

Distribution and Characteristics of Pancreatic Volume Using Computed Tomography Volumetry

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Objectives: Changes in the pancreatic volume (PV) are useful as potential clinical markers for some pancreatic-related diseases. The objective of this study was to measure the volume of the pancreas using computed tomography (CT) volumetry and to evaluate the relationships between sex, age, body mass index (BMI), and sarcopenia. **Methods:** We retrospectively analyzed the abdominal CT scans of 1,003 subjects whose ages ranged between 10 and 90 years. The pancreas was segmented manually to define the region of interest (ROI) based on CT images, and then the PVs were measured by counting the voxels in all ROIs within the pancreas boundary. Sarcopenia was identified by examination of CT images that determined the cross-sectional area of the skeletal muscle around the third lumbar vertebra. **Results:** The mean volume of the pancreas was $62.648 \pm 19.094 \text{ cm}^3$. The results indicated a negative correlation between the PV and age. There was a positive correlation between the PV and BMI for both sexes, females, and males ($r = 0.343, p < 0.001$; $r = 0.461, p < 0.001$; and $r = 0.244, p < 0.001$, respectively). Additionally, there was a positive correlation between the PV and sarcopenia for females ($r = 0.253, p < 0.001$) and males ($r = 0.200, p < 0.001$). **Conclusions:** CT pancreas volumetry results may help physicians follow up or predict conditions of the pancreas after interventions for pancreatic-related disease in the future.

Keywords: Pancreas, Deep Learning, Body Mass Index (BMI), Sarcopenia, Computed Tomography (CT)

Submitted: July 26, 2020

Revised: August 2, 2020

Accepted: September 8, 2020

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1. Introduction

Determination of the pancreatic volume (PV) has significant potential for solving clinical problems [1]. Changes in the PV are related to pathological conditions of the pancreatic endocrine or exocrine function [2]. Thus, the PV can be used as a clinical marker for disease progression [3]. Several studies have indicated that chronic pancreatitis and diabetes reduce the size of pancreas [4], and pancreatic cancer and acute pancreatitis make the pancreas become focal or show diffuse enlargement [1]. The PV can also be used as a predictor of long-term outcomes or the prevalence of organ-specific diseases after resection [5,6]. Therefore, it is necessary to know the normal anatomic range of the PV for defining pathological conditions.

Computed tomography (CT) has been widely used to non-invasively determine the PV and investigate the relationship between the size of the pancreas and its endocrine and exocrine functions. Previous studies have suggested the average PV using CT [7,8]. According to several studies, various clinical parameters affect the PV. The condition of fat deposition in the pancreas has been associated with PV, age, sex, obesity, and dyslipidemia [7,9]. Additionally, sarcopenia is defined as a reduction in the muscle mass and strength, and it is a progressive disease with aging [10], which leads to functional impairment and physical disability. It increases the risk of obesity and is related to fat deposition in the pancreas [9,11]. Since sarcopenia is common in patients with pancreatic cancer and is known to affect prognosis after surgical resection and chemotherapy [12], studies on the relationship between sarcopenia and PV are needed. However, studies on the PV have suggested different values [1,4,7-9]. Because most study populations enrolled have been selected from other ethnicities, study of the average PV is needed for Korean populations. In a recent study, it was found that, compared with Caucasians, Koreans had a significantly lower PV and tended to have a higher fat content in the pancreas [13]. However, the small sample sizes in the study on the PV limited the interpretation of the results; a larger number of subjects is needed to clarify the association between the PV and pancreatic function.

In this study, we investigated the normal PV range using CT volumetry for large populations. Additionally, we analyzed the correlations between the PV and gender, age, obesity, and sarcopenia using CT images.

II. Methods

1. Subject Selection

A total of 1,003 routine health checkup subjects who visited Gachon University Gil Medical Center between January 2017 and February 2020 and underwent abdominal CT scans, were enrolled in this study. The exclusion criterion was the presence of either clinical or CT signs of pancreatic or peri-pancreatic pathology. Additionally, subjects with pathological conditions affecting the PV were excluded, e.g., peritonitis, or a history of chemoradiation due to malignancy in subjects below 19 years of age.

