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Can graphic tablets facilitate expedited and more accurate volume measurements?

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Abstract

Volume measurements of organs and structures are crucial for medical assessments and have traditionally been performed using computers, with a recent interest in tablets with digital pens. This study aims to evaluate the reliability of the computer mouse and graphic tablet in organ volume measurements based on the Cavalieri Principle. It will compare the advantages and disadvantages of each device, focusing on consistency and measurement duration. The study analyzed a dataset comprising 22 abdominal CT images from females and 21 from males, sourced from the Department of Radiology. Spleen and kidney volumes were quantified using Image J software and the Cavalieri Principle, utilizing both a computer equipped with a mouse and a graphic tablet with a drawing pen. The results revealed that computer mouse and graphic tablet measurements showed similar organ volumes, with average kidney volumes of 181.53 ±51.72 cm^3 and 179.34 ±51.37 cm^3, respectively, and spleen volumes of 211.03 ±78.47 cm^3 and 205.93 ±77.52 cm^3, respectively. The computer mouse required 283.55 ±56.03 seconds for the kidney and 386.74 ±106.66 seconds for the spleen, whereas the graphic tablet took only 128.79 ±33.32 seconds for the kidney and 141.91 ±40.18 seconds for the spleen, demonstrating a statistically significant reduction in measurement time ($p < 0.001$). The findings of this study suggest that graphic tablet provides a comparable level of reliability to the computer mouse for organ volume measurements using the Cavalieri Principle. Additionally, the tablet offers the significant benefit of faster measurement times.

Keywords: Cavalieri Principle, graphical tablet, kidney, spleen, volume

1. Introduction

The health of the human body relies on its organs working together properly and staying healthy. These organs are vital for life, carrying out different functions. Their sizes can change based on factors such as race, height, and weight, but there are average sizes known from studies. If an organ's size is much different from the norm, it might signal health issues like enlarged spleen, liver, heart, thyroid, or kidneys, making it important to measure organ size for diagnosing diseases (1-5). Also, measuring the size of organs or tissues is crucial for doctors before and after surgery to help plan treatment and track the progress of a disease, which plays a big role in patient care.

Determining the volume of structures within living organisms is challenging due to the impracticality of traditional methods like Archimedean principles and the limitations of geometric formulas for organic three-dimensional shapes. The Cavalieri principle, introduced by Bonaventura Cavalieri in the 17th century, offers a solution by enabling volume measurements of both macroscopic and microscopic structures (6, 7). This method involves sectioning the structure into slices, either physically or through three-dimensional radiological imaging techniques such as computed tomography (CT) or magnetic resonance (MR) imaging, and then calculating the area of each slice using computer-aided imaging methods. Despite its widespread adoption, the use of a computer mouse for digital delineation often leads to control and precision issues. In contrast, graphic tablets provide higher precision, easier control, and comfort, further enhanced by their decreasing costs, portability, and sensitive interface pens, making them ideal for precise, fast, and comfortable volume evaluations in medical research and practice.

In the present study, our objective was to estimate the volumes of isolated and semi-isolated organs, specifically using the spleen and kidney as examples. We measured volumes of these organs on radiological images utilizing a computer equipped with a mouse and a tablet equipped with a drawing pen. We then compared the results of the volume measurements and the duration of time required for each tool between the two devices.

2. Materials and methods

2.1. CT Acquisition

Our study utilized CT images from individuals who applied to

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Ondokuz Mayıs University, Health Research and Application Center for radiological examinations, specifically for suspected urinary tract stones. The CT images were acquired using the standard stone protocol, which involves scanning in the axial plane with patients lying in the supine position. The imaging parameters were set at 120 kV, 75 mAS, and 150 mA, producing images with 3 mm thickness. We excluded images of individuals with kidney stones, kidney deformities, or splenomegaly. After screening, 43 CT image series from 22 female and 21 male participants, showing no abdominal pathologies and deemed visually normal, were selected for the study.

All patient images were converted to DICOM format and analyzed using ImageJ software developed by the National Institute of Health, USA. We selected a minimum of 15 sections per series, focusing on the spleen and kidneys, and adjusted the contrast to distinguish these organs from surrounding tissues better. Using ImageJ's tools, including the "Polygon Selection" tool, we calculated the areas of the spleen and left kidney in each section from the contrast-enhanced images. These area measurements were then used to calculate organ volumes according to the Cavalieri Principle.

