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Assessment of intraorbital structure volume using a numerical segmentation image technique (NSI): the fatty tissue and the eyeball

Ocena objętości struktur wewnątrzoczodołowych przy zastosowaniu techniki cyfrowej segmentacji obrazów (CSO): ciało tłuszczowe i gałka oczna

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Abstract

Introduction: Measurement of the degree of exophthalmos is one of the main methods used in the assessment of pathological processes that occur in the orbital space and is widely used. However, this only provides initial information about the volume relations between the intraorbital structures.

The aims of our work were as follows: to draw up a new computer application, namely the numerical segmentation image (NSI) technique, for the automatic calculation of the volume of the intraorbital structures on the basis of magnetic resonance imaging (MRI) images, to determine its usefulness in the segmentation of fatty tissue and the eyeball and to estimate their volume in relation to the degree of exophthalmos.

Material and methods: A total of 45 patients (90 orbits) were included in the study. All the patients underwent MRI examination of the orbits by a 1.5 T scanner using a head coil. The degree of exophthalmos was determined clinically and radiologically in relation to the interzygomatic line. Quantitative assessment of the eyeball and fatty tissue was made using an NSI application.

Results: The influence of fatty tissue volume on the degree of exophthalmos was determined as being statistically significant ($r = 0.367$, $p = 0.000374$) but was smaller in comparison with the relationship between total eye muscle volume and degree of exophthalmos; eyeball volume was found to have the least influence ($r = 0.344$, $p = 0.000374$). Two eyeballs of significantly smaller volume were found in the group of 90 orbits analysed.

Conclusions: The NSI technique is a clinically useful application, providing objective data calculated individually for each orbit. A credible protocol for estimating the degree of exophthalmos on the basis of the NSI technique should include the eye muscle volume, fatty tissue volume and, in cases where eyeball pathologies coexist, the eyeball volume as well.

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Key words: *exophthalmos, volume counting, orbital structures, computer applications*

Streszczenie

Wstęp: Pomiar stopnia wytrzeszczu jest jedną z najszerzej stosowanych metod w ocenie procesów patologicznych toczących się w przestrzeni oczodołu. Jednak zapewnia on jedynie wstępną informację o stosunkach objętościowych struktur wewnątrzoczodołowych.

Celem pracy było stworzenie nowej aplikacji komputerowej niemal automatycznie liczącej objętość anatomicznych struktur oczodołu na podstawie obrazów rezonansu magnetycznego (MRI, *magnetic resonance imaging*), przedstawienie jej użyteczności w segmentacji tkanki tłuszczowej i gałki ocznej oraz określenie tych objętości w stosunku do stopnia wytrzeszczu.

Materiał i metody: Do badania włączono 45 pacjentów (90 oczodołów). Wszystkich pacjentów poddano badaniu metodą rezonansu magnetycznego oczodołów w skanerze 1,5 T przy użyciu cewki głowowej. Stopień wytrzeszczu został określony klinicznie, jak i radiologicznie w stosunku do linii międzyjarzmowej. Ocena ilościowa ciała tłuszczowego i gałki ocznej

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została przeprowadzona przy zastosowaniu aplikacji CSO, stanowiącej nowy program komputerowy opracowany przez autorów.
Wyniki: Wpływ objętości ciała tłuszczowego na stopień wytrzeszczu określono jako istotny statystycznie (r = 0,367; p = = 0,000374), ale mniejszy w porównaniu z korelacją wytrzeszczu z objętością mięśni gałkoruchowych, natomiast wpływ objętości gałki ocznej — jako najmniejszy (r = 0,344; p = 0,000374). Ponadto w grupie badanej stwierdzono obecność dwóch gałek ocznych o znacząco mniejszej objętości.
Wnioski: Rezonans magnetyczny jest użyteczną klinicznie aplikacją pozwalającą na obiektywne określenie wartości objętości w sposób indywidualny dla każdego oczodołu. Wiarygodny protokół oceny wytrzeszczu w oparciu o technikę CSO powinien uwzględniać objętość mięśni gałkoruchowych, tkanki tłuszczowej, a w niektórych przypadkach koincydencji patologii także objętość gałki ocznej.

