Normal pancreatic volume assessment using abdominal computed tomography volumetry

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Abstract
To determine the normal range of pancreatic volume (PV) in Chinese adults using computed tomography (CT) volumetry. To assess the relationships of PV with patient demographics and clinical parameters. To analyze the degree of correlation between PV values determined by manual segmentation and those calculated by formulas.

A total of 240 adults (120 women, 120 men) between the ages of 18 and 79 years were reviewed. There were 6 groups of patients, with 40 patients in each decade regarding age. PV was segmented manually on computed tomography images slice by slice for each patient, and 2 formulas were used to calculate PV" and PV#.

The mean PV was 77.44 ± 19.11 cm³ (range from 28.55–138.15 cm³). PV was significantly correlated with height (r = 0.427, P < .001), weight (r = 0.525, P < .001), body mass index (r = 0.377, P < .001), the width of the first lumbar vertebral body (r = 0.166, P = .001), the transverse abdominal diameter (r = 0.495, P < .001), and the sagittal abdominal diameter (r = 0.456, P < .001). There was a negative correlation between PV and age (r = −0.209, P = .001). The correlation coefficients between PV and PV" and PV# were 0.676 and 0.376, respectively, with both P < .001. PV associated with patient demographics and clinical parameters. A more accurate and simpler formula should be used in the future to calculate and monitor changes in PV.

Abbreviations: AP = anterior-posterior, BMI = body mass index, CC = cranial-caudal, CT = computed tomography, L1 = first lumbar vertebral body, PV = pancreatic volume, ROI = region of interest, SAD = sagittal abdominal diameter, TAD = transverse abdominal diameter.

Keywords: body mass index, computed tomography, pancreas, pancreatic volume

1. Introduction
Changes in pancreatic volume (PV) have been reported to be associated with many pancreatic diseases. For example, chronic pancreatitis and diabetes can reduce the size of the pancreas, whereas acute pancreatitis and neoplasms can increase PV.[1–3] In addition, PV can be used to not only assess disease progression but also determine long-term prognoses.[3] The quantification of changes in PV can lead to new insights in pancreatic diseases diagnosis and treatment. Accordingly, it is important to know the normal range of PV values to identify pathological conditions.

Several studies have reported normal ranges of PV values, but the ranges are inconsistent. Kipp et al[1] reported that the mean PV was 77.9 cm³, with inter-individual variability ranging from 18.8 to 139.8 cm³, and that sex had no independent influence on PV. Djuric-Stefanovic et al[5] showed that the average PV was 79.21 cm³ (ranging from 37.4–168.2 cm³) and significantly correlated with sex. However, in a recent Korean study, it was found that the mean PV was 62.648 cm³ and that there was a negative correlation between PV and age.[3] In addition, ethnicity may be related to PV.[2,4] To our knowledge, the normal range of PV values in Chinese adults has not been reported in the English literature.

Computed tomography (CT) is the first-line imaging modality for suspected pancreatic disease, and most reported PV values were determined with CT. The method of measuring PV in which the margin of the pancreas is outlined on all slices is most accurate but time consuming. Therefore, PV is still not commonly used. Two formulas have been developed to make it easier to calculate PV (Table 1).[2,5] However, the validity of these 2 formulas has yet to be assessed. The goals of this study were to determine the normal range of PV values in Chinese adults using CT; to assess the relationships of PV with sex, age, body mass index (BMI), and other factors; and to analyze the degree of correlation between PV determined by outlining the margin of the pancreas on all slices and PV calculated by the above 2 formulas.
2. Materials and methods

2.1. Subject selection

Approval for this retrospective study was obtained from the Ethics Administration Office of our hospital, and informed consent from the patients was not required. From October 2020 through January 2021, at our hospital, 240 contrast-enhanced abdominal CT scans of adult patients with a normal pancreas were reviewed from the picture archiving and communication system. The exclusion criteria were as follows: clinical or CT signs of a pancreatic pathology, such as acute and chronic pancreatitis, trauma, main pancreatic duct dilatation, or pancreatic neoplasm; a peripancreatic pathology, such as a stomach or spleen malignant tumor, lymph node enlargement with compression, seroperitoneum; diabetes or other diseases that may be related to the pancreas; images of poor quality; and an age younger than 18 years because these individuals may not have reached a mature organ state.