The first step for accurate volume estimation using the Cavalieri Principle involves obtaining precise area measurements from each section. A common approach for this is the manual delineation of the area's boundaries on radiological images using digital tools provided by image analysis software. For this purpose, we selected a computer mouse (Logitech G703 Lightspeed) that matched the researcher's hand size for optimal convenience and accuracy. This mouse, known for its 1-millisecond response time, facilitated precise delineation of organ boundaries using the Polygon Selection tool in the ImageJ software. This process allowed for accurate area determination on the section surfaces.

The initial step in measuring organ volumes from radiological images, based on the Cavalieri Principle, involved using a graphic tablet with a pressure-sensitive and ergonomically designed pen. For this purpose, we utilized a Wacom Cintiq 13HD TOUCH graphic tablet. This tablet features a 13.3-inch full HD LED display with a resolution of 1920x1080, supports 2048 pressure levels for precise control, offers wireless functionality, allows working at various angles, and comes with a battery-free Wacom Pro pen capable of displaying 16.7 million colors with a brightness of 250cd/m^2. The delineation of organ boundaries was performed directly on the tablet's screen using its specialized pen, employing the Freehand Selection tool from the ImageJ software. To ensure the reliability of our measurements and reduce any potential for practice-based bias, these area measurements were repeated three months later for patient-specific radiological images.

The volumes were estimated by multiplying the total area of the section cut surfaces through the structure of all sections with the section thickness of images.

The planimetric volume estimation formula is:

$$est_1 V = t \times \sum a \ cm^3$$

Where Σa denotes the section areas in cm^2 and t is the sectioning interval in cm for the consecutive sections. The Cavalieri principle includes the calculation of the coefficient of error (CE) to evaluate the reliability of the point density of the grids and sectioning intervals. The CE represents the precision of the volume estimate and is calculated using specialized formulas. It is important to note that the appropriate grid size and number of slices should be determined at the beginning of the study to minimize the need to recalculate the CE in repeated sessions.

In the planimetry method, the CE of estimates may be obtained using the following formula:

$$CE = \left(\sum_{i=1}^{m} A_i \right)^{-1} \times \left[\frac{1}{12} \left(3\sum_{i=1}^{m} A_i^2 - 4\sum_{i=1}^{m-1} A_i A_{i+1} + \sum_{i=1}^{m-2} A_i A_{i+2} \right) \right]^{1/2}$$

Where, i=1, 2, …, m is the number of sections. A is the measured area of the sections using planimetry, and the others are constants. This formula allows the researcher to evaluate the area changes and the measured cut surface areas in the consecutive section series (8, 9). The Error coefficient value obtained is the final data of the calculation and must be less than 5%.

We timed these delineation tasks to assess the efficiency and repeatability of the two methods, establishing a baseline for measurement speed. We conducted these measurements again after three months using the same methodology, targeting images from the same patients. This repetition aimed to minimize error margins and eliminate any bias resulting from practice, ensuring the reliability of our volume measurements. The mean time for each measurement method is also recorded.

2.2. Statistical Analysis

We conducted statistical analyses using SPSS version 22. We assessed the normal distribution of variables using analytical methods (Kolmogorov-Smirnov and Shapiro-Wilk tests). The analyses revealed that the volume data for kidneys and spleens measured with both a computer mouse and a graphic tablet did not meet the criteria for parametric tests. Consequently, we used the Wilcoxon test to evaluate statistical significance and applied Bonferroni correction for pairwise comparisons. The time efficiency data from volume measurements followed a normal distribution and was analyzed using a Repeated Measures Analysis of Variance (ANOVA) with Bonferroni correction for detailed time parameter comparisons. Additionally, we compared measurement results from the two devices using Bland-Altman analysis in MedCalc (V16) software (10-12). Intra-rater reliability, which assesses the consistency of repeated measurements from the same subject by the same observer or instrument, was evaluated using the Intra Class Correlation Coefficient (ICC) test.

3. Results

In our study, we conducted a preliminary evaluation involving 43 individuals to assess kidney and spleen volumes using CT images.

The mean initial kidney volume determined using a computer mouse was 181.53 ±51.72 cm³. In the subsequent measurements conducted with the same instrument, the kidney volume was calculated to be 180.64 ±51.29 cm³. This reflected a statistically significant decrease in the volume as per the second set of measurements ($p = 0.024$).