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Słowa kluczowe: *wytrzeszcz, obliczanie objętości, struktury wewnątrzoczodołowe, programy komputerowe*

Introduction

Measurement of the degree of exophthalmos is one of the main methods used in the assessment of pathological processes that occur in the orbital space and is widely used. Measurement may be made by means of Hertel's exophthalmometer, although more precise results are obtained on the basis of computed tomography (CT) or magnetic resonance imaging (MRI) images [1–5]. However, this only provides initial information about the volume relations between the intraorbital structures. Eyeball position is a result of its volume and the volumes of the extraocular muscles and fatty tissues in relation to the orbital volume within its bone walls.

Contemporary computer systems raise the possibility of carrying out very detailed calculations without excessive outlay in terms of labour and time and can be used in daily clinical practice. They enable medical images to be thoroughly analysed and numerical data to be processed quickly into clinically essential information.

The aims of our work were:
- to draw up a new computer application, namely the numerical segmentation imaging (NSI) technique, for the automatic calculation of the volume of the intraorbital structures on the basis of MRI images and to determinate its usefulness in the segmentation of fatty tissue and the eyeball;
- to estimate their volume in relation to the degree of exophthalmos.

Material and methods

A total of 45 patients (90 orbits) qualified for the study and these were made up of 6 men and 39 women aged between 19 and 72 years, with a mean age of 55. The most frequent indication for MRI examination was Graves' ophthalmopathy, while others included suspicion of myopia and paranasal sinus disease. Patients in whom pathological processes, post-traumatic effects or surgical intervention had disrupted the integrity of the bone wall of the orbit were excluded from the study.

All patients gave their written consent prior to their inclusion in the study. The study was approved by the Local Ethics Committee of the Medical University of Łódź (decision no. KBUM/23/04) in accordance with the Helsinki Declaration.

The measurement of the degree of exophthalmos was found clinically and radiologically as well as by MRI examination, as presented in part I of this study.

The numerical segmentation image (NSI) technique

Quantitative assessment was made of the eyeball and fatty tissue for each patient using a computer application devised by the authors.

Data from the MRI sequences were sent to a PC and saved at the workstation in DICOM format. The MRI images were in the form of two-dimensional section runs. The chosen run was loaded into the program in the proper catalogue and then all the images were combined into one three-dimensional image. The images used for volume estimation were characterised by $512 \times 512 \times 14$ voxel resolution at a single voxel size of $0.5 \times 0.5 \times 3$ mm.

Mathematical models of the eyeball and the fatty tissue shapes were used. The aim of segmentation was to distinguish on the MRI images those areas that belonged to previously defined compartments of signal intensity, transformed there as pixels of different brightness. The regions of interest for chosen anatomical structures were indicated by marking them on subsequent sections. Next, the examined areas were delineated by points in defined locations. For the fatty tissue these were situated in three planes: in the orbital apex area, in the region of the largest sections of muscle bellies and at the rear border of the eyeball within the bone walls of the orbit. For the eyeball the points were located on its circumference and were set in two perpendicular planes, X and Y (transversal and coronal).