The Institutional Review Board of Gachon University Gil Medical Center approved this study (No. GDIRB2020-121), and no informed consent from the subjects was required. We adhered to the Declaration of Helsinki (1975).

2. Assessment of PV

The subjects underwent abdominal-protocol 3-mm-thick three-phase contrast-enhanced axial and coronal CT for the screening program. The pancreas was segmented manually to define the region of interest (ROI) using software that was developed in-house. The ROI was drawn on all axial planes where the pancreas was present, and all ROIs were joined to construct the volume. The PV was determined by multiplying the total number of pixels in all ROIs by the X-axis, Y-axis pixel spacing, and slice thickness within the pancreas boundary.

3. Assessment of Skeletal Muscle Using CT Images

The skeletal muscle area around the third lumbar vertebra (L3) region was measured and was selected as the standard landmark, as described in previous studies [14]. We used in-house software Gachon_DeepBody developed at Gachon University to automatically determine the skeletal muscle area within a range of -25 to 150 Hounsfield units. The Gachon_DeepBody segmented skeletal muscle using the trained deep-learning model and measured the volume. The deep-learning model was trained using the U-Net [14] in CT images of 2,504 cases. The accuracy for skeletal muscle segmentation was 94.87%. Sarcopenia was determined to be present when the L3 skeletal muscle index (SMI) was $\leq 55 \text{ cm}^2/\text{m}^2$ for men and $\leq 39 \text{ cm}^2/\text{m}^2$ for women, according to previously reported cutoff values for the Korean population [14]. L3 SMI was defined as the cross-sectional area of the muscle at the L3 level normalized with respect to the height, as is conventional for the BMI.

4. Statistical Analysis

Continuous variables are presented as the mean \pm standard deviation (for normally distributed variables) or as the median and range (for non-normally distributed variables). The continuous variables were compared between the two groups using independent-sample *t*-tests and one-way analysis of variance (ANOVA), and categorical parameters were compared using the χ^2 test. The Duncan multiple comparison test was used to compare group means. The subjects were classified into the following groups: underweight (BMI $< 18.5 \text{ kg}/\text{m}^2$), normal weight ($18.5 \leq \text{BMI} \leq 22.9 \text{ kg}/\text{m}^2$), overweight ($23.0 \leq \text{BMI} \leq 24.9 \text{ kg}/\text{m}^2$), and obese (BMI $\geq 25 \text{ kg}/\text{m}^2$) [15]. All analyses were performed using SPSS Statistics software version 20.0 (IBM Corp., Armonk, NY, USA), and $p < 0.05$ was set as the limit for statistical significance.

Table 1. Baseline characteristics of study population

	Total (n = 1,003)	Female (n = 474)	Male (n = 529)	t	p-value
Age (yr)	55.323 ± 15.621	54.964 ± 15.980	55.645 ± 15.300	0.689	0.491
Pancreatic volume (cm ³)	62.648 ± 19.094	55.762 ± 16.064	68.818 ± 19.493	11.498	<0.001
Height (cm)	163.580 ± 8.947	157.000 ± 6.244	169.000 ± 6.804	29.515	<0.001
Weight (kg)	65.289 ± 12.146	59.620 ± 10.018	70.368 ± 11.635	15.589	<0.001
BMI (kg/m ²)	24.316 ± 3.519	24.147 ± 3.752	24.466 ± 3.294	1.435	0.155
Sarcopenia (yes)	411 (43.97)	269 (65.45)	142 (34.55)	-10.082	<0.001

Values are presented as mean ± standard deviation or number (%).

BMI: body mass index.

p-values correspond to comparisons between men and women.

