Original Article

Development and validation of a new formula to predict standard pancreas volume in Chinese adults using body surface area

Yaping Zhang[1#], Feng Chen[2#], Jiasheng Cao[3], Domenech Asbun[4], Kai Siang Chan[5,6], Jose M. Ramia[7], Dongju Xiao[1], Jun Fang[8,9*], Jiliang Shen[3*]

[1]Department of Anesthesiology, Sir Run Run Shaw Hospital, Zhejiang University School of Medicine, Hangzhou, China; [2]Department of Breast Surgery, Zhejiang Cancer Hospital, Hangzhou, China; [3]Department of General Surgery, Sir Run Run Shaw Hospital, Zhejiang University School of Medicine, Hangzhou, China; [4]Division of Hepatobiliary and Pancreas Surgery, Miami Cancer Institute, Miami, FL, USA; [5]Department of General Surgery, Tan Tock Seng Hospital, Singapore, Singapore; [6]Lee Kong Chian School of Medicine, Nanyang Technological University, Singapore, Singapore; [7]Department of Surgery, General Hospital Dr. Balmis, Alicante, Spain; [8]Department of Radiation Oncology, Zhejiang Cancer Hospital, Hangzhou, China; [9]Key Laboratory of Radiation Oncology of Zhejiang Province, Hangzhou, China

Contributions: (I) Conception and design: Y Zhang; (II) Administrative support: J Fang, J Shen; (III) Provision of study materials or patients: J Shen; (IV) Collection and assembly of data: F Chen; (V) Data analysis and interpretation: J Cao, D Xiao; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

[#]These authors contributed equally to this work as co-first authors.

*These authors contributed equally to this work.

Correspondence to: Jiliang Shen, PhD. Department of General surgery, Sir Run Run Shaw Hospital, Zhejiang University School of Medicine, 3 Eastern Qingchun Road, Hangzhou 310000, China. Email: 3416233@zju.edu.cn; Jun Fang, MS. Department of Radiation Oncology, Zhejiang Cancer Hospital, 1 Eastern Banshan Road, Hangzhou 310000, China; Key Laboratory of Radiation Oncology of Zhejiang Province, Hangzhou 310000, China. Email: fangjun@zju.edu.cn.

Background: Changes in pancreas volume have been reported in many disorders. In clinical practice, pre-disease total pancreas volume (TPV) is often unavailable for patients with pancreatic pathologies (e.g., tumors, cysts, or pancreatitis), as prior imaging may not exist or may reflect abnormal volumes. While three-dimensional (3D) computed tomography (CT) reconstruction provides accurate TPV measurements, its utility is limited in these scenarios, necessitating a predictive formula. However, no widely clinically accepted standard pancreas volume (SPV) formula currently exists. This study aims to develop an SPV prediction formula based on 3D CT reconstruction and the characteristics of Chinese adults.

Methods: The TPV of 377 Chinese adults were obtained via CT 3D reconstruction estimation, 287 of whom were used to construct the formula and 90 of whom were used to validate the formula. The associations of age, gender, weight, height, body mass index (BMI), and body surface area (BSA) with TPV were assessed using Pearson correlation analysis. Stepwise multiple linear regression analysis was used to identify the independent correlation factors that could predict TPV.

Results: Age, gender, weight, height, BMI, and BSA significantly correlated with TPV. In addition, stepwise multiple linear regression showed that BSA was the only independent correlation factor for TPV. Therefore, BSA was used as the factor in the following formula for calculating SPV: SPV (cm^3) = 52.40 × BSA (m^2) – 21.33 (R^2=0.384).

Conclusions: We created a BSA-based formula to predict SPV in Chinese adults. It can be used to evaluate pancreas volume changes in patients with diabetes or other pancreatic diseases.