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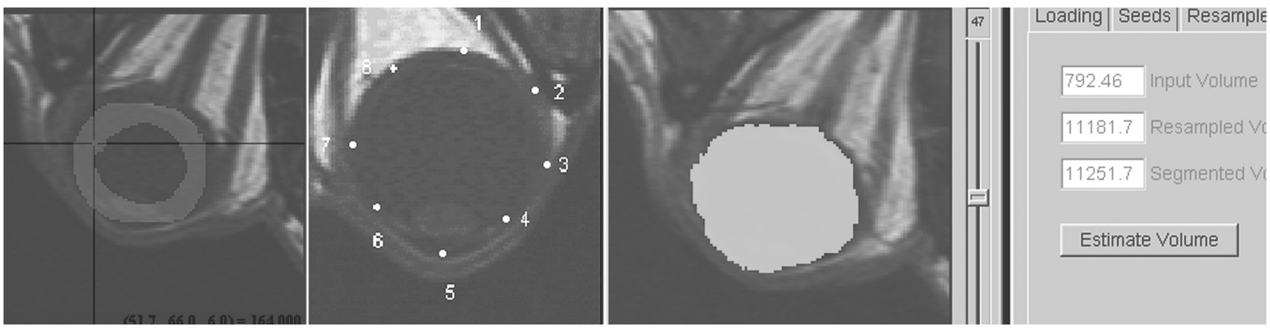
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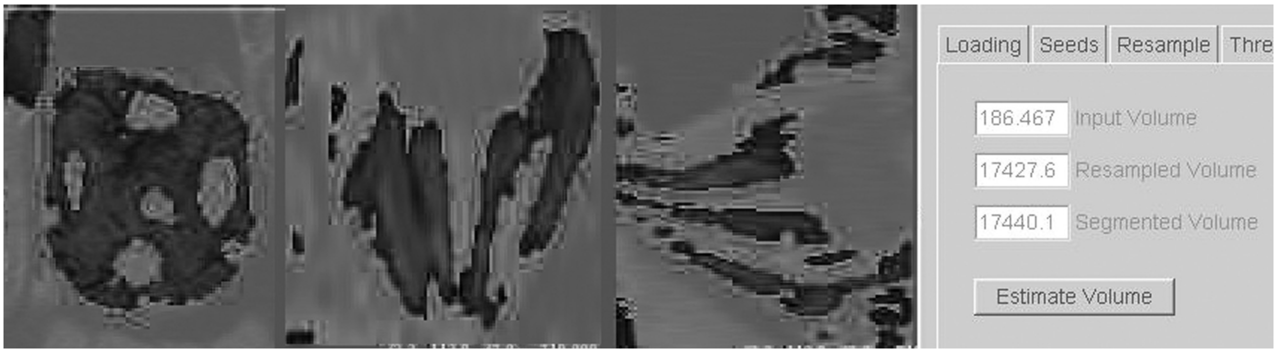
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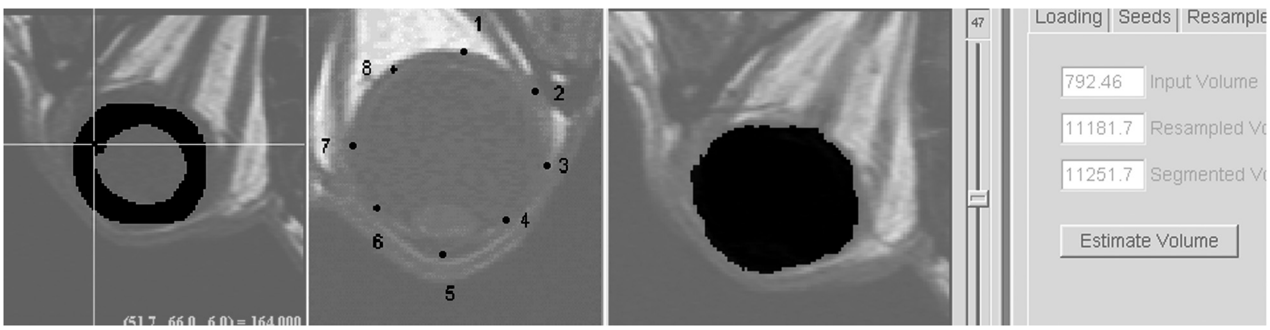