Table 2. Change in the pancreatic volume with respect to age

Age (yr)	n	Pancreatic volume (cm ³)			t	p-value
		Total	Female	Male		
11-20	30	64.384 ± 19.404	61.122 ± 26.053	66.879 ± 12.575	0.800	0.430
21-30	53	64.642 ± 15.943	60.361 ± 13.693	70.225 ± 17.207	2.325	0.024
31-40	135	69.691 ± 16.147	64.466 ± 14.652	75.487 ± 15.847	4.198	<0.001
41-50	144	70.508 ± 20.413	61.186 ± 16.737	78.178 ± 20.053	5.446	<0.001
51-60	241	64.098 ± 18.766	55.503 ± 15.357	71.437 ± 18.337	7.240	<0.001
61-70	239	59.175 ± 17.977	52.126 ± 14.043	64.699 ± 18.819	5.711	<0.001
71-80	161	51.720 ± 17.085	46.047 ± 12.365	57.187 ± 19.176	4.363	<0.001

Values are presented as mean ± standard deviation.

p-values correspond to comparisons between men and women.

III. Results

Table 1 shows the baseline characteristics of the subjects, PV, and clinical variables. The mean PV was significantly higher for males (68.818 ± 19.493 cm³) than for females (55.762 ± 16.064 cm³). The mean PV values for female and male subjects exhibited a statistically significant difference (p < 0.001).

1. The Relationship between Age and PV

The PV increases slightly from the early teens to the 40s and declines thereafter (Table 2, Figure 1). The PV was maximized in the 40s for all groups except for the female group. A significant difference in the PV between females and males was observed for all age groups except for teens.

2. The Relationship between BMI and PV

Table 3 presents the mean PV results for each group. A comparison of PVs according to BMI groups revealed significant differences between the normal weight group and the other groups.

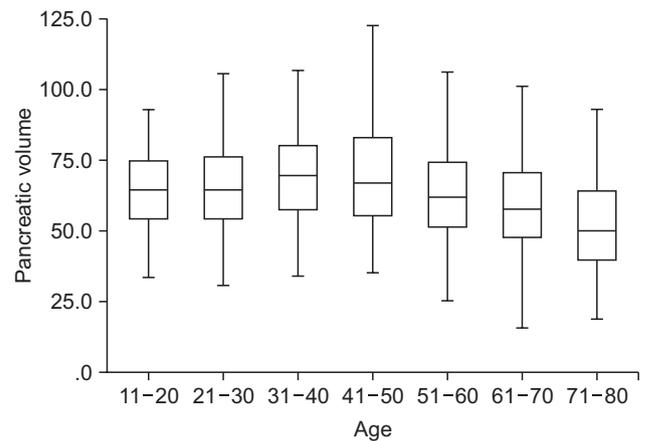


Figure 1. Box-and-whisker plots of pancreatic volume with respect to age. Boxes indicate median and 25th-75th percentile ranges.

3. The Relationship between Sarcopenia and PV

As seen in Table 4, the PV was significantly higher for subjects with sarcopenia than for those without sarcopenia (p = 0.002). The BMI of subjects with sarcopenia was 26.023 ± 3.496 kg/m², and the BMI of subjects without sarcopenia was

Table 3. Relationship between BMI and pancreatic volume

Group	BMI (kg/m ²)	n	Pancreatic volume (cm ³)	F	p-value
Underweight	<18.5	44	46.855 ± 13.616 ^a	33.874	<0.001
Normal weight	18.5–22.9	316	57.162 ± 17.177 ^b		
Overweight	23.0–24.9	248	63.249 ± 18.433 ^c		
Obese	≥25.0	395	68.419 ± 19.299 ^d		

Values are presented as mean ± standard deviation.

BMI: body mass index.

Statistical significances were tested by one-way analysis of variances among groups.

The superscripts indicate significant difference between groups based on Duncan multiple comparison test.