There were 120 male and 120 female patients aged 18 to 79 years, with 20 patients in each decade regarding age for a total of 6 groups. One of the assessors retrieved data from the patients’ medical records, such as sex, age, height, and weight. Additionally, BMI (weight [kg]/height [m²]) was calculated.

2.2. CT image acquisition

All patients fasted for 8 hours and drank 800 to 1000 mL of water to distend the gastrointestinal tract before the CT examination. The patients were scanned using a 64-slice LightSpeed VCT machine (GE Healthcare, Milwaukee, WI). The same protocol was used across patients with the following parameters: 120 kVp, 200 to 280 mAs, matrix size of 512 × 512, pitch of 0.8 to 1.0, and section thickness and section distance of 5 mm. The arterial phase, portal venous phase, and delayed phase were obtained at 25 to 30 seconds, 50 to 60 seconds, and 120 seconds, respectively, after an 80 to 100 mL injection of non-ionic contrast medium (Visipaque 320; GE Healthcare). Subsequently, the thin-slice images recorded at a thickness of 0.625 mm were transferred to a workstation (version 4.7, GE Healthcare).

2.3. Assessment of PV

PV was measured by 2 radiologists (doctor A and doctor B with 5 and 10 years of experience in abdominal radiology, respectively), and each radiologist measured half of the PV values. In the axial image of the venous phase, the pancreas was segmented manually on each section to define the region of interest (ROI) using GE Healthcare workstation software (Fig. 1). Peripheral fat and blood vessels (e.g., splenic artery and portal venous system) were avoided as much as possible. The PV was determined by joining all ROIs.

2.4. Assessment of other parameters

Lengthsbody&tail was defined as the maximal linear distance from the pancreatic neck to the tip of the pancreatic tail; the diameters of anterior-posterior (APtail) and APbody were measured from the lienal vein to the anterior contour of the pancreas; and diameter of the APhead was measured at the level at which both the superior mesenteric vein and artery were observed. The diameters of cranial-caudal (CCbody) and CChead were measured on sagittal images at the largest part of the body and between the portal vein and the transverse duodenum, respectively. In addition, the maximal lateral-lateral diameter was measured at the level of the first lumbar vertebral body (L1). The transverse abdominal diameter (TAD) and sagittal abdominal diameter (SAD) were measured at the level of the fourth lumbar vertebra and was defined as the distance between the skin on the 2 sides and the distance between the anterior and posterior skin, respectively. These parameters were defined and are depicted clearly in previous studies.\[1,2,6\]

### Table 1

Calculation formulas for pancreas volume.

| PV (cm³) | Formulas |
|----------|----------|
| PV= | \((\text{AP}_{\text{tail}} + \text{AP}_{\text{body}})/2 \times \text{Lengths}_{\text{body&tail}} \times \text{CC}_{\text{body}} + (\text{AP}_{\text{head}}/2)^3 \times 3.14 \times \text{CC}_{\text{head}}\) |
| PV² | 23.8 + 2.48x |

\(\text{AP} = \) anterior-posterior, \(\text{CC} = \) cranial-caudal, \(\text{PV} = \) pancreatic volume, \(x = \) body mass index.

2.5. Volume rendering

PV was calculated using volume rendering software (GE Healthcare). Figure 1. Representative thin-slice (0.625 mm) venous phase image. A white border was drawn by hand to define the area containing the pancreas without vessels (A). Volume rendering image showed that a full volume of segmented images was used to calculate pancreatic volume (B).
2.5. Intra-observer and inter-observer variability

Two weeks after the PV measurements were taken, intra-observer and inter-observer variability in outlining ROIs was studied. Ten random patients were re-evaluated by the 2 observers independently to calculate intra-observer variability. Then, 10 random patients were selected for re-evaluation by the 2 observers to calculate inter-observer variability.

