Evaluation of Standard Liver Volume in Adult Thai Population Using CT Volumetric Measurement

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Objective: *1) to assess the various existing formulas and the simple, diameter-base equation for calculation of standard liver volume (SLV) in a Thai population, using CT volumetric measurement (CTV) as gold standard. 2) to develop a new formula for calculation of SLV in a Thai population.*
Material and Method: *Liver volume of 117 patients who underwent abdominal MDCT for various indications was measured, using CTV. Correlation between CTV and calculated liver volume, acquired from the simple, diameter-base equation and six previously reported formulas, were analyzed. The new formula correlating body weight (BW) or body surface area (BSA) to the measured liver volume from CTV were established using regression analysis.*
Results: *All existing formulas offer fair to moderate agreement with the measured liver volume from CTV with intra-class correlation (ICC) ranging from 0.280 to 0.576. BW was found to correlate with the measured liver volume from CTV more closely than BSA, then the new formula based on BW was constructed; 21.127 x BW (kg). However, our new formula still has only moderate agreement with measured liver volume from CTV (ICC = 0.598). Liver volume calculated from simple, diameter-base equation offer very strong agreement with the measured liver volume from CTV (ICC = 0.829).*
Conclusion: *All formulas based on BW and BSA offer only fair to moderate agreement with measured liver volume CTV, which can lead to high degree error in liver volume estimation. The present study supports that liver volume can be more accurately estimated on CT scan using simple, diameter-based equation. This simple, reproducible method can be used as a good alternative for liver volume calculation. It is particularly useful in case where there is no Digital Imaging and Communications in Medicine (DICOM) data or dedicated 3D software with volumetric measurement application available.*

Keywords: *Standard liver volume, CT volumetry, CT volumetric measurement*

J Med Assoc Thai 2013; 96 (2): 217-24
Full text. e-Journal: *http://jmat.mat.or.th*

It has been shown that an increasing number of patients with end stage liver disease and hepatic malignancy can be cured with liver transplantation or hepatic resection. In major hepatic resection, most surgeons believe that at least 25 to 35% of the liver must be left in place to ensure that patients have sufficient hepatic tissue to meet the metabolic demand. The standard liver volume (SLV) and the remaining hepatic volume should be preoperatively measured to prevent postoperative liver failure[1].

In a living donor and split-liver transplantation, accurate estimation of SLV of living donor and recipient is crucial[2]. Overestimation of the donor's SLV may result in excessive hepatic resection leading to liver failure, while underestimation of the recipient's SLV may result in small-for-size graft syndrome[3].

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Various different methods for liver volume assessment have been described in literatures. Many investigators had studied and confirmed the accuracy of volume measurement using CTV[4-6]. Recently, CTV has been increasingly used and became a standard method for liver volume assessment. However, CTV is a relatively time-consuming process and needs trained users as well as specialized computer software. Thus, it is more desirable to have a simple method for rapid calculation of liver volume for therapeutic monitoring in the follow-up examination.

In 2009, Muggli D et al[7] described a method that can accurately estimate total liver volume on cross-sectional images, using a simple, diameter-base equation. The fundamental of this method based on basic volumetric calculation as the shape of the liver is comparable to tetrahedron. Their proposed equation for estimation of liver volume is Liver volume = craniocaudal diameter (cc) x ventrodorsal diameter (vd) x coronal diameter (cor) x 0.31.

Other than the direct measurement from CT data, many different formulas for predicting of SLV based on BW or BSA have been reported in literatures from various countries[1,8-12]. In Thailand, Hatthapornsawan[1] had developed a formula to predict liver volume based on BW in a Thai population. Their suggested formula is total liver volume (TLV) = 19.59 x BW.

The purposes of the present study were to assess the various existing formulas and the simple, diameter-base equation for calculation of standard liver volume (SLV) in Thai population, using CTV as a gold standard and to develop a new formula for calculation of SLV in Thai population.

Material and Method

This retrospective study was conducted with approval from the authors' institutional review board.