Keywords: Standard pancreas volume (SPV); total pancreas volume (TPV); Chinese adults; three-dimensional computed tomography reconstruction (3D CT reconstruction); body surface area-based formula (BSA-based formula)

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Introduction

The pancreas plays an important role in metabolism and is associated with the pathogenesis of various diseases, such as diabetes (1), pancreatitis (2), pancreatic neoplasia (3), and pancreatic cyst (4). Changes in pancreas size have been reported in many disorders (5-7). Pancreas volume, which is a quantitative measure of pancreas size, may be affected by various disease states. Previous studies have reported that the pancreas volume of patients with diabetes is reduced compared with that in healthy people (5,8-11); moreover, pancreas volume was also found to be atrophied in patients with chronic pancreatitis due to progressive inflammation resulting in irreversible damage to pancreatic tissue and subsequent atrophy (12). However, these studies only compared the pancreas volume of patients with existing pancreatic disease with that of healthy individuals. There is a lack of direct comparison in pancreas volume before and after the onset of disease in the same individual.

We recently endeavored to conduct two researches related to pancreas volume; one research was in patients with severe acute pancreatitis (SAP), while the other was on patients who received distal pancreatectomy. However, both researches were limited as there was no data on TPV before disease onset.

One of the research examined the correlation between the ratio of residual pancreas volume (RPV) to total pancreas volume (TPV) and the overall prognosis and the occurrence of diabetes in patients after recovery from SAP (*Figure 1A*). We could calculate patients' RPV based on a computed tomography (CT) scan after recovery from SAP via three-dimensional (3D) reconstruction, but in most cases, we could not determine their TPVs, as many patients had not undergone CT or magnetic resonance imaging (MRI) examinations before the onset of the disease. The pancreas may become edematous, exudative, or necrotic at the time that SAP is diagnosed. At this point, the volume of the pancreas appearing on CT is no longer normal. The purpose of our second research was to analyze the ratio of RPV to TPV in patients who received distal pancreatectomy (*Figure 1B*). Most of these patients had undergone both preoperative and postoperative pancreatic CT or MRI. However, the patients who required pancreatectomy often had pancreatic-related diseases, such as pancreatic tumors or pancreatic cystic diseases, which according to a previous study (13), could affect pancreas volume. Therefore, the TPV calculated based on their preoperative CT or MRI could not adequately represent the individual's pancreas volume, thus necessitating correction of the corresponding changes. The optimal means to solving the problem that arose in these two researches is to establish a standard pancreas volume (SPV) formula to predict the TPV.

The use of image-guided measurement of organ volume has been applied in hepatopancreatobiliary surgery, especially in liver surgery, with vast amount of literature on standard liver volume (SLV) (14,15), and its clinical utility in predicting post-hepatectomy liver failure. However, to our knowledge, there is limited literature on the use of SPV to predict TPV. Considering the above issues, we believe that accurate estimation of TPV holds considerable value for pancreatic-related studies. In cases where TPV is not available or TPV needs to be corrected, an SPV is needed as a reference. However, no widely accepted clinical SPV formula currently exists. With the development of 3D computer algorithms in the late 1970s, it became possible to rapidly acquire volumetric data using 3D CT reconstruction without the degradation caused by respiration or physiological movements (16). The development of spiral CT, improvement of imaging technology, and the application of 3D reconstruction software have enabled 3D CT reconstruction to mature as a method for measuring pancreas volume.

Considering the limitations of the imaging technology, we believe it is necessary to devise a new formula based on the current high-definition CT imaging and improved 3D reconstruction technology. This study aims to use various

Highlight box

Key findings

- A new formula for predicting standard pancreas volume (SPV) in Chinese adults was devised.

What is known and what is new?

- The total pancreas volume of Chinese adults can be obtained by three-dimensional computed tomography reconstruction estimation and basic information such as age, gender, weight, height, body mass index, and body surface area (BSA). However, there is no formula accounting for the association between SPV and these demographic data.
- We devised the following BSA-based formula to predict SPV in Chinese adults: SPV (cm^3) = 52.40 × BSA (m^2) − 21.33 (R^2=0.384).

What is the implication, and what should change now?

- This simple formula may be used in clinic to quickly evaluate changes in pancreas volume in patients with diabetes or pancreatic disease. It may also be used in preoperative planning for pancreatic surgery in the future.