The average time required for the initial and secondary volume measurements of the kidneys utilizing a computer mouse averaged 283.55 ±56.03 seconds and 237.11 ±63.28 seconds, respectively. This indicated a statistically significant reduction in the time taken for the measurements in the second measurement ($p < 0.001$).

The initial kidney volume, determined using a graphic tablet, was recorded as 179.34 ±51.37 cm³, and in subsequent measurements with the same device, the volume was noted as 179.10 ±51.35 cm³. There was no difference between the initial and subsequent measurements taken over the kidneys using a graphic tablet ($p = 1.000$).

The average durations for the initial and subsequent volume measurements of the kidney using the graphic tablet were 128.79 ±33.32 seconds and 119.56 ±31.35 seconds, respectively. The comparison of the two measurement durations revealed no significant differences ($p = 0.109$).

The initial volume measurements of the spleen conducted with a computer mouse averaged 211.03 ±78.47 cm³, whereas the subsequent measurements with the same device yielded a spleen volume of 211.76 ±81.70 cm³. A comparison of the data between the first and second measurements revealed no significant difference in spleen volume ($p = 1.000$).

The average durations for the initial and subsequent volume measurements for the spleen using a computer mouse were 386.74 ±106.66 seconds and 281.19 ±77.48 seconds, respectively. The comparison of the two measurement durations revealed no significant differences ($p < 0.001$).

The initial volume measurements of the spleen conducted with a graphic tablet averaged 205.93 ±77.52 cm³, while the subsequent measurements with the same device yielded a spleen volume of 206.06 ±77.44 cm³. No statistically significant difference was found between the first and second measurements ($p = 1.000$) (Table 1).

The average durations for the initial and subsequent volume measurements over the spleen using a graphic tablet were 141.91 ±40.18 seconds and 132.09 ±39.09 seconds, respectively. The comparison of the two measurement durations revealed significant differences ($p < 0.001$).

The results of the volumes in two sessions using the computer and tablet and the duration of the delineations are shown in Table 1 and Table 2.

Table 1. Comparison of repeated volume measurements (cm³) taken on kidney and spleen using a computer mouse and a graphics tablet

		Computer mouse	Graphic tablet	
		Mean ±SD	Mean ±SD	P
Kidney	1st measurement	181.5 ±51.7	179.3 ±51.4	**<0.001**
	2nd measurement	180.7 ±51.3	179.1 ±51.4	0.179
	P	**0.024**	1.000	
Spleen	1st measurement	211 ±78.5	205.9 ±77.5	**0.007**
	2nd measurement	211.8 ±81.7	206.1 ±77.4	0.397
	P	1.000	1.000	

Table 2. Comparison of repeated volume measurement times (second) taken from kidney and spleen using a computer mouse and a graphics tablet

		Computer mouse	Graphic tablet	
		Mean ±SD	Mean ±SD	P
Kidney	1st measurement time	283.6 ±56	128.8 ±33.3	**<0.001**
	2nd measurement time	237.1 ±63.3	119.6 ±31.4	**<0.001**
	P	**<0.001**	0.109	
Spleen	1st measurement time	386.7 ±106.7	141.9 ±40.2	**<0.001**
	2nd measurement time	281.2 ±77.5	132.1 ±39.1	**<0.001**
	P	**<0.001**	**<0.001**	

The study also checked the Intra Class Correlation Coefficient (ICC) value. Measurements yielded ICC of 0.989 ($p<0.001$) for kidneys and 0.991 ($p<0.001$) for spleen images using a computer mouse. Graphic tablet measurements resulted in a higher ICC of 0.999 ($p<0.001$) for kidneys and 0.998 ($p<0.001$) for spleen images.

According to the Bland-Altman analysis, the limits of agreement (represented by brown dashed lines) for measurements taken over the kidney using a computer mouse showed a difference of (10.3+|-8.5|)=18.8 cm^3, whereas the limits of agreement for measurements taken using a graphic tablet showed a higher difference of (2.1+|-1.7|)=3.8 cm^3. It shows that kidney volume measurements are more successful with this tablet. (Fig. 1).