Patient selection

The authors retrospectively selected Thai adult patients (age $\geq$18 years) who underwent thin-sliced contrast-enhanced abdominal MDCT in Siriraj Hospital between March 2008 and November 2011.

The patients who met the following criteria were included in the present study; 1) those who had no history of liver disease, 2) normal liver function test (including AST, ALT, TB, PT, ALP, and ALB), 3) not detectable any gross liver lesion in contrast enhanced abdominal MDCT scan.

The patients with these following criteria were excluded from the present study; 1) history of liver disease or underwent previous liver surgery, 2) the patients whose medical records (sex, age, BW (kg), and height (cm)), and liver function test cannot be collected, 3) not available MDCT data for review on our picture archiving and communication system (PACS), 4) the patients who have any liver lesion on CT images, 5) the patients that have free fluid or considerable motion artifact on CT images.

Patient sex, age (years), body weight (kg), and height (cm) were recorded. Body surface area (BSA) was calculated using Mosteller's formula[13] as followed: BSA (m^2) = square root ([Ht (cm) x BW (kg)]/3,600).

Imaging acquisition

All MDCT examinations were performed with one of the following MDCT scanners, a Lightspeed VCT (GE Healthcare) or a Somatom (Siemens). Each patient received 100 ml of nonionic intravenous contrast material at a rate of 3 to 5 ml/s using an automatic power injector. Portovenous phase (80 seconds after contrast injection) MDCT images were obtained during full inspiration. Image reconstructions were performed with 1.2 to 1.5 mm slice thickness.

Liver volume measurement

CTV were acquired by one radiologist, who manually outlined the liver in each CT axial image excluding inferior vena cava, extraparenchymal portal veins, and gallbladder. Then, the volumetric measurement was automatic interpolated by the commercial computer software (Advantage Workstation version 4.2_07, GE Healthcare) (Fig. 1). CTV were used as the gold standard in the present study.

The greatest craniocaudal diameter (cc), ventrodorsal (vd) and coronal diameter (cor) were measured on coronal and axial CT images, using an electronic caliper (Fig. 2). The authors then applied the simple, diameter-based equation which previously described by Muggli D et al[7] to estimate liver volume;

LV (cm^3) = cc (cm) x vd (cm) x cor (cm) x 0.31

The estimated liver volume based on BSA or BW was also calculated, using six formulas as shown in Table 1.

Statistical analysis

Descriptive statistics were used to summarize the data. Agreement in measured liver volume from CTV and calculated liver volume from other methods including simple, diameter-base equation and the six previous reported formulas were analyzed using intraclass correlation coefficient (ICC). The ICC of 0 to 0.2, 0.3 to 0.4, 0.5 to 0.6, 0.7 to 0.8, and >0.8

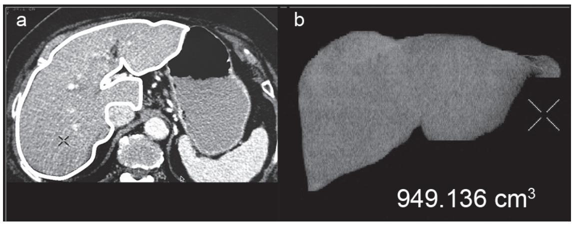

Fig. 1 Shows liver volume measurement using CTV. (a) Liver surface was manually outlined on axial CT images (white line), excluding IVC, extraparenchymal portal veins and gallbladder. (b) Volume rendering image of liver with the measured liver volume which was automatic interpolated by the dedicated computer software (white numbers) were shown.