2.6. Statistical analysis

The statistical analyses were performed using SPSS software (version 17.0; SPSS Chicago, IL). P values less than .05 were considered significant. The continuous variables are presented as the mean ± standard deviation, and the variances among the groups was assessed by Levene test, independent-samples t test and one-way analysis of variance. Pearson correlation coefficient was used to evaluate the correlations.

3. Results

The intra-observer and inter-observer variability of the PV measurements are shown in Table 2. The P values showed that the intra-observer and inter-observer variability of PV measurement were excellent.

The data of 240 patients with a normal pancreas were analyzed. The patient demographics and clinical assessment parameters are shown in Table 3. The total mean PV was 77.44 ± 19.11 cm³ (range, 28.55–138.15 cm³). The average PV values of the male and female groups were 82.82 ± 19.55 cm³ (range, 38.60–131.00 cm³), and 72.06 ± 17.03 cm³ (range, 28.55–138.15 cm³), respectively. Except for age, all parameters were significantly higher in the men than in the women.

The relationships between PV and patient demographics and clinical assessment parameters are shown in Table 4. There was a negative correlation between PV and age for all patients (r = −0.209, P < .001), the women (r = −0.298, P < .001), and the men

| Table 2 | Intra-observer and inter-observer variability of PV measurement. |
|---------|-----------------------------------------------------------------|
|         | The first measurement (n = 10)                  | The second measurement (n = 10) | t   | P   |
| Doctor A (men group) | 83.19 ± 20.97 | 84.11 ± 19.98 | 0.003 | .998 |
| Doctor B (women group) | 75.27 ± 8.96 | 75.67 ± 8.13 | 0.100 | .992 |
| Doctor A vs Doctor B | 79.18 ± 11.91 by doctor B | 75.51 ± 10.62 by doctor A | 0.711 | .486 |

PV = pancreatic volume.
∗ By doctor B.
† By doctor A.

| Table 3 | Baseline characteristics of study population. |
|---------|----------------------------------------------|
|         | Total (n = 240) | Men (n = 120) | Women (n = 120) | t   | P   |
| Age (year) | 49.30 ± 17.10 | 49.50 ± 17.11 | 49.10 ± 17.09 | 0.184 | .854 |
| Height (m) | 1.63 ± 0.08 | 1.68 ± 0.07 | 1.58 ± 0.06 | 12.765 | <.001 |
| Weight (kg) | 61.0 ± 11.90 | 66.7 ± 11.50 | 55.2 ± 9.18 | 8.566 | <.001 |
| BMI (kg/m²) | 22.9 ± 3.46 | 23.5 ± 3.19 | 22.2 ± 3.60 | 2.894 | .004 |
| Width of L1 body (cm) | 3.94 ± 0.35 | 4.08 ± 0.34 | 3.80 ± 0.31 | 6.456 | <.001 |
| TAD (cm) | 29.36 ± 2.88 | 30.50 ± 2.60 | 28.27 ± 2.70 | 6.481 | <.001 |
| SAD (cm) | 20.93 ± 2.80 | 22.07 ± 2.66 | 19.79 ± 2.47 | 6.841 | <.001 |
| PV (cm³) | 77.44 ± 19.11 | 82.82 ± 19.55 | 72.06 ± 17.03 | 4.532 | <.001 |

BMI = body mass index, L1 = first lumbar vertebral body, PV = pancreatic volume, SAD = sagittal abdominal diameter, TAD = transverse abdominal diameter.