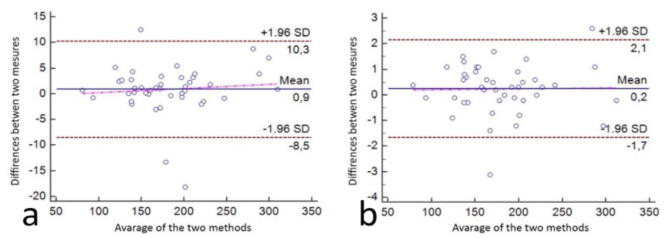

Fig. 1. Bland-Altman plot of volume data obtained for the kidney using a computer mouse (a) and a graphic tablet (b)

In the measurement results obtained over the spleen using a computer mouse, the difference between the limits of agreement was found to be (32.8+|-34.2|) =67.0 cm^3, whereas for measurements taken using a graphic tablet, the difference between the limits of agreement was observed to be higher at (2.2+|-2.5|)=4.7 cm^3. It shows that spleen volume measurements are more successful with this tablet (Fig. 2).

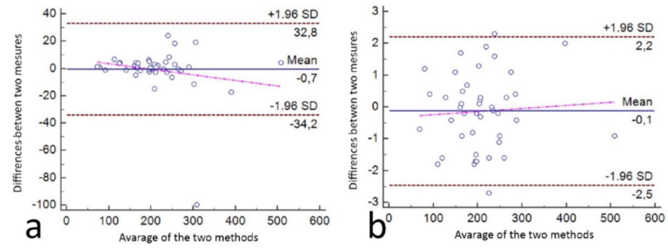

Fig. 2. Bland-Altman plot of volume data obtained for the spleen using a computer mouse (a) and a graphic tablet (b)

4. Discussion

Changes in the size of organs in the human body can indicate many pathologies. Anomalies such as splenomegaly, hepatomegaly, cardiomegaly, goiter and nephromegaly give physicians the first clue about diagnosing various diseases. In this context, it is essential to evaluate the dimensions of the structures accurately and quantitatively in the human body. Visual and qualitative assessments of the dimensions of the relevant organ, which has organic forms, can often be misleading. Knowing the dimensions of these structures' width, length, and thickness may not provide a sufficient parameter. For this reason, knowing the volumetric value occupied by the relevant three-dimensional structure accurately guides the physician or researcher in making more accurate evaluations. Digital devices, which are becoming smaller and easier to access with advancing technological developments, enable healthcare professionals to access patient information and images almost anywhere.

Our study aimed to compare the usability of tablets, which are increasingly common today, for sensitive operations such as volume measurements in terms of consistency, sensitivity and time. Our findings are that pen tablets are a fast, time-saving device that provides consistent results for precise measurements such as volume. The scope of this study is to evaluate the practicality and consistency of the graphic tablet in organ volume calculations. For this purpose, CT images of individuals with no intra-abdominal pathology were taken for routine stone diagnosis and were considered healthy. Control over the cursor increases sensitivity during volume measurement. Stylus pens used instead of a computer mouse increase this dominance. Another advantage of using a pen is that it does not cause wrist discomfort due to long-term computer mouse use, as stated in the literature (13-15). The shape and simplicity of the stylus pens, as well as the fact that they are highly suitable for human ergonomics, provide the user with this sensitivity and speed. Using a stylus instead of a regular computer mouse makes these measurements more accurate and is easier on the wrist, making it a better choice for health professionals.

We measured the average sizes of kidneys and spleens and compared them with what is already known in medical studies. Our results matched well with these studies, showing that tablets can be trusted for medical measurements. Our study also showed that tablets could give more precise measurements with less variation than other methods.

In our study, the average volume of the kidneys we measured to evaluate the device efficiency was 179.3 cm^3. This value is compatible with the studies in the literature. It is also noteworthy that the standard deviation values of our measurements made using a graphic tablet are smaller than those found in studies in the literature.

Seuss et al. measured kidney volumes with planimetry, found it to be 143.7 cm3, and used it as a reference. In the same sample, they found the measurements taken with the ellipsoid formula to be 174.3 cm^3 and the spheroid formula to be 346.9 cm^3. It is seen that ellipsoid and spheroid formulas may mislead the researcher by showing deviations from the reference value (16).

Kyaw et al. conducted a study wherein they employed a stereological method to determine pre-transplant kidney volumes based on CT images before kidney transplantation. The researchers underscored the reliability of the method utilized. Specifically, they delineated left kidney volumes within two distinct groups, denoting 139.5 cm^3 and 145 cm^3, respectively. These values were consistent with the volume of kidneys removed during transplantation, affirming the reliability of stereological methodologies in kidney volume assessment. To increase the speed and sensitivity of these methods, it is important to use easy-to-control devices, as we stated in our study (17).