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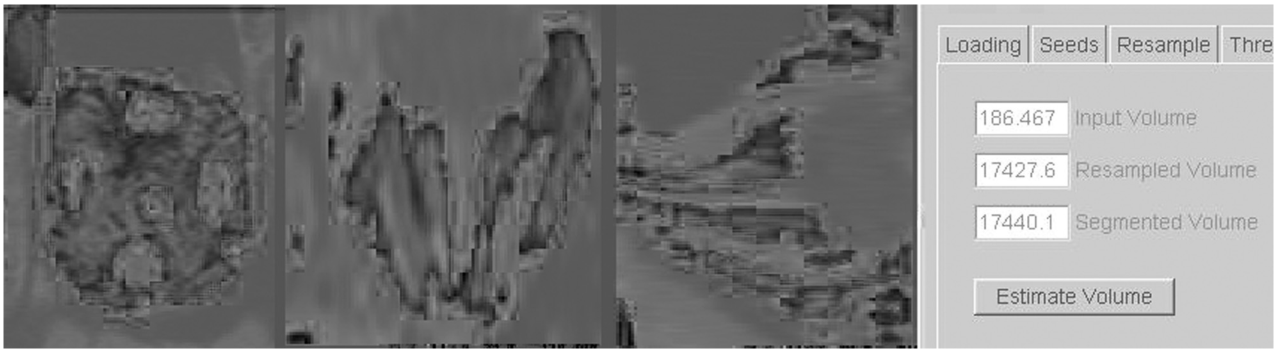
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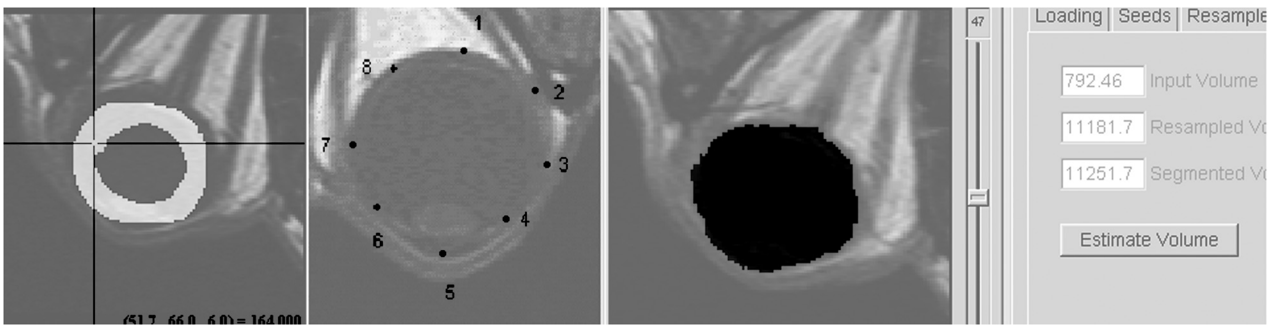
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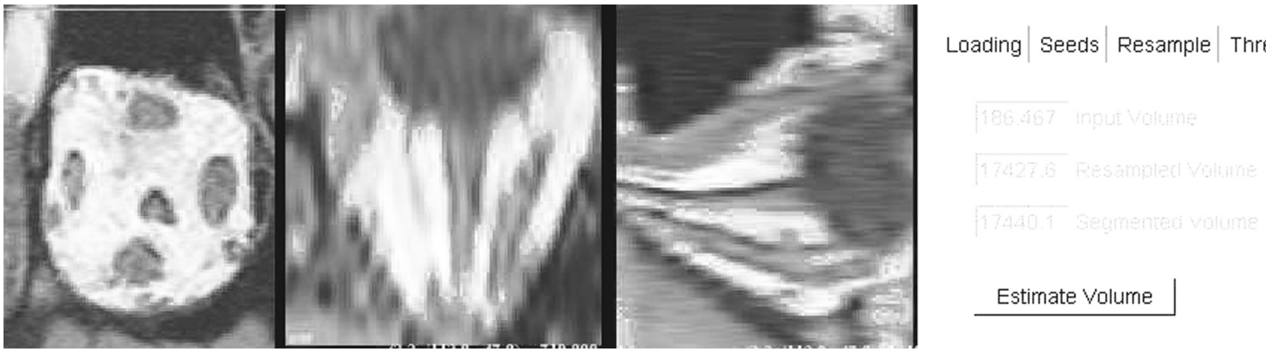