Table 4. Relationship between sarcopenia and pancreatic volume

	Normal muscle mass (n = 592)	Sarcopenia (n = 411)	t	p-value
Weight (kg)	63.660 ± 11.266	67.633 ± 12.970	-5.157	<0.001
Height (cm)	165.537 ± 8.422	160.757 ± 8.937	8.621	<0.001
BMI (kg/m ²)	23.130 ± 3.014	26.023 ± 3.450	-13.994	<0.001
Underweight	36 (6.1)	8 (1.9)		
Normal weight	256 (43.2)	60 (14.6)		
Overweight	147 (24.8)	101 (58.9)		
Obesity	153 (25.8)	242 (58.9)		
Gender			-10.082	<0.001
Female	205	269		
Male	387	142		
Age (yr)	56.534 ± 15.665	53.579 ± 15.410	2.957	0.003
Pancreatic volume (cm ³)	61.070 ± 19.086	64.921 ± 18.898	-3.155	0.002

Values are presented as mean ± standard deviation or number (%).

BMI: body mass index.

Table 5. Association between clinical variables studied and pancreatic volume

	Pancreatic volume					
	Total (n = 1,003)		Female (n = 529)		Male (n = 474)	
	r	p-value	r	p-value	r	p-value
Age	-0.274	<0.001	-0.259	<0.05	-0.357	<0.001
Weight	0.532	<0.001	0.524	<0.05	0.34	<0.001
Height	0.428	<0.001	0.297	<0.05	0.265	<0.001
BMI	0.343	<0.001	0.461	<0.05	0.224	<0.001
Sarcopenia	0.099	<0.001	0.253	<0.05	0.2	<0.001

r is Pearson correlation coefficient.

23.130 ± 3.0143 kg/m².

4. Association between Clinical Variables and PV

As seen in Table 5, the Pearson correlation analysis revealed a statistically significant correlation between the parameters

used and the PV. For all three groups, the PV was positively correlated with weight and height. There was a negative correlation between the PV and age for both sexes ($r = -0.274, p < 0.001$), females ($r = -0.259, p < 0.001$), and males ($r = -0.357, p < 0.001$). We found a statistically significant correla-

tion between the PV and BMI for both sexes, females, and males ($r = 0.343$, $p < 0.001$; $r = 0.461$, $p < 0.001$; and $r = 0.224$, $p < 0.001$, respectively). There was also a statistically positive relationship between sarcopenia and the PV ($p = 0.002$).

IV. Discussion

In this study, we investigated the PV range for healthy subjects and the relationship between the PV and clinical variables, namely, sex, age, BMI, and sarcopenia.

We found that the mean PV for 1,003 individuals was $62.648 \pm 19.094 \text{ cm}^3$. Various studies have been performed on the PV [1,4,8,9,13,16-18]. For example, Goda et al. [4] reported values in the range of $71.5 \pm 18.7 \text{ cm}^3$ for 22 individuals (mean age of 46 years), Geraghty et al. [8] reported values in the range of $64.4 \pm 18.1 \text{ cm}^3$ for 46 female individuals and $87.4 \pm 21.3 \text{ cm}^3$ for 57 male individuals (mean ages of 49 and 48 years, respectively). The discrepancies in the mean PV compared with those from previous studies may be due to differences in the number, average age, anthropometric characteristics, and genders of the individuals enrolled in the study and differences in the ethnicities between the study populations.

We found a statistically significant correlation between the PV and the age of the participants in the present study. For healthy people, the PV increased with age, and it started to decline after 50 years, which is consistent with the findings of previous studies [16,17].

We found that the mean PV based on CT was 55.76 cm^3 for females and 68.82 cm^3 for males. The mean PV was 19.0% larger for males than for females, which is consistent with the findings of previous anatomical and radiological studies [1,8,9,16,19]. However, the PV obtained in this study is smaller than those of other studies involving Korean individuals [13]. This could be attributed to differences in the BMI (26.1 kg/m^2 in the study of Lim et al. [13] vs. 24 kg/m^2 in our study), the number of subjects enrolled, and differences in the anthropometric characteristics.