| Table 4 | Relationship between PV and the parameters. |
|---------|--------------------------------------------|
|         | Total (n = 240) | Men (n = 120) | Women (n = 120) |
| r          | P   | r          | P   | r          | P   |
| Age (year) | −0.209 | .001 | −0.156 | .019 | −0.298 | .001 |
| Height (m) | 0.427 | <.001 | 0.301 | <.001 | 0.383 | <.001 |
| Weight (kg) | 0.525 | <.001 | 0.506 | <.001 | 0.402 | <.001 |
| BMI (kg/m²) | 0.377 | <.001 | 0.433 | <.001 | 0.250 | .006 |
| L1 width (cm) | 0.166 | .19 | 0.066 | .471 | 0.062 | .504 |
| TAD (cm) | 0.455 | <.001 | 0.536 | <.001 | 0.233 | .01 |
| SAD (cm) | 0.456 | <.001 | 0.516 | <.001 | 0.235 | .01 |

BMI = body mass index, L1 = first lumbar vertebral body, PV = pancreatic volume, r = correlation coefficient, SAD = sagittal abdominal diameter, TAD = transverse abdominal diameter.
(\(r = -0.156, P = .089\)). According to this table, in all 3 groups, there was a statistically significant correlation between PV and height, weight, BMI, TAD, and SAD. There was a positive correlation between the PV and the width of L1 body in the entire group (\(r = 0.166, P < .01\)) but not in the male and female groups specifically.

Table 5 shows the relationship between PV and age. PV reaches a maximum in the fourth decade for all groups and declines thereafter, except in the sixth decade in the male group (Fig. 2). There was a significant difference in PV between the female and male groups in the third and seventh decades.

The measured diameters of the pancreas are shown in Table 6. All measured diameters of the pancreas were longer in the men than in the women except \(CC_{body}\). The mean PV\(^{\ast}\) values of the entire group, male group, and female group were 104.98 ± 31.13 cm\(^3\) (range, 24.86–200.40 cm\(^3\)), 114.01 ± 34.58 cm\(^3\) (range, 34.21–200.40 cm\(^3\)), and 95.95 ± 34.58 cm\(^3\) (range, 24.86–193.32 cm\(^3\)), respectively.

Based on the formula \(y = 23.8 + 2.48x\), the mean PV\(^{\#}\) values of the entire group, male group, and female group were 80.64 ± 18.46 cm\(^3\) (range, 60.96–106.46 cm\(^3\)), 89.29 ± 18.94 cm\(^3\) (range, 63.52–105.32 cm\(^3\)), and 77.25 ± 15.76 cm\(^3\) (range, 60.96–106.46 cm\(^3\)), respectively.

The correlation coefficients between PV and PV\(^{\ast}\) and PV\(^{\#}\) were 0.676 and 0.376, respectively, with both \(P < .001\).

### Table 5

| Age (year) | Total (n=40) PV (cm\(^3\)) | Men (n=20) PV (cm\(^3\)) | Women (n=20) PV (cm\(^3\)) | t | P |
|-----------|-----------------------------|----------------------------|-----------------------------|---|---|
| 18–29     | 75.50 ± 19.15               | 80.64 ± 18.46              | 70.40 ± 12.85               | 1.986 | .054 |
| 30–39     | 82.90 ± 16.10               | 89.29 ± 18.94              | 76.46 ± 8.81               | 2.683 | .012 |
| 40–49     | 89.00 ± 15.90               | 93.18 ± 16.77              | 84.75 ± 13.85               | 1.691 | .099 |
| 50–59     | 77.10 ± 17.27               | 77.25 ± 15.76              | 77.01 ± 18.65               | 0.045 | .965 |
| 60–69     | 73.00 ± 18.48               | 80.40 ± 18.61              | 65.67 ± 15.12               | 0.561 | .578 |
| 70–79     | 67.10 ± 21.59               | 76.18 ± 21.98              | 58.08 ± 16.88               | 2.848 | .007 |

PV = pancreatic volume.