Figure 1. *The orbital fatty tissue volume calculated by the NSI application; control of process accuracy in three planes and determination of the final value*

Rycina 1. *Obliczanie objętości ciała tłuszczowego metodą CSO; kontrola dokładności procesu w trzech płaszczyznach przestrzennych i określanie rezultatu końcowego*

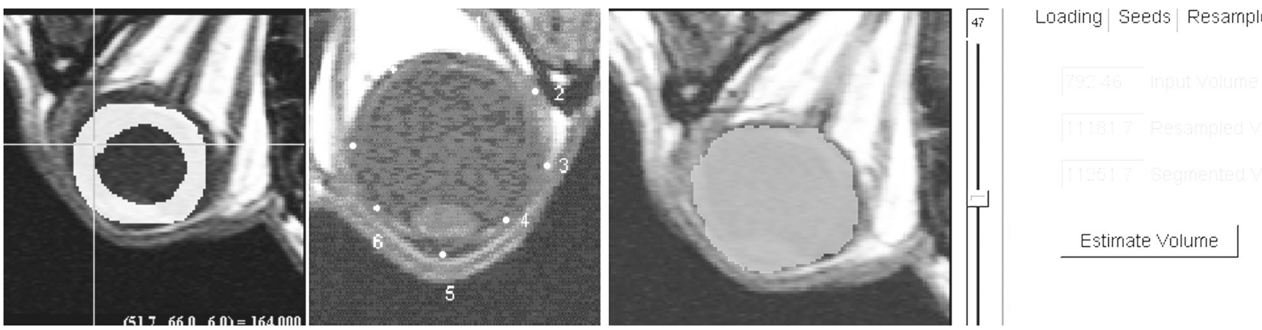


Figure 2. *The eyeball volume calculated by the NSI application; drawing an area of interest inside the eyeball, indicating the borders of the area at defined points, control of process accuracy and determination of the final value*

Rycina 2. *Obliczanie objętości gałki ocznej metodą CSO; zaznaczenie obszaru zainteresowania, zdefiniowane położenia punktów do określenia granic przestrzeni badanej, kontrola dokładności procesu i określanie rezultatu końcowego*

On this basis the NSI technique adjusted the model of the anatomical shape of the chosen structure (mask) created earlier to that of the actual MRI image. There was also the possibility of providing manual correction when there was a divergence between the proposed computer design and real spatial relations. The program determined the volume of the model created in mathematical space from anatomical sections to an accuracy of one millimetre (Fig. 1, 2). The average time required to determine the volume of the fatty tissue and the eyeball was 5 minutes 13 seconds. Finally, the sum of the volumes of all the intraorbital structures analysed was calculated.

Statistical analysis

The correlations were evaluated between the degree of exophthalmos (in millimetres) measured in relation to the interzygomatic line and the fatty tissue and the volumes (in cubic millimetres).

The relations between characteristics were described using the Pearson linear correlation coefficient with assessment of its significance and linear regression equations. The parameters of these were calculated by the least squares method. Multifactor regression analysis with a choice of variables to a regression model was used for estimating the influence of many variables on one dependent variable. The multivariant analysis method was used for enclosing or rejecting variables from the model. When the multifactor regression analysis was made estimation adjustment and rest analysis were carried out. Correlation graphs were made to illustrate the results calculated.

Results

The sum of the volumes of the important anatomical structures, namely the extraocular muscles, the fatty tissue and the eyeball, was found to be the most objective parameter for determining the eyeball position inside the orbit. The analysis confirmed that there was the strongest relation between this parameter and the degree of exophthalmos.

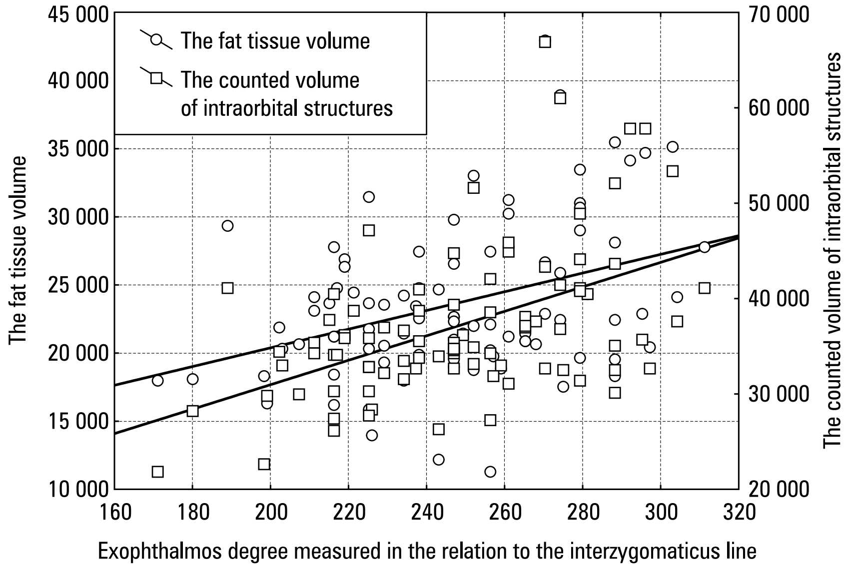


Figure 3. *The correlation between the degree of exophthalmos measured in relation to the interzygomatic line, the fatty tissue volume and the calculated volume of the intraorbital structures*