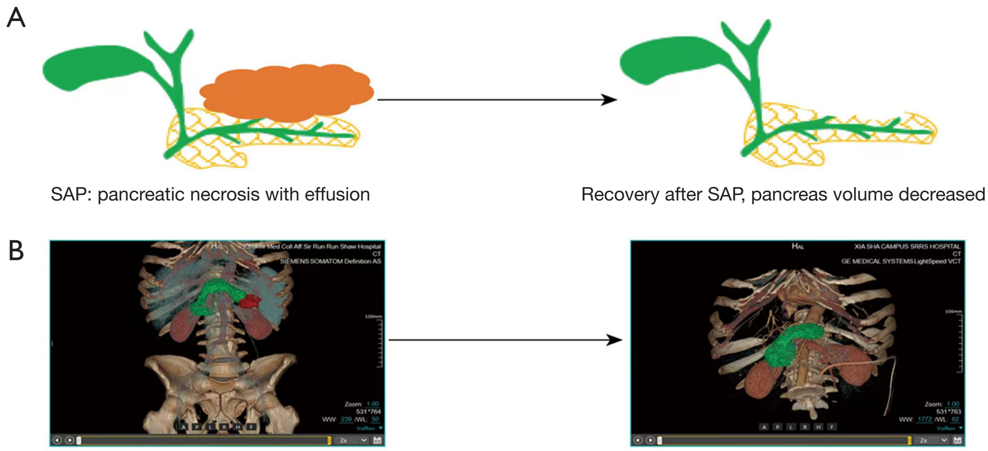

Figure 1 Pancreas volume changes in pancreatic disease. (A) Preoperative and postoperative pancreas volume changes in SAP. (B) Preoperative and postoperative pancreas volume changes in distal pancreatectomy. SAP, severe acute pancreatitis; TPV, total pancreas volume; RPV, residual pancreas volume.

patient individual characteristics [age, gender, weight, height, body mass index (BMI), and body surface area (BSA)] to develop a formula to predict SPV, which may be of clinical use in the future. We present this article in accordance with the TRIPOD reporting checklist (available at https://gs.amegroups.com/article/view/10.21037/gs-2024-550/rc).

Methods

Data source

This was a retrospective study on 1,500 patients who underwent abdominal CT in Sir Run Run Shaw Hospital, Zhejiang University from January 2020 to November 2021.The inclusion criterion was age >18 years old, and there were no restrictions in terms of gender. The exclusion criteria were as follows: (I) missing data for age, gender, weight, or height; (II) patients with diabetes; (III) disease that could influence TPV (pancreatitis, pancreatic cysts, etc.); (IV) confirmed or highly suspected primary or secondary tumors; and (V) connective tissue diseases, hematological diseases, inflammatory bowel disease, or serious infectious diseases. Remaining 377 individuals according to the inclusion and exclusion criteria were included to build and verify the SPV formula. Subjects were randomly split into training (n=287) and validation (n=90) cohorts. This retrospective cohort study utilized convenience sampling, with sample size informed by similar organ volume prediction studies. Training and validation cohorts were randomly stratified by age and gender to ensure representativeness. Validation accuracy thresholds (±10%, ±15%) between SPV and TPV were based on prior liver volume studies by Feng *et al.* (17).

The formula for calculating BMI was follows: BMI = body weight (kg)/body height (m)^2. The formula for calculating BSA was follows: $BSA = \sqrt{\text{body weight (kg)} \times \text{body height (cm)}/3600}$ (18).

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was reviewed and approved by the Institutional Review Board (IRB) of Sir Run Run Shaw Hospital, Zhejiang University (No. 2022-404-01), and the requirement for individual consent was waived due to the retrospective nature of the analysis. This study was registered in the Chinese Clinical Trial Registry (ChiCTR2200060465).