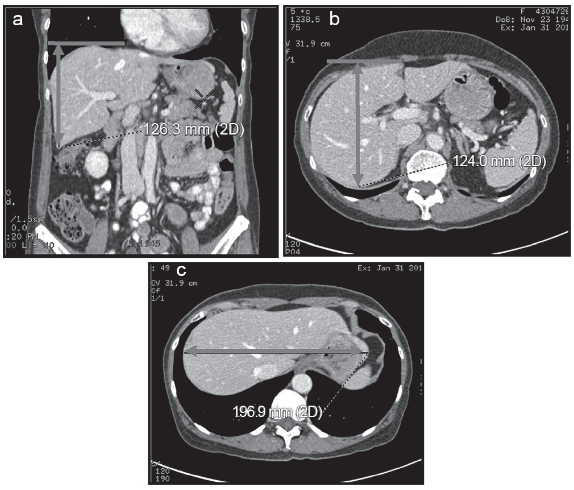

Fig. 2 Shows liver diameter measurements using in simple, diameter-based equation method greatest craniocaudal diameter (a) were measured on coronal image. The greatest ventrodorsal (b), and greatest coronal diameters (c) were measured on axial images.

were considered as poor, fair, moderate, strong, and very strong agreement respectively.

Pearson's correlation was applied to assess the correlation between measured liver volume from CTV and BW (kg), BSA (m^2). The linear regression analysis of measured liver volume from CTV on BW (kg) was also performed to develop liver volume formula.

Statistical analysis was performed with a statistical software package (SPSS version 19).

Results

There were 117 patients included in the present study [48 males (41%) and 69 females (59%); mean age (±SD) = 60.9±12.7 years; range 18-87 years]. The patient's height ranged from 140 to 180 cm, mean height (±SD) = 159.9±8.6 cm. The patient's BW ranged from 39 to 102 kg with a mean BW (±SD) = 59.8±11.4 kg. The BSA ranged from 1.26 to 2.14 m^2 with a mean BSA (±SD) = 1.62±0.18 m^2.

The measured liver volume using CTV ranged from 729.6 to 2,034.1 cm^3 with a mean = 1,275.6±294.0 cm^3. The mean measured liver volume was higher in male (1,339.3±303.0 cm^3) than in females (1,231.3±281.3 cm^3).

The mean (±SD) and range of measured liver volume obtained by CTV, calculated liver volume from simple, diameter-based equation and six previous described formulas are summarized in Table 2. The difference between measured liver volume from CTV and calculated liver volume from simple, based equation and six formulas are shown in Table 3 and Fig. 3.

Agreement in measured liver volume acquired from CTV and calculated liver volume from simple, based equation and six previously described formulas are displayed in Fig. 4. Intraclass correlation coefficient (ICC) between CTV and simple, diameter-based equation was highest (ICC = 0.829), representing very strong agreement, whereas the ICC between CTV and six previously described formulas ranged from 0.375-0.576, representing fair to moderate agreement.

The measured liver volume from CTV was moderately correlated with BW (r = 0.609, $p<0.001$) and BSA (r = 0.590, $p<0.001$). Simple linear regression analyses of measured liver volume from CTV on BW revealed the following results:

SLV (cm^3) = 332.42+15.76 x BW (kg)
($R^2 = 0.371$; $p<0.001$)
SLV (cm^3) = 21.13 x BW (kg)
($R^2 = 0.966$; $p<0.001$)

Table 1. Six previously described formulas for calculation of standard liver volume, based on BSA or BW

Author, year of publication	Formulas	Gold standard	Race, number of patient
Urata et al.[8], 1995	SLV (cm^3) = 706.2 x BSA (m^2)+2.4	CTV	Japanese, 96
Vauthey et al.[10], 2002	SLV (cm^3) = 18.51 x BW (kg) + 191.8	CTV	Western, 292
Heinemann et al.[9], 1999	SLV (cm^3) = 1072.8 x BSA (m^2) - 345.7	Autopsy	Caucasian, 1,332
Hatthapornsawan et al.[1], 2004	SLV (cm^3) = 19.59 x BW (kg)	Autopsy	Thai, 20
Chandramohan et al.[11], 2007	SLV (cm^3) = 243 + [186 x BSA (m^2)] + [11.4 x BW (kg)]	CTV	Indian, 238
Li et al.[12], 2009	SLV (cm^3) = 11.508 x BW (kg) + 334.024	LDLT*	Chinese, 115

* Living donor liver transplantation. The weights and volumes of resected right lobe liver grafts not including middle hepatic veins were measured. Then, the actual total liver volume was calculated from the right lobe graft volume divided by the proportion of the right lobe as indicated in the computed tomography.