Rycina 3. *Zależność między stopniem wytrzeszczu określanego względem linii dwujarzmowej, objętością ciała tłuszczowego oraz obliczoną objętością struktur wewnątrzoczodołowych*

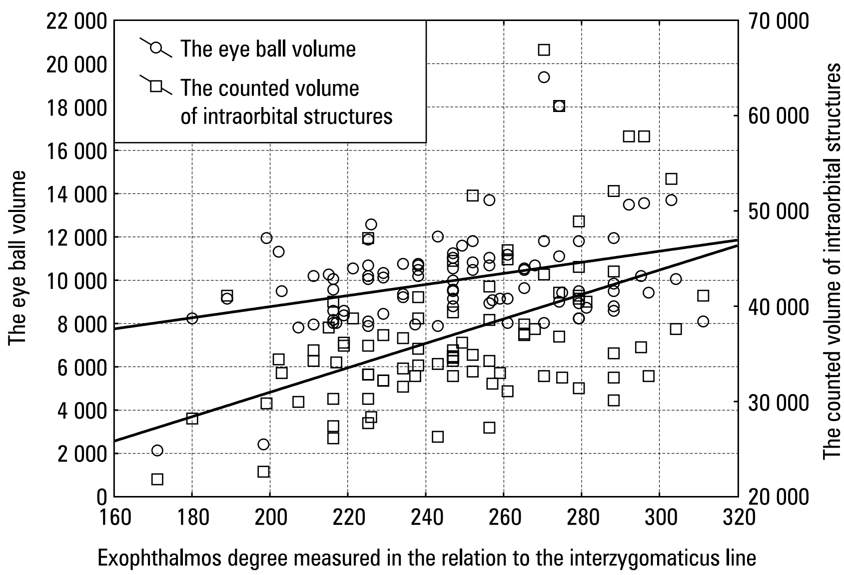


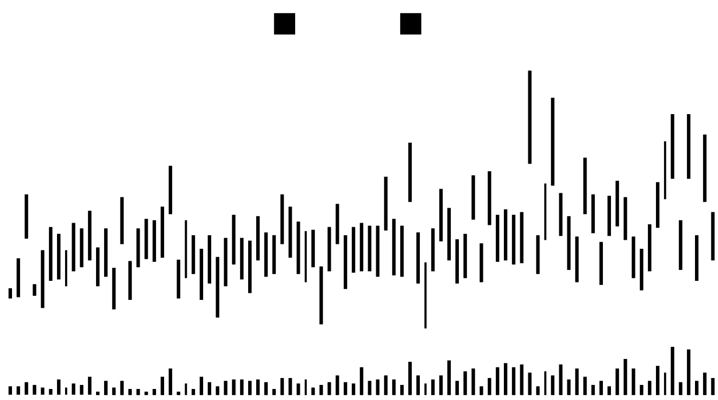
Figure 4. *The correlation between the degree of exophthalmos measured in relation to the interzygomatic line, the eyeball volume and the calculated volume of the intraorbital structures*

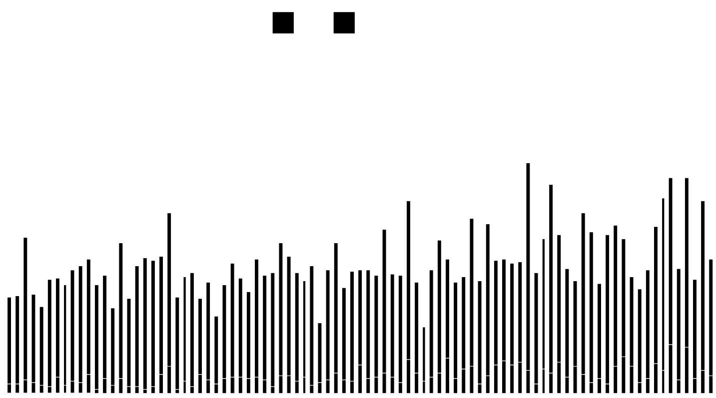
Rycina 4. *Zależność między stopniem wytrzeszczu określanego względem linii dwujarzmowej, objętością gałki ocznej oraz obliczoną objętością struktur wewnątrzoczodołowych*

The influence of the fatty tissue volume on the degree of exophthalmos was determined as statistically significant but smaller in comparison with the influence of the volume of all the eyeball muscles on this parameter (Part I Fig. 3).

