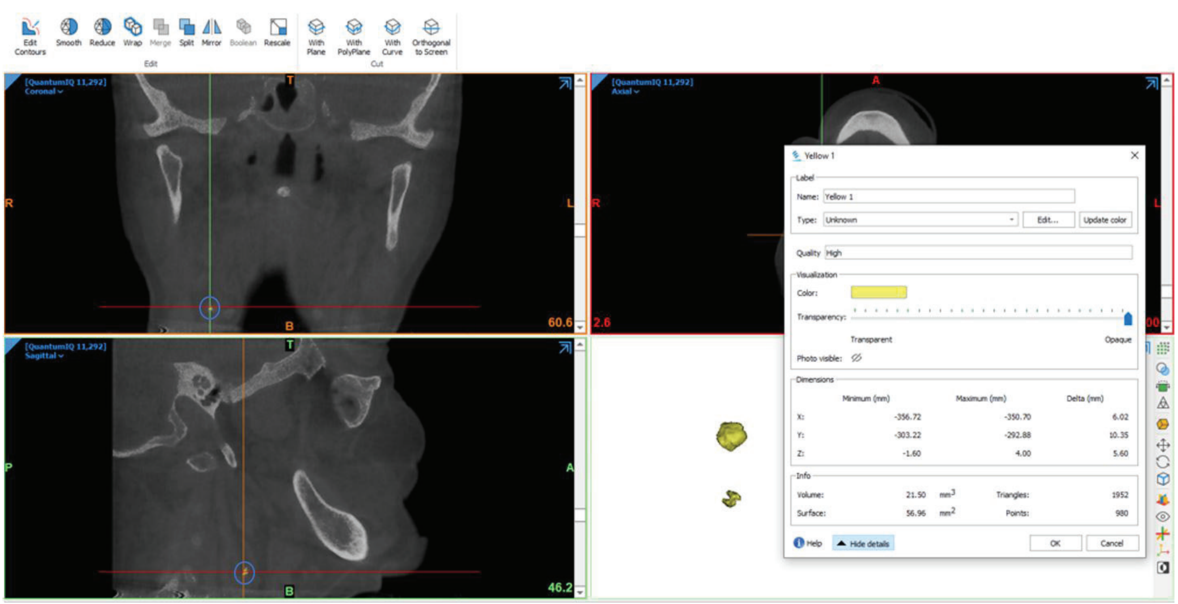

Figure 3. An example of volumetric measurement of the right extra-cranial carotid artery calcification on the Mimics Medical software.

The segmentation processes performed by using the commercial Mimics software included selecting the adequate threshold interval for visualizing the calcification region, generating a mask limited to the ROI, region growing, and calculation of total volume of CAC (Figure 3). The total volume (mm^3) and calcified segmentation area (CSA) (mm^2) measurements of the calcification were automatically calculated by the two softwares.

All examinations were conducted by an oral and maxillofacial radiologist (N.K.) with at least 7 years of experience in CBCT imaging. Prior to analysis, the examiner was calibrated with the use of 10 CBCT scans and measurements were done twice within an interval of 15 days.

Statistical analysis

Statistical analysis was performed using VassarStat Computation Website (http://vassarstats.net/). Intraclass correlation coefficient (ICC) was used to evaluate the intra-observer reliability. The difference in measurements between two software groups was evaluated with the t-test. P value < .05 was considered statistically significant.

Table 1. Age distribution of extra-cranial carotid calcifications

		Right (%)	Left (%)	Bilateral (%)	Total
Age	48 – 55	5 (41.7)	4 (33.3)	3 (25.0)	12
	56 – 65	2 (17.7)	4 (33.3)	6 (50.0)	12
	66 – 75	6 (46.1)	1 (7.7)	6 (46.1)	13
	76 – 83	0 (0.0)	2 (28.5)	5 (71.5)	7
Total		13 (29.5)	11 (25.0)	20 (45.5)	44

Table 2. Gender distribution of extra-cranial carotid calcifications

		Right (%)	Left (%)	Bilateral (%)	Total
Gender	Female	8 (32.0)	7 (28.0)	10 (40.0)	25
	Male	5 (26.3)	4 (21.1)	10 (52.6)	19
Total		13 (29.5)	11 (25.0)	20 (45.5)	44

RESULTS

The ICC was above 0.90 for all measurements. Among 44 patients with ECACs, 25 were females and 19 were males, whose mean age was 63.31 ± 10.21 years (ranged from 48 to 83 years). The ECACs were unilateral in 24 cases and bilateral in 20 cases. The age and gender distribution of ECACs is shown in Tables 1 and 2, respectively.