Assessment of TPV with CT

Multislice spiral CT scanners with a collimated reconstruction thickness of 1.25 or 2 mm to perform the CT imaging (GE LightSpeed VCT, Fairfield, USA). The border of the pancreas on each CT frame was defined by two senior doctors after discussion. 3D reconstruction of the pancreas was performed using a reconstruction software (United Imaging, Shanghai, China). The evaluated

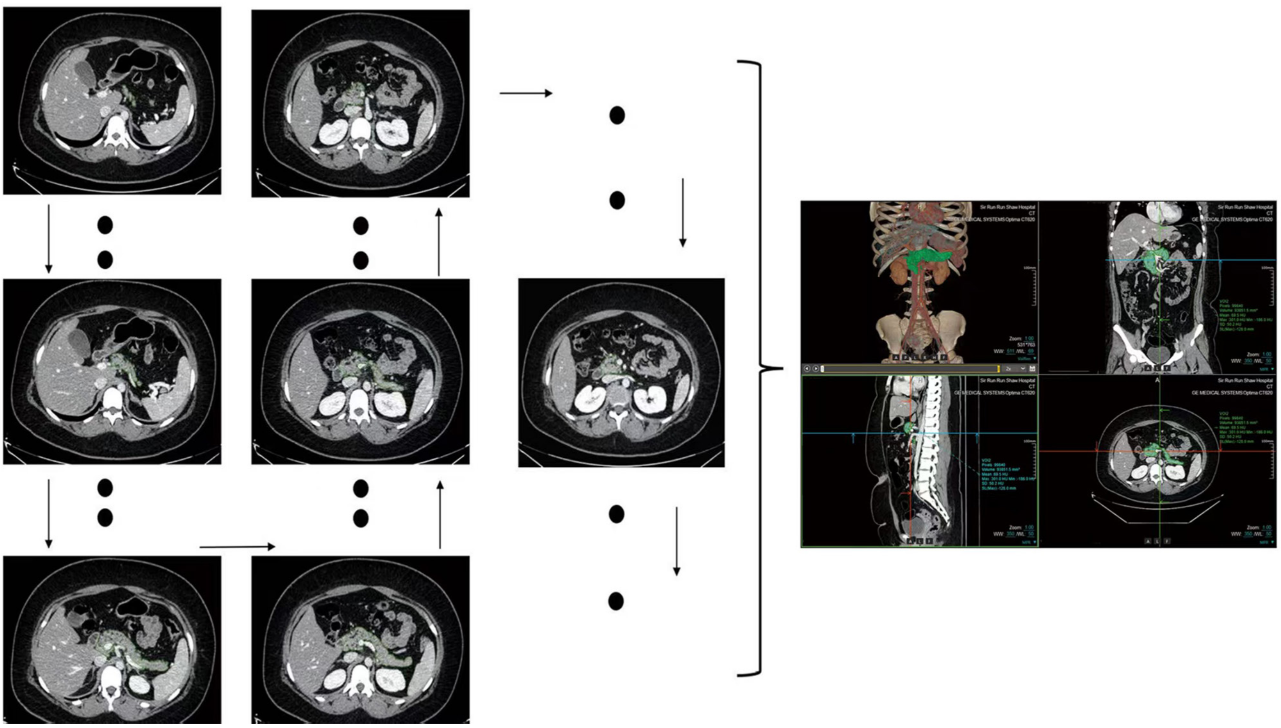

Figure 2 Pancreatic borders on each computed tomography frame and three-dimensional reconstruction-estimated pancreas volume (green).

morphological index was the 3D CT reconstruction-estimated TPV (*Figure 2*).

Statistical analysis

Analytical tests were performed using SPSS 16 (IBM Corp., Armonk, NY, USA). Continuous data were expressed as the mean ± standard deviation (SD). The correlations between TPV and age, sex (female =0, male =1), weight, height, BMI, and BSA were analyzed via Pearson correlation analysis. Stepwise multiple linear regression analysis was used to identify the independent correlation factors and develop an equation to predict TPV. Thus, we derived a new formula for predicting SPV. Next, we compared the SPV to the TPV, and the following formula was used to calculate the percentage error: percentage error = (SPV − TPV)/TPV × 100. Acceptable percentage errors range for estimating the difference between SPV and TPV were ±10% and ±15%, referred to the evaluation criteria for new formulas for SLV previously established by Feng *et al.* (17). All statistical analyses were two-tailed, and $P<0.05$ was considered to indicate statistical significance.