The volume of the eyeball was found to have the smallest influence on the extent of exophthalmos (Fig. 4, Table I).

In the study group of 90 orbits two eyeballs of significantly smaller volume were found: V1 = 2158 mm^3





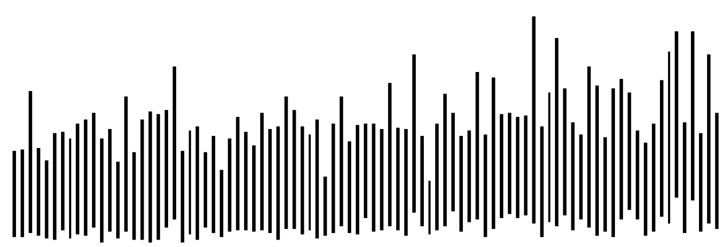


Table I
The statistical values of correlations

Tabela I
Statystyczne wartości korelacji

	Fatty tissue volume		Eyeball volume		Total volume of intraorbital structures	
Statistical analysis	**Linear corr. coefficient**	**Spaerm corr. coefficient**	**Linear corr. coefficient**	**Spaerm corr. coefficient**	**Linear corr. coefficient**	**Spaerm corr. coefficient**
Extent of exophthalmos	r = 0.367 p = 0.000374	r = 0.319 p = 0.00213	r = 0.344 p = 0.000374	r = 0.233 p = 0.26845	r = 0.492 p = 8.48 E-07	r = 0.492 p = 8.48 E-07

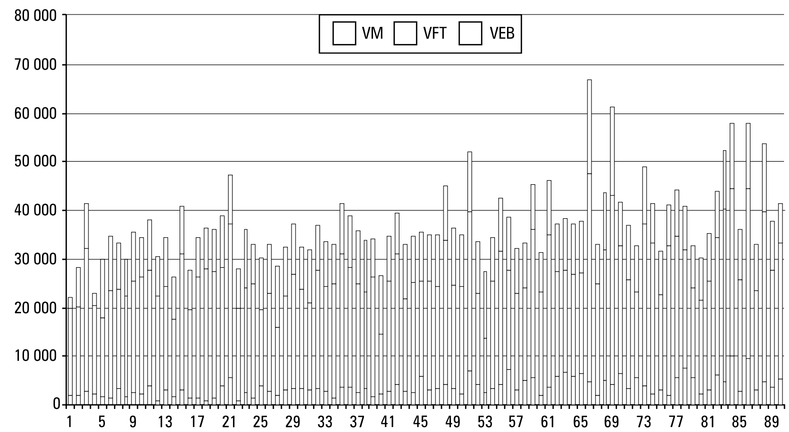


Figure 5. *Results of volume calculations for the whole of the analysed population, the patients presented consecutively*

VM — volume of all the muscles; VFT — fatty tissue volume; VEB — eyeball volume; Blue — muscle volume; Red — volume of fatty tissue; Green — volume of eyeball. Cases nos. 1 and 4 with eyeballs of significantly smaller volume; Cases nos. 66 and 69 with eyeballs of significantly larger volume.

Rycina 5. *Wyniki obliczonych objętości struktur wewnątrzoczodołowych analizowanej grupy dla każdego oczodołu przedstawione w kolejności badań; VM (*all muscles volume*) — objętość mięśni, VFT (*fatty tissue volume*) — objętość ciała tłuszczowego, VEB (*eyeball volume*) — objętość gałki ocznej; kolor niebieski —objętość mięśni; kolor czerwony — objętość ciała tłuszczowego; kolor zielony — objętość gałki ocznej; pozycja nr 1 i nr 4 — gałki oczne o istotnie mniejszej objętości; pozycja nr 66 i nr 69 gałki oczne o istotnie większej objętości*

and V2 = 2426 mm^3, as well as two eyeballs of greater volume V3 = 18 408 mm^3 and V4 = 19 408 mm^3, with an average value of V = 9 992.9 mm^3 (Fig. 5).