Cheong et al.'s study evaluated the ellipsoid formula, stereological measurement and Archimedes' principle together. They found the standard deviation of kidney volume calculated stereologically from high-resolution MR images to be the smallest. On the other hand, they reported that the volumes calculated using the ellipsoid formula differed by 17% to 29% from the volume values measured using the Archimedes principle. In this study, precise measurement in disease and transplantation is emphasized (18). It is important to achieve more precise measurements for many pathologies and surgical interventions where volumetric change is important.

Many studies have emphasized the importance of expert perspective and practicality in volume calculations (18-20). Stereological measurement methods such as the Cavaleri Principle are applications that can be gained practice in a short time. It also allows the researcher to test himself on the coefficient of error.

Many studies have conducted methodological studies on kidney volume measurement using images of autosomal dominant polycystic kidney disease patients (19, 21-24). Making measurements on these images may cause deviations due to diseases other than the method. A strength of our study is that we did not use images of healthy kidneys without kidney pathology.

In our study, the average spleen volume we measured to evaluate the device efficiency was 205.9 cm^3. This value is compatible with the studies in the literature. It is also noteworthy that the standard deviation values of our measurements made using a graphic tablet are smaller than those found in studies in the literature.

Mazonakis et al. measured the average spleen volume using planimetry from CT images of the European population, reporting a volume of 204.8 cm^3 (25). Similarly, Prassopoulos et al., in their CT study on the European population, reported a spleen volume of 214.6 cm^3 (24). Additionally, Henderson et al. assessed spleen volume in Europeans through CT imaging, yielding a mean volume of 209.0 cm^3 (27).

Variable data regarding the average and upper limits of normal spleen volume in adults (21, 22) is available. In their study with 300 people, Fateh et al. reported that the average spleen volume was 174.41 cm^3 (28). Badran et al. utilized conventional ultrasound to assess spleen volume in the Jordanian population, reporting an average spleen volume of 184 cm^3 (29). Ehimwenma and Tagbo determined spleen size in an endemic tropical environment (Nigeria), reporting mean spleen volumes of 177.5 cm^3 (30).

In the study conducted by Asghar et al., they calculated the spleen volume using three different techniques. Their study stated that volume determination with 2D USG may be inaccurate due to the variable contour of the spleen and the overlap of the spleen outline with bone, intestinal gas or the left kidney. The spleen volume was 161.57 cm^3 with the volume rendering technique and 259.29 cm^3 with the ellipsoid formula. They found 254.01 cm^3 with the surface rendering technique. Additionally, they emphasized that 3D reconstruction of CT images is more accurate than 2D ultrasonography (31).

More studies need to address the duration required for volume calculations. The time expended during measurements holds significance, particularly in studies involving sizable populations. The Cavalier principle offers notable advantages in this context, facilitating rapid measurements with minimal time investment, a benefit that accrues with the researcher's increased proficiency. Furthermore, our study underscores the efficiency gains of stylus employment in expediting these processes.

When we looked at other ways of measuring organ sizes, like using different formulas or methods, we found that some could be off or not as reliable. Our work supports the use of more accurate methods, like the ones we used, which match up well with the actual sizes seen in surgeries. An important part of our study was that we did not use images from patients with a specific kidney disease, making measurements tricky. This made our findings more reliable for understanding the actual size of healthy organs.

Our research shows that using tablets with a stylus pen is an excellent way for doctors and researchers to measure organ sizes accurately and comfortably. This technology could improve diagnosing and planning surgeries, showing the need to bring such tools into everyday medical use. Our findings are reliable and in line with other medical research, suggesting that this method could be widely used for more accurate medical assessments.

Ethical Statement

Our study underwent review by the Ondokuz Mayıs University Clinical Research Ethics Committee and received official approval with Decision No. OMU KAEK 2017/21 (Date: 12.01.2017).

Conflict of interest

The authors declare that they have no competing interests.

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None to declare.

Authors' contributions

Concept: B.Ş., Design: B.Ş., Data Collection or Processing: B.Ş., Analysis or Interpretation: M.N., Literature Search: M.N., Writing: M.N.

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