



Published in final edited form as:

J Diagn Med Sonogr. 2016 ; 32(1): 12–19. doi:10.1177/8756479315621287.

Ultrasound Accuracy of Liver Length Measurement with Cadaveric Specimens

Bárbara L. Riestra-Candelaria, BS¹, Wilma Rodríguez-Mojica, MD, FACR², Luis E. Vázquez-Quiñones, PhD³, and Juan Carlos Jorge, PhD^{1,*}

¹Department of Anatomy and Neurobiology, School of Medicine, University of Puerto Rico

²Director of Ultrasound, Department of Radiological Sciences, School of Medicine, University of Puerto Rico

³School of Sciences and Technology, Universidad Metropolitana- Sistema Ana G. Méndez

Abstract

The liver is one of the principal organs of our body involved in over 500 physiological functions related to metabolism, digestion, immunity, and storage of nutrients, which makes it an essential organ to preserve life. Given that there are a number of approaches to measure liver length through diagnostic 2D sonography, this work aims to determine the most accurate measurement of this organ. Cadaveric specimens ($n = 21$) were employed to assess measurements in midclavicular line (MCL) and midaxillary line (MAL). Each measurement was calculated in anteroposterior (AP) and craniocaudal (CC) planes. In addition, *in situ* measurements were obtained by accessing the organ through the anterior thoracoabdominal wall. Statistical differences were detected between MCL and MAL measurements ($p < 0.05$), a positive correlation between MAL CC and *in situ* anterior measurements were noted ($r = 0.97$). Liver size, as assessed through *in situ* measurements, varied as a function of BMI and waist circumference ($p < 0.05$). It is concluded that CC measurement of the RLL in MAL from the uppermost right hemi-diaphragm to the inferior tip of the right lobe through a horizontal line parallel to the anterior liver wall is the most accurate measurement of the organ by sonography.

Keywords

liver length; liver anatomy; cadaveric specimen; sonography

Introduction

Accurate measurement of the liver by sonography is particularly relevant when hepatic disease is suspected. As a noninvasive and inexpensive method when compared to other methods¹⁻³, diagnostic sonography is particularly useful to evaluate liver size and texture. In recent years, diagnostic sonography has shown specificity and positive predictive value in

*Corresponding author: Juan Carlos Jorge, PhD, Department of Anatomy and Neurobiology, School of Medicine, University of Puerto Rico, PO Box 365067, San Juan, Puerto Rico 00936-5067, 1-787-758-2525, ext. 1506 (Voice), 1-787-767-0788 (Fax), juan.jorge@upr.edu.

assessing the liver and its various diseases.⁴⁻⁶ But according to a number of validated sources, measurement of liver length still varies greatly across modalities and techniques used by the operator.⁷⁻¹² It is clear that liver disease alters its texture, and sometimes, its size as well.¹³ Therefore, it becomes an important issue to use the most accurate measure of liver size in the hope of detecting gradual changes in organ size. In addition, it would be clinically advantageous to establish the range for normal liver sizes according to anthropometry and sex of the patient.

The liver occupies 5% of the mature fetus' body cavity and it constitutes 2.5% of the adult body weight.¹³ Liver weight in the adult male is approximately 1400 – 1500 g² and it serves over 500 physiological functions related to metabolism, digestion, immunity, and storage of nutrients.¹⁴⁻¹⁸ Access for accurate measurements of the liver through imaging techniques is not always possible, which produces a wide range of measurements across techniques. This is partly due to variations in shape and to inherent limitations of imaging techniques to capture the appropriate anatomical boundaries of the organ.¹⁹ Therefore, it is of interest to address this significant issue in the field by contrasting several right liver lobe (RLL) measurements by ultrasonography with anterior *in situ* direct measurements of the organ from cadaveric specimens.

Materials and Methods

Specimens

Cadaveric specimens were obtained from the Pathology Laboratory, Puerto Rico Institute of Forensic Science (IFS-PR) and the Department of Anatomy and Neurobiology, School of Medicine, University of Puerto Rico (UPR). Approval of the study protocol was obtained from the Anatomical Donation Board (ADB), Medical Science Campus, UPR. The specimens were evaluated in June 2013. Liver sonographic measurements were obtained from twenty-seven (27) fresh cadaveric specimens without right upper quadrant trauma. Six cadavers were excluded from the study because *in situ* measurements were not performed. Twenty-one (n = 21) specimens were included in the study. Although an effort was made to include specimens from both sexes, the final sample was constituted by 18 male and 3 female cadaveric specimens. Data on age, sex, weight, and height for each specimen were obtained from the Institute of Forensic Science or Anatomical Donation Board records. Body mass index (BMI) was calculated according to: $BMI = \text{weight (kilograms)} / \text{height (meters)}^2$. BMI values were classified according to: underweight (BMI < 18.5 kg/m²), adequate weight (BMI = 19.0 - 24.9 kg/m²), overweight (BMI = 25 - 29.9 kg/m²), and obesity (BMI ≥ 30 kg/m²)^{20, 21}. Specimens were placed in the supine position for measurement of waist circumference (WC) (in cm, navel level). Given that 18 out of 21 specimens were males, waist circumference was evaluated by using 102 cm as the cut-off reference value for a typical male waist circumference^{20, 21}. Images shown in Figure 1 were taken from 2 volunteers.