Discussion

The fatty tissue

It is not only the volume of the eye muscles that affects the extent of exophthalmos. The volume of fatty tissue also plays a significant role, as it is difficult to recognise and assess morphological changes in the fatty tissue. It fills the space between well-delineated structures such as muscles, the optical nerve and the eyeball and does not have any specific shape. This is probably the reason why there are not many papers reporting fatty tissue volume calculations [6–9].

The NSI technique based on image segmentation allowed fatty tissue to be distinguished relatively simply from the other anatomical elements inside the orbit. The fatty tissue signal intensity in SE T1 sequences differs significantly from that of other tissues and is transformed on MRI images into the degree of pixel brightness.

Statistical analysis of the results obtained revealed that the correlation between the volume of fatty tissue and the degree of exophthalmos was significant (Fig. 3, Table I).

The enlargement of fatty tissue in Graves' ophthalmopathy is as great as, or slightly less than, the increase in total volume of the extraocular muscles [6, 10]. When the much greater absolute values for fatty tissue volume in relation to the volume of all the muscles is taken into account, it becomes clear that even a relatively small volume increase of the fatty tissue substantially influences the topographical relations inside the orbit and therefore the extent of the exophthalmos.

Nishida and Tian determined fatty tissue volume on the basis of extraction of other orbital structures, namely muscles, the optical nerve and the eyeball, from the total orbital volume [6, 11]. The areas of the separated structures were multiplied by the number and thickness of the section layers. In our study, as in Tian's observations but contrary to Nishida's results, the correlation between fatty tissue enlargement and the degree of exophthalmos was smaller than the correlation between muscle volume and exophthalmos. These differences can be linked to different methods of calculation, a subjective division of the orbit into compartments and differences in enclosing other anatomical structures situated in the orbit, such as the lacrimal gland.

The eyeball

The eyeball plays an important role in volume relations in the orbit. The location of the cornea apex in relation to the interzygomatic line is the basis for its measurement both on CT and MRI images and in Hertel's method as well [12, 13]. We could not find any earlier papers which consider the role of eyeball size in relation to the extent of exophthalmos.

The size of the eyeball is essential in some diseases such as myopia. Errors of refraction can coexist with other diseases in the orbit, including Graves' ophthalmopathy. The influence of eyeball volume on the extent of exophthalmos was found to be statistically significant on the basis of our results but to a lesser degree than total muscle or fatty tissue volume (Fig. 4, Table I).

The presence of two eyeballs of a significantly smaller volume was found in the group analysed and those values adversely affected the statistical correlations between the volume of all the muscles and the extent of the exophthalmos (Fig. 5).

Assessment of eyeball volume does not seem to have any practical meaning in monitoring Graves' ophthalmopathy and other diseases which do not concern the eyeball itself. Determination of its volume should be considered only when a related pathology exists.

NSI is a method that enables the volume of single anatomical elements to be determined credibly as well as their total impact on eyeball position. It provides objective data which is computed for each orbit individually. This is of key significance because the most desirable and the most interesting application of computer techniques would seem to be the precise monitoring of changes inside the intraorbital structures during the course of disease and its treatment.

A promising perspective for the use of numerical methods in the field of diagnostic imaging is the possibility of obtaining underlying images from various imaging techniques or from different periods of time. A fusion of MRI and CT images can have special value in the interpretation of changes inside the orbital space. A CT examination, carried out just once, would provide detailed information about the bone borders of the orbit, allowing its volume to be determined accurately. MRI examinations repeated several times would add information about the state of the soft tissues. This would raise the possibility of acquiring full objective information about the topographical relations of this area, the most important being the actual relations in a single patient, which could be determined individually. Work is in progress on providing such an algorithm.

Conclusions

1. The numerical segmentation imaging technique is a clinically useful application, providing objective data calculated individually for each orbit.
2. A credible protocol for estimating the extent of exophthalmos on the basis of the numerical segmentation imaging technique should include the volume of the extraocular muscles and fatty tissue and, where there is coincidence of eyeball pathology, the eyeball volume as well.

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