### Discussion

In this study, we investigated the range of PV values in healthy adults without a history of pancreatic disease, the relationship between PV and clinical characteristics (e.g., age and BMI), and the correlation between PV determined manually and PV calculated by 2 formulas.

Ranges of PV values have been reported by several studies, and most of them were determined on the basis of CT images. In the present study, the mean PV was 77.44 ± 19.11 cm\(^3\) in all 240 adults, 72.06 ± 17.03 cm\(^3\) in the female group, and 82.82 ± 19.55 cm\(^3\) in the male group. A wide range of PV values from 28.55 to 138.15 cm\(^3\) was observed. However, in a previous study, the mean PV was 40.4 cm\(^3\), which is nearly 2 times smaller than that in our study. Caglar et al\(^{[6]}\) reported that PV was 67.71 ± 16.03 cm\(^3\) in all individuals, 63.68 ± 15.08 cm\(^3\) in females, and 71.75 ± 15.99 cm\(^3\) in males. Geraghty et al\(^{[8]}\) reported that the mean PV values in 46 female individuals and 57 male individuals were 64.4 ± 18.1 cm\(^3\) and 87.4 ± 21.3 cm\(^3\), respectively. Kipp et al\(^{[1]}\) reported that the mean PV was 77.9 ± 21.7 cm\(^3\) in all individuals, 72.3 ± 19.2 cm\(^3\) in women, and 83.7 ± 22.7 cm\(^3\) in men. Djuric-Stefanovic et al\(^{[2]}\) used a formula and calculated the mean PV to be 79.21 ± 24.1 cm\(^3\). A simple formula was used to calculate the PV of Japanese adults, and the mean PV was 79.0 ± 21.6 cm\(^3\). These studies results are consistent with our results. Recently, a Korean study showed that the mean PV values for
1003 individuals, 474 females, and 529 males were $62.648 \pm 19.094 \text{cm}^3$, $55.762 \pm 16.064 \text{cm}^3$, and $68.818 \pm 19.494 \text{cm}^3$, respectively.\cite{3} The inconsistency in the PV values may be due to differences in patient number, mean age, sex, BMI, and region. Another important reason is that in CT image reconstruction, the use of thinner images may result in more accurate measurements of PV.

In this study, we found a statistically significant correlation between the mean PV and all patient demographics and clinical assessment parameters (Table 4). In this study, the mean PV increased with age, and then started to decline after 50 years, which is consistent with the results of previous studies.\cite{3, 5, 6} However, the mean PV of the individuals aged 60 years was larger than that of the individuals aged 50 years in the male group, possibly because PV was also associated with BMI. An interesting finding that PV seemed to have a significant correlation with age only in females but not males. This may provide explanation for the non-significant yet persistent sex differences in PV values across studies. The PV is larger in obese people than in normal-weight and overweight people, which is consistent with the results of previous studies.\cite{3, 5, 6}

The width of L1 is known to remain consistent with age and is believed to be correlated with PV.\cite{1} Interestingly, although we found that the width of L1 was positively correlated with the mean PV in the entire group, the correlation was not statistically significant in the female group or the male group. This finding could be attributed to differences in the number of subjects enrolled.

We found a statistically significant correlation between the mean PV and TAD and SAD, which is founding consistent with the results of previous studies.\cite{3, 5, 6} TAD and SAD are believed to be good indicators of the amount of body fat, which depends on the waist circumference, and all these parameters are associated with BMI.