Table 2. Estimated liver volume (cm^3) by CTV, calculated liver volume using simple diameter base equation and six previously described formulas

Formula	Mean±SD	Min-max
CTV	1,275.6±294.0	729.6-2,034.1
Male (48 patients, 41%)	1,339.3±303.0	828.7-2,034.1
Female (69 patients, 59%)	1,231.3±281.3	729.6-1,978.3
Simple, diameter-based equation[7]	1,372.2±388.2	725.6-2,342.2
Formulas		
Urata et al.: Japanase[8]	1,149.9±127.7	890.6-1,512.2
Vauthey et al.: Western[10]	1,299.4±210.1	913.7-2,083.5
Heinemann et al.: Caucasian[9]	1,397.4±193.9	1,003.5-1,947.8
Hatthapornsawan et al.: Thai[1]	1,172.2±222.4	764.0-2,002.1
Chandramohan et al.: Indian[11]	1,227.3±162.4	921.5-1,805.7
Li et al.: Chinese[12]	1,022.6±130.7	782.8-1,510.1

Table 3. Difference in measured liver volume obtained from CTV and calculated liver volume using simple, diameter-based equation and six previously described formulas

	CTV-formula 1	CTV-formula 2	CTV-formula 3	CTV-formula 4	CTV-formula 5	CTV-formula 6	CTV-simple, diameter-based equation
Mean	125.8	-23.8	-121.8	103.4	48.3	253.0	-96.5
SD	241.8	235.3	238.4	237.3	234.2	238.2	182.2
Median	79.6	-5.6	-124.0	120.4	24.0	215.7	-81.6
Min	-480.2	-793.4	-850.8	-693.4	-616.2	-340.5	-699.3
Max	750.2	622.7	518.4	752.9	682.6	879.6	263.0

The second model had a much higher coefficient of determination ($R^2 = 0.966$).

Agreements in measured liver volume from CTV and those predicted from two linear regression equations showed ICC of 0.543 and 0.598, respectively, which were considered as moderate agreement (Fig. 5).

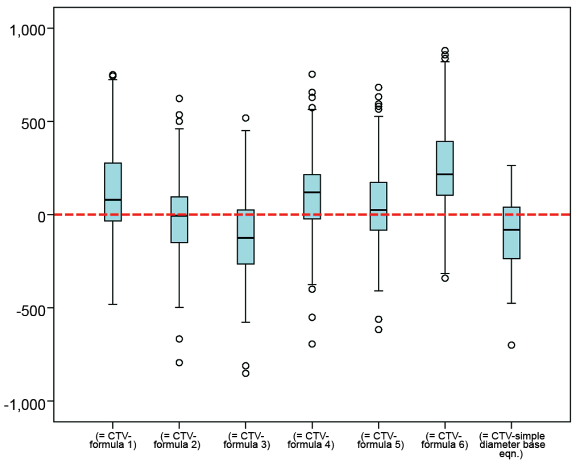

Fig. 3 Box plots show the difference between measured liver volume from CTV and calculated liver volume from simple, based equation and six formulas.

Discussion

Previous studies showed that liver volume correlates with BW, height, BSA, and BMI. Many formulas for liver volume calculation have been developed in many different populations, including Western, Japanese, Chinese, Indian, and Thai[1,8-12]. Most of these existing formulas used body weight or BSA-based equation to calculate individual liver volume.

The authors' results show that calculated liver volume from formula 2 (by Vauthey et al, based on a Western population) and formula 5 (by Chandramohan A et al, based on an Indian population) had the least mean of differences from the measured liver volume by CTV, whereas, formula 1 (by Urata et al, based on a Japanese population), formula 3 (by Heinemann et al, based on Caucasian population), and formula 4 (by Hatthapornsawan et al, based on a Thai population) had equivalent mean of differences from measured liver volume by CTV. The calculated liver volume from formula 6 (by Li FG et al, based on Chinese population)