Results

Characteristics and TPV distribution

The training cohort included 287 participants (175 men and 112 women) to develop the SPV formula. The age of the population we studied was distributed between 19 and 84 years. The mean age was 53.78±13.82 years old, with no differences between men and women (men 52.69±13.49 years, women 55.49±14.21 years; P=0.09) (*Table 1*). The difference in mean BMI between the gender was also not significantly different (men 24.51±3.16, women 24.74±5.24; P=0.68) (*Table 1*). The overall TPV ranged from 32.0 to 120.5 cm^3, and the mean TPV was 70.81±16.76 cm^3 [95% confidence interval (CI): 68.86–72.75]. Men had a larger TPV compared to women (men 74.00±16.68 cm^3, women 65.82±15.70 cm^3; P<0.001) (*Table 1*). The range for TPV in most individuals was 50–89.9 cm^3 (50–59.9 cm^3: n=48; 60–69.9 cm^3: n=66; 70–79.9 cm^3: n=64; 80–89.9 cm^3: n=46) (*Figure 3*).

Factors related to TPV

Pearson correlation analysis showed that all factors

Table 1 Physical characteristics and 3D CT-reconstructed TPV

Characteristics	Total (n=287)	Male (n=175)	Female (n=112)	P value
Age (years)	53.78±13.82	52.69±13.49	55.49±14.21	0.09
Height (cm)	165.61±8.01	170.17±5.75	158.49±5.44	<0.001
Weight (kg)	67.71±13.46	71.14±11.08	62.35±15.05	<0.001
BMI (kg/m^2)	24.60±4.10	24.51±3.16	24.74±5.24	0.68
BSA (m^2)	1.76±0.20	1.83±0.16	1.64±0.20	<0.001
TPV (cm^3)	70.81±16.76	74.00±16.68	65.82±15.70	<0.001

Data are presented as mean ± standard deviation. 3D CT, three-dimensional computed tomography; TPV, total pancreas volume; BMI, body mass index; BSA, body surface area.

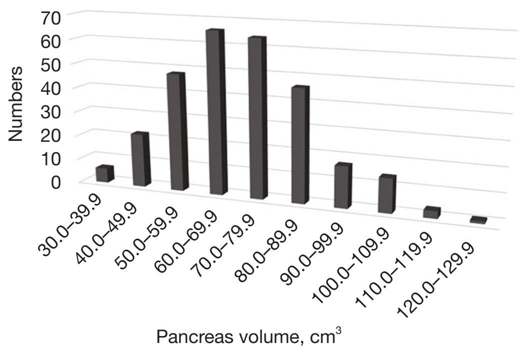

Figure 3 Distribution of pancreas volumes in 287 adults.

Table 2 Factors correlated with 3D CT-reconstructed TPV

Factors	r value	P value
Age	–0.285	<0.001
Gender	0.239	<0.001
Height	0.421	<0.001
Weight	0.606	<0.001
BMI	0.477	<0.001
BSA	0.619	<0.001

3D CT, three-dimensional computed tomography; TPV, total pancreas volume; BMI, body mass index; BSA, body surface area.

including age, gender, height, weight, BMI, and BSA were statistically significantly associated with TPV. Among them, age was negatively correlated with TPV (r=–0.285) (*Table 2*), while other factors including gender, height, weight, BMI, and BSA were positively correlated with TPV (r=0.239, r=0.421, r=0.606, r=0.477, r=0.619, respectively) (*Table 2*). Of these factors, BSA had the strongest correlation (r=0.619; P<0.001). Subsequently, stepwise multiple linear regression analysis suggested that BSA was the only independent correlation for TPV. Therefore, BSA was used to create the SPV formula for predicting TPV as follows: SPV (cm^3) = 52.40 × BSA (m^2) – 21.33 (R^2=0.384). The scatter plot for the correlation between CT-estimated TPV and BSA in 287 adults is shown in *Figure 4*.

Difference between TPV and SPV

Another 90 adults were used to validate the formula. In the validation cohort, 41% and 53% of SPV estimates fell within ±10% and ±15% of TPV, respectively.