In this study, we also used 2 formulas to calculate the $PV^t$ and $PV^v$, which were $104.98 \pm 31.13 \text{cm}^3$ and $80.51 \pm 8.58 \text{cm}^3$, respectively. Although the mean PV was closer to $PV^t$ ($77.44 \text{cm}^3$ vs $80.51 \text{cm}^3$), the correlation between the mean PV and $PV^v$ was stronger than was the correlation between the mean PV and $PV^t$ ($0.676$ vs $0.376$). This result suggests that the formula $PV^v = (AP_{tail} + AP_{body})/2 \times Lengths_{body\&tail} \times CC_{body} + (AP_{head}/2)^2 \times 3.14 \times CC_{head}$ is more accurate than the formula $PV^t = (AP_{tail} + AP_{body})/2 \times Lengths_{body\&tail} \times CC_{body} + (AP_{head}/2)^2 \times 3.14 \times CC_{head}$. The reason may be that the latter formula only considers BMI, and that PV is also related to many other factors. However, the latter formula is simpler.

Our study had several limitations. First, the sample size is small. There were only 20 patients in each age group, stratified by sex, which may have impacted the precision of the estimates of the mean PV, and the results cannot be generalized to the entire Chinese population. Studies with larger sample sizes are needed in the future. Second, although pancreatic peripheral fat is not included in the PV segmentation process, pancreatic fat infiltration is inevitably included, especially in obese patients, resulting in increased PV. Third, alcohol consumption was not included in the analysis.\cite{9} This factor may impact the mean PV in the male group, which could bias the results of this study. Fourth, we did not include $\beta$-cell function in the pancreas. A previous study showed that the $\beta$-cell function is suppressed with age and reduces the PV.\cite{10} This factor may impact the results, although magnitude of impact is likely small.\cite{15}

In conclusion, we determined the range of normal PV in Chinese adults. We demonstrated a positive correlation between PV and patient demographics and clinical assessment parameters, and these results were similar to those of previous studies. We compared the PV determined manually with PV calculated by formulas, and recommend that a more accurate and simpler formula is used in the future to calculate and monitor changes in PV.

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**References**

1. Kipp JP, Olesen SS, Mark EB, Frederiksen LC, Drewes AM, Frokjaer JB. Normal pancreatic volume in adults is influenced by visceral fat, vertebral body width and age. Abdom Radiol (NY) 2019;44:958–66.
2. Djuric-Stefanovic A, Masulovic D, Kostic J, Randic K, Saranovic D. CT volumetry of normal pancreas: correlation with the pancreatic diameters measurable by the cross-sectional imaging, and relationship with the gender, age, and body constitution. Surg Radiol Anat 2012;34:811–7.
3. Yoon J, Kim KG, Kim YJ, et al. Distribution and characteristics of pancreatic volume using computed tomography volumetry. Healthc Inform Res 2020;26:321–7.
[4] Lim S, Bae JH, Chun EJ, et al. Differences in pancreatic volume, fat content, and fat density measured by multidetector-row computed tomography according to the duration of diabetes. Acta Diabetol 2014;51:739–48.

[5] Kou K, Saiho Y, Jinzaki M, Itoh H. Relationship between body mass index and pancreas volume in Japanese people. JOP 2014;15:626–7.

[6] Caglar V, Songur A, Yagmurca M, Acar M, Toktas M, Gonul Y. Age-related volumetric changes in pancreas: a stereological study on computed tomography. Surg Radiol Anat 2012;34:935–41.

[7] Schulz HG, Christou A, Gursky S, Rother P. Computerized tomography studies of normal morphology and volumetry of parenchymatous epigastric organs in humans. Anat Anz 1986;162:1–12.

[8] Geraghty EM, Boone JM, Mcgahan JP, Jain K. Normal organ volume assessment from abdominal CT. Abdom Imaging 2004;29:482–90.

[9] Yoonhee C, Jung K, Eo E, et al. The relationship between alcohol consumption and injury in ED trauma patients. Am J Emerg Med 2009;27:956–60.

[10] Oya J, Nakagami T, Yamamoto Y, et al. Effects of age on insulin resistance and secretion in subjects without diabetes. Intern Med 2014;53:941–7.

[11] Balzano G, Dugnani E, Gandolfi A, et al. Effect of diabetes on survival after resection of pancreatic adenocarcinoma: a prospective, observational study. PLoS One 2016;11:e0166008.