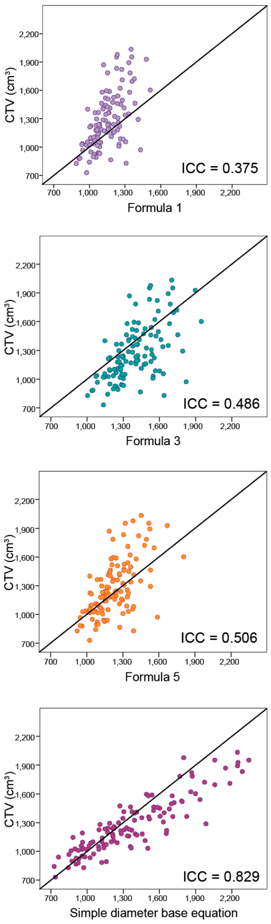

Fig. 4 Agreement in measured liver volume acquired from CTV and calculated liver volume from simple, based equation and six formulas and six formulas (ICC = intraclass correlation coefficient).

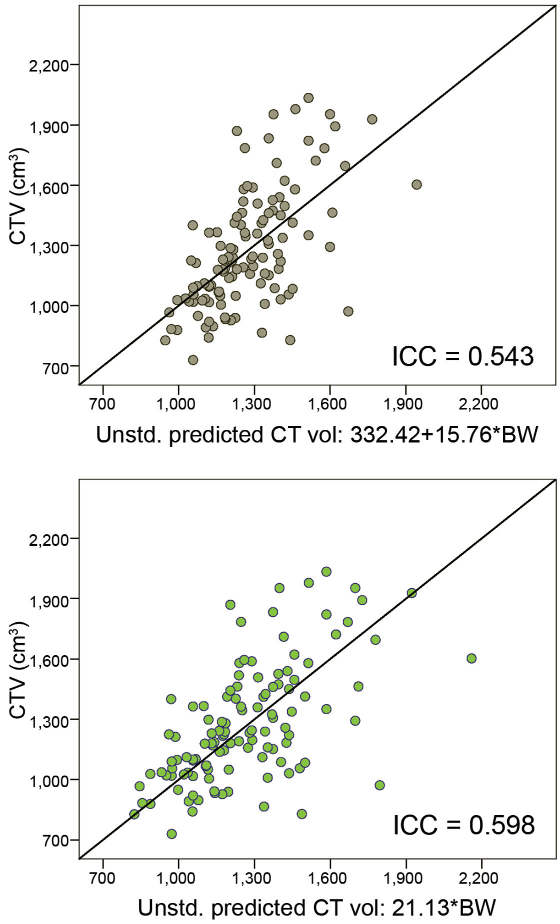

Fig. 5 Agreement between observed volume from CT volumetry (CTV) and predicted volume from 2 linear regression equations (ICC = intraclass correlation coefficient).

had the most mean of differences from the measured liver volume by CTV.

The explanation for the differences between calculated liver volume from the previously described formulas and CTV includes ethnic differences. The authors found that the formulas derived from researches conducted in an Asian population (Japanese, Chinese, Indian, and Thai) tend to underestimate liver volume while those derived from Western countries tends to overestimate liver volume.

Regardless of the ethnic difference, the different gold standard between studies may contribute to the differences between calculated liver volume from the previously described formulas and CTV. Formula 2 and 5 were derived from researches conducted using same gold standard (CTV) to our study so that the calculated liver volumes from these formulas were closest to the measured liver volume from CTV in the present study. On the other hand, formula 6 was derived from research conducted using liver donor liver transplantation as the gold standard. With this method, the weights and volumes of resected right lobe liver grafts were measured. Then, the actual total liver volume was calculated from the right lobe graft volume divided by the proportion of the right lobe as indicated in the computed tomography. The substantial differences between calculated liver volume from Li FG et al formula and CTV in the present study may be attributed to the complex calculation involved in the process.