Discussion

The assessment of pancreas volume may be helpful in patients undergoing pancreas-related surgery. However, there is no general formula for SPV. We searched for articles related to formula for pancreas volume calculation on PubMed, and only one study, conducted by Japanese researchers in 2014, provided a formula, which was based on BMI of pancreas volume (19). However, this study did not analyze the possible correlation between pancreas volume and other individual characteristics except for BMI. Considering the differences between populations, we aimed to develop an SPV prediction formula for Chinese adults based on the 3D CT reconstruction pancreas volume of Chinese adults. Recent advancements in 3D CT reconstruction, as demonstrated in skeletal and calcaneal imaging (20,21), underscore its reliability for volumetric assessments.

Existing literature showed that various body indices are

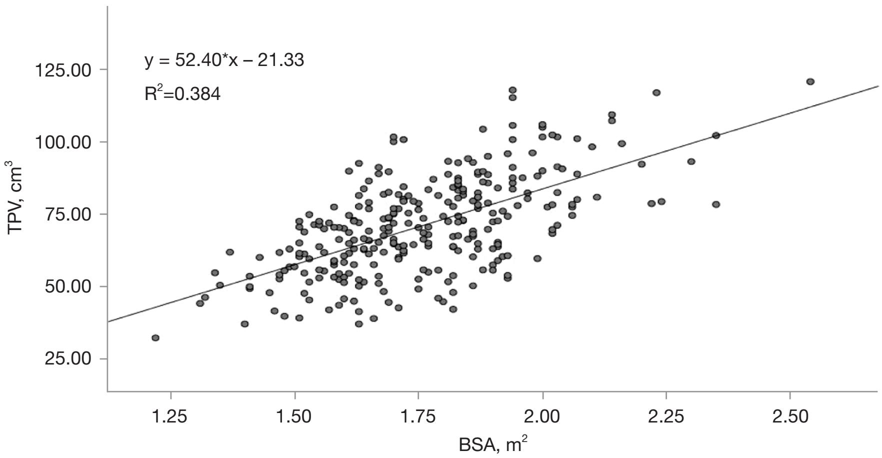

Figure 4 Correlation between computed tomography-estimated total pancreas volume and body surface area in 287 adults. BSA, body surface area; TPV, total pancreas volume.

correlated with pancreas volume, including age (22,23), gender (24), height (25), weight (25), BMI (25), and BSA (26). In our study, Pearson correlation analysis and stepwise multiple linear regression analysis identified BSA as the only independently correlated indicator which correlated with TPV. Therefore, BSA was selected to develop the formula for SPV, which provided further support for the link between BSA and SPV.

Age is an important consideration in the assessment of SPV. It has been reported that pancreas volume reaches a plateau from age 20 to 60 years and then declines thereafter (11). This has been postulated to be due to fibrosis and lipomatosis which occurs with ageing, resulting in fatty degeneration and pancreatic parenchymal atrophy (27). The age of the population we studied was distributed between 19 to 84 years, and age was negatively correlated with TPV (r=−0.285) in the Pearson correlation analysis, suggesting that pancreas volume may decrease with increasing age. However, the association of age with pancreas volume was weak, and age was excluded from stepwise multiple linear regression analysis.

Gender is a big determinant of body size parameters such as height, weight and fat composition; these differences in body constitution due to sex in turn affects TPV. Gender is another important factor which indirectly affects pancreas volume (24), and in our statistical analysis, men had a greater TPV than did women (P<0.001). Also, men had greater height, weight, and BSA values as compared to women, which may be due to the difference in body size between the gender (P<0.001) (*Table 1*). However, our stepwise multiple linear regression analysis showed that gender was not an independent predictor of TPV. These conflicting results may be attributable to the effect of gender on TPV being included in BSA. Thus, we further compared the values of TPV/BSA between men and women and found there to be no significant difference [men 40.29±7.56 (cm^3/m^2), women 39.82±7.61 (cm^3/m^2); P=0.61].