There was a correlation between the PV and BMI ($r = 0.343$, $p < 0.05$), and these results were consistent with previous reports [9,17]. The correlation suggests that obesity affects the PV. The fact that the PV was greater in obese people may be due to an increase in the amount of pancreatic fat rather than in pancreatic parenchyma [9]. The incidence of fatty replacement, which is also known as lipomatosis, is associated with obesity and DM [11,17].

Additionally, there was a statistically significant correlation between the PV and sarcopenia. In this study, approximately

98% of the subjects had sarcopenia and were of normal weight or overweight/obese, and only 2% of the subjects had sarcopenia and were underweight. This indicates the limitation of body-composition evaluation based on BMI. BMI, which is based on the overall body mass, does not differentiate between fat mass and muscle mass [20].

In our study, sarcopenia was measured using CT, which allowed for the determination of changes in the skeletal muscle mass. Sarcopenia is defined as a reduction in the muscle mass and strength and is a progressive disease related to frailty in elderly subjects [21]. Sarcopenia is related to fat deposition in the pancreas as well as in muscle [22]. In the present study, the mean age of subjects with sarcopenia was 53 years, and sarcopenia was present in 41% of the subjects with a larger BMI. We also considered the concept of sarcopenic obesity [23], which occurs with aging and may lead to an increased risk of both sarcopenia and obesity. The subjects with sarcopenia in our study were obese, which is consistent with the findings of a previous study, indicating that the PV is correlated with a high BMI [24].

In contrast, some studies have indicated that the β -cell function in the pancreas is suppressed with aging [25], reducing the PV. For example, in a study on patients with type I diabetes, the PV was lower for insulin-dependent diabetic patients than for normal subjects [26], suggesting that reduced PV is associated with β -cell dysfunction. Additionally, a study on the association between sarcopenia and the clinical parameters of β -cell function and insulin resistance revealed that reduced β -cell function is associated with reduced skeletal muscle mass in subjects without diabetes [27]. We used CT images to measure the PV; thus, pathological changes, such as reduced β -cell function in the pancreas, could not be directly evaluated. However, CT allows accurate noninvasive measurement of the PV *in vivo*, as well as parameters that affect the PV. A recent study on patients undergoing pancreatoduodenectomy indicated that PV measurement via CT was useful for evaluating the pancreatic endocrine function [28].

Our study had several limitations. First, we measured the PV using CT images. Thus, confounding factors (e.g., patients with conditions such as prediabetes, diabetes, and hypertension; contrast medium factors; and CT scanning factors) may have influenced the PV analysis. Second, because the study was conducted at a single tertiary care hospital, the results cannot be extrapolated to the entire population of Korea. Third, we did not measure endocrine cell function in the pancreas. Additionally, because this was a cross-sectional study, we cannot explain the sequential relationship between

the PV and the individual-matched variables used in this study. Additionally, sarcopenia is known to be related to aging. In our study, we found that subjects in their teens were diagnosed with sarcopenia using CT images. Therefore, it might be difficult to understand all the comorbidities for the subjects.

The present study had several strengths. First, the results may be more reliable than those of previous studies because a large number of subjects were examined, which may have improved the significance and clinical value of the findings. Second, there were previously no studies in which the PV was correlated with sarcopenia.

In summary, we found a positive correlation between BMI and the PV in a large number of Koreans, which is consistent with the findings of previous studies. Additionally, we found a relationship between sarcopenia and the PV. This study may be useful for the early diagnosis of sarcopenia using CT scans and the prevalence of new-onset diabetes after surgery for pancreatic diseases.

Conflict of Interest

Kwang Gi Kim is an editor of Healthcare Informatics Research; however, he did not involve in the peer reviewer selection, evaluation, and decision process of this article. Otherwise, no potential conflict of interest relevant to this article was reported.

Acknowledgments

This work was supported by Institute for National IT Industry Promotion Agency (NIPA) grant funded by the Korea government (MSIT) (No. A0602-19-1032, Intelligent surgical guide system & service from surgery video data analytics), and the Gachon University Gil Medical Center (No. FRD2019-16).

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