Moreover, Formula 4 (by Hatthapornsawan et al, developed in a Thai population, using autopsy as the reference standard) show lower estimated liver volume compared to CTV in the present study. This result is not unexpected as it has been known that the estimated liver volume from CTV tends to be overestimate compare to the actual liver volume derived from autopsy with the margin of error of 5 to 25%[14]. Since CTV were done by manually drawing the line along the entire liver surface. The intra-parenchyma vessels, fat, or intersperse ligament could be included into the region of interest, resulting in liver volume overestimation. Another explanation is that the perioperative blood loss and lack of perfusion after liver resection, causing liquid volume loss, and collapse of supporting structures. These reasons result in the reduction of liver volume in autopsy compare to preoperative CTV[14].

Similar to Hatthapornsawan et al, the authors also found that BW was correlated more closely (r = 0.609) with CTV than BSA (r = 0.590). Our proposed formula for calculation of liver volume based on BW is, Liver volume (cm^3) = 21.13 x BW (kg). This formulas had high coefficient of determination (R^2 = 0.966).

Nevertheless, the authors found that the calculated liver volume from all six previously described formulas as well as our newly proposed formulas had only fair to moderate agreement to the measured liver volume from CTV (ICC ranged from 0.375-0.598). In contrast, we found a very strong agreement between estimated liver volume from simple, diameter-based equation and CTV with ICC = 0.829. The present result confirms the feasibility of simple, diameter-based equation with high correlation to the CTV in liver volume estimation. With this method, the measurements of three diameters on cross-sectional images were obtained and the liver volume calculation was based on the patient's actual liver anatomy. Thus, the influence of patient's extreme size such as very tall, very short, or obese patient could be reduced.

The present study has some limitations. First, the present study was conducted using measured liver volume from CTV as the reference standard. Some may argue that CTV may not be a perfect gold standard due to its limitation such as slight volume overestimation. However, it has been proved to provide sufficiently accurate for determination of liver weight and volume[15], yet it is the least invasive tool, and most readily available compared to the other methods with comparable accuracy. It has now been used for liver volume estimation in clinical practice in many institutions. Second, this is the single-center study that may not represent the entire Thai population. However, the authors tried to include equal proportion of male and female patient with a wide range of patient's age, BW and BSA in the study to minimize selection bias.

Conclusion

All formulas based on BW and BSA offer only fair to moderate agreement with measured liver volume CTV, which can lead to high degree error in liver volume calculation. The present study supports that liver volume can be more accurately estimated on CT scan using simple, diameter-based equation. This is a simple, reproducible method that can be a good alternative way for liver volume estimation. This method is particularly useful in case there is no Digital Imaging and Communications in Medicine (DICOM) data or dedicated 3D software with volumetric measurement application available.

Acknowledgement

The authors wish to thank Assistant professor Dr. Chulalak komoltri and Dr. Sasima Tongsai, office for Research and Development, for assistance with statistical analysis. The authors also thank Associated Professor Dr. Orasa chawalparit and Assistant professor Dr. Chantima Rongviriyapanich for very kind advice. This research was funded by the Faculty of Medicine, Siriraj Hospital, Mahidol University.

Potential conflicts of interest

None.

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การประมาณค่าปริมาตรตับมาตรฐานในคนไทยโดยการวัดปริมาตรตับสามมิติด้วยเครื่องคอมพิวเตอร์สแกน

ตรงธรรม ทองดี, ภาษิตา แก้วแหวน, รณิษฐา ทองดี

วัตถุประสงค์: *การศึกษานี้มีวัตถุประสงค์สองข้อ ข้อแรกคือต้องการประเมินการประมาณค่าปริมาตรตับมาตรฐานในคนไทยด้วยวิธีต่าง ๆ เทียบกับการวัดปริมาตรตับสามมิติด้วยเครื่องคอมพิวเตอร์สแกน ข้อที่สองคือต้องการนำเสนอสูตรในการคำนวณหาปริมาตรตับมาตรฐานในคนไทย*

วัสดุและวิธีการ: *โดยการวัดปริมาตรตับโดยการใช้ข้อมูลจากภาพคอมพิวเตอร์สแกนชนิดมัลติดีเทคเตอร์ของผู้ป่วยที่ได้รับการทำคอมพิวเตอร์สแกนของช่องท้องด้วยสาเหตุต่าง ๆ จำนวน 117 ราย โดยผู้ป่วยเหล่านี้ต้องไม่มีรอยโรคในตับ และมีค่าการทำงานของตับปกติ จากนั้นคำนวณหาค่าปริมาตรตับจากสูตรคำนวณต่าง ๆ และวิธีการวัดปริมาตรตับอย่างง่ายจากรูปคอมพิวเตอร์สแกนที่เคยมีการนำเสนอในการศึกษาก่อนหน้า และนำผลมาเปรียบเทียบกับปริมาตรตับที่วัดได้จากการวัดปริมาตรตับสามมิติด้วยคอมพิวเตอร์สแกน นอกจากนั้นยังนำเสนอสูตรคำนวณใหม่จากน้ำหนักตัวหรือพื้นที่ผิวกาย เพื่อหาค่าปริมาตรตับมาตรฐานในคนไทยบนพื้นฐานของข้อมูลที่รวบรวมได้ทั้งหมดโดยใช้ค่าปริมาตรตับสามมิติด้วยคอมพิวเตอร์สแกนเป็นค่ามาตรฐาน*

ผลการศึกษา: *ค่าปริมาตรตับที่คำนวณได้จากสูตรต่าง ๆ ที่ใช้น้ำหนักตัวหรือพื้นที่ผิวกายที่มีผู้เคยนำเสนอในการศึกษาก่อนหน้าทั้งหกสูตร มีความเห็นพ้องค่อนข้างต่ำถึงดีปานกลางต่อปริมาตรตับบที่วัดได้จากคอมพิวเตอร์สแกน และค่าสัมประสิทธิ์สหสัมพันธ์ภายในกลุ่มค่อนข้างต่ำ (ICC = 0.280-0.576) ความแตกต่างดังกล่าวทำให้มีความผิดพลาดในการหาปริมาตรตับโดยใช้สูตรคำนวณดังกล่าวค่อนข้างมาก การศึกษาครั้งนี้พบว่าน้ำหนักตัวมีความสัมพันธ์ต่อปริมาตรตับมากกว่าพื้นที่ผิวกาย จากผลการศึกษาผู้นิพนธ์เสนอสมการใหม่ที่ใช้คำนวณปริมาตรตับในคนไทยจากน้ำหนักตัว ดังนี้คือ 21.127 x น้ำหนักตัว (กิโลกรัม) อย่างไรก็ตามพบว่าสมการดังกล่าวแม้จะให้ค่าปริมาตรตับใกล้เคียงกว่าสูตรเดิม แต่ยังให้ค่าความเห็นพ้องเพียงดีปานกลางต่อปริมาตรตับที่วัดได้จากคอมพิวเตอร์สแกน ผลการศึกษาของครั้งนี้สนับสนุนว่าการวัดปริมาตรตับอย่างง่ายจากรูปคอมพิวเตอร์สแกนให้ค่าความเห็นพ้องดีมากต่อปริมาตรตับสามมิติที่วัดด้วยคอมพิวเตอร์สแกน*

สรุป: *จากการศึกษาพบว่าสูตรต่าง ๆ ที่คำนวณปริมาตรตับโดยการใช้น้ำหนักตัวหรือพื้นที่ผิวกายมีความผิดพลาดได้ค่อนข้างมาก การศึกษาของผู้นิพนธ์สนับสนุนว่าการว่าปริมาตรตับอย่างง่ายจากรูปคอมพิวเตอร์สแกนนั้นเป็นวิธีที่รวดเร็ว, ง่ายต่อการทำซ้ำ และให้ค่าปริมาตรตับที่ค่อนข้างแม่นยำ เมื่อเทียบกับการวัดปริมาตรตับสามมิติด้วยคอมพิวเตอร์สแกน มีประโยชน์อย่างยิ่งสำหรับใช้ในกรณีที่ไม่มีซอฟแวร์ที่ใช้สำหรับวัดภาพสามมิติ หรือ ภาพดิจิตอล*