In addition, we found a correlation of TPV with both height and weight (r=0.421 and r=0.61, respectively). This similarly supports what has been demonstrated in existing literature, that body position is a determinant of TPV (25). With the increase of height or weight, there was a gradual increase in TPV. However, stepwise multiple linear regression analyses showed that height and weight were also not independent predictors of TPV. However, our study showed that BSA (which was calculated from both height and weight) had an excellent correlation with TPV, and thus volume may be not exactly predicted by weight or height alone but the combined effect of both. Interestingly, BMI, which similarly uses height and weight in its calculation, was not an independent predictor of TPV in our study. This is in contrary to the study by a Japanese group by Kou *et al.*, which developed a BMI-based pancreas volume formula using their CT-derived pancreas volume assessment (11), where pancreas volume = 23.8 + 2.48 × BMI (19). With advancements in CT imaging, we devised a new calculation formula evaluation via multiple linear regression analysis, and BMI was excluded from our new SPV formula. Another possible reason why BSA instead of BMI was statistically significant in our study may be because BSA has also been shown to be more accurate in physiological assessments and a better estimate of metabolic mass compared to BMI (28).

We referred to the evaluation criteria for new formulas for SLV previously established by Feng *et al.* with the percentage errors within ±10% and ±15% (17). In their formula, the percentage of estimated SLV error with comparison to total liver volume (TLV) within ±10% and ±15% was 44.0% and 60.8%, respectively. Their new formula predicted SLV more accurately than did any other previously reported formulas in Chinese adults. Meanwhile, the percentage errors within ±10% and ±15% between SPV calculated by our formula and TPV were 41% and 53%, respectively. Therefore, our formula for evaluating SPV appears to be relatively accurate. While the R^2 (0.384) reflects moderate explanatory power, biological variability in pancreas volume and unaccounted factors (e.g., genetics, lifestyle) likely contribute. Despite this, our formula provides a pragmatic tool for clinical scenarios where pre-disease TPV is unavailable. Comparable studies in liver volumetry report similar R^2 values (0.3–0.5), yet their formulas remain clinically useful.

The SPV formula based on BSA is a simple and convenient formula with considerable application value. First, in patients with diabetes or pancreatitis, calculation of the SPV of and comparison with actual pancreas volume may be used to assess the severity of the disease. Next, the evaluation of the RPV:SPV ratio, instead of the RPV:TPV ratio, in patients who have no preoperative TPV or preoperative TPV needs to be adjusted due in cased of pancreatic tumors or cysts. In addition, SPV may have certain reference value for the optimal size of pancreatectomy in patients with pancreatic cancer. In total, clinically, SPV estimation is critical for preoperative planning in pancreatic surgery and assessing volume loss in diseases like diabetes. BSA is prioritized due to its strong correlation with TPV (r=0.619) and practicality as a single variable.

There are certain limitations to this study which should be noted. First, given the possibility of ethnic differences, the data on adult Chinese patients examined in this study may not be applicable to other ethnic groups. Moreover, without analyses of the differences in TPV across ethnic groups, the accuracy of our formula in ethnic minorities is unclear. Second, the accuracy of the obtained SPV formula may have certain limitations given the limited sample size. Third, other factors that contribute to a difference between TPV and SPV might not have been included, and this may limit the applicability of our formula. Limitations include ethnic specificity to Chinese adults and unmeasured confounders. Future studies should incorporate larger, diverse cohorts and explore additional predictors (e.g., genetic, metabolic factors).

Conclusions

This preliminary BSA-based formula offers a practical method for SPV estimation in Chinese adults, particularly when pre-disease TPV is inaccessible. Further multi-ethnic studies are warranted to enhance generalizability.

Acknowledgments

None.

Footnote

Reporting Checklist: The authors have completed the TRIPOD reporting checklist. Available at https://gs.amegroups.com/article/view/10.21037/gs-2024-550/rc

Data Sharing Statement: Available at https://gs.amegroups.com/article/view/10.21037/gs-2024-550/dss

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://gs.amegroups.com/article/view/10.21037/gs-2024-550/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was reviewed and approved by the Institutional Review Board (IRB) of Sir Run Run Shaw Hospital, Zhejiang University (No. 2022-404-01), and the requirement for individual consent was waived due to the retrospective nature of the analysis.

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