The overall mean volume obtained with Mimics software was 52.97 ± 48.97 mm^3 while that obtained with 3D-DOCTOR software was 39.70 ± 34.40 mm^3 (P=0.001). Similarly, significant differences between Mimics (109.55 ± 85.40 mm^2) and 3D-DOCTOR (98.99 ± 75.34 mm^2) softwares were observed for areal measurements (P=0.001). Table 3 summarizes the details of measured data.

Table 3. Minimum (Min), maximum (Max), mean (mm), and standard deviation (SD) for measurements

Measurement	3D-DOCTOR				Mimics Medical				
	Min	Max	Mean	SD	Min	Max	Mean	SD	P*
Volume (mm^3)	4.44	135.02	39.70	34.40	4.86	235.64	52.97	48.97	0.001
Surface area (mm^2)	16.26	297.13	98.99	75.34	20.91	402.73	109.55	85.40	0.001

*T-test

DISCUSSION

The findings of the present study show that Mimics Medical and 3D-DOCTOR software programs provide significantly different values for carotid calcification volume and area. Mean differences for measured volume and CSA in this study between Mimics and 3D-DOCTOR were 13.27 mm^3 and 10.56 mm^3, respectively. To the author's best knowledge, this is the first study to investigate the volumetric measurement of the CACs on CBCT by using the two software programs. Thus, there are no comparable data available.

Third-party CBCT software programs are widely used in dentistry in 3D analysis of pharyngeal dimension,[16] pulp/tooth volume,[17] maxillofacial grafting procedures,[18] postoperative changes following osteotomies,[19] implant sites,[20] periodontal defects,[21] external root resorptions,[22] paranasal sinus volumes,[23] and temporomandibular joints.[24] Mimics Medical and 3D-DOCTOR are the two popular among the many different 3D reconstruction software programs, including Amira, InVesalius, ITK-Snap, 3D Slicer, Synapse 3D, and OsiriX.[25,26]

It is important for clinicians and researchers to know whether a software package provide accurate and reliable data. When comparing two commonly used software programs, the results obtained may be expected to be similar. However, as in the present study, significant differences might be attributed to the disparity in segmentation processes, especially considering the high agreement in repeated measurements among two software programs. For example, 3D-DOCTOR allows delineation of the boundaries of the ROI only in the axial sections, while the Mimics software enables multiplanar sections to outline ROI, which might have been improved the visualization of the CACs and helped determine the exact boundaries. It should also be considered that despite being statistically significant, the difference may be out of clinical relevance.

Quantitative evaluation of CAC has been made by assessing plaque volume and components on CT angiography (CTA) and multidetector CTA and correlated with the degree of CAS.[27-29] On axial CTA images, the measurements of plaque volume and components were done by using the Polymeasure plug-in for the freely available software package ImageJ (National Institute of Mental Health, Bethesda, MA, USA), which was proposed by de Weert et al.[30] By using the software, ROIs were drawn manually in consecutive axial images and the total number of voxels and the number of voxels of different Hounsfield-Unit (HU) value ranges within these ROI were automatically calculated. The carotid plaque was defined as the calcification and/or thickening of the vessel wall. According to the different attenuation values, it was possible to identify different plaque components based on the HU value ranges: calcification, >130 HU; fibrous tissue, 60–130 HU; lipid core, <60 HU. The presence of vascular wall density above 130 HU, that was more hyperdense than vascular lumen and adjacent parenchyma, was considered as vascular calcification.[27] The calcified plaque volume was then measured by multiplying the calcification area on axial slices by the slice increment.[30]

The identification of the CACs on CBCT has been well documented in the literature.[7-9,12,14,15] However, volumetric assessment of CACs on CBCT has yet to be adequately described. More studies are needed to establish a validated method for volumetric measurements on CBCT and to compare software accuracy. Moreover, a standardized assessment method would improve the consistency and reliability in the quantitative evaluation of the CACs on CBCT.

CONCLUSION

Within the limitations of the study, volumetric and areal measurements of the ECACs obtained with Mimics Medical were higher than those obtained with 3D-DOCTOR.

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CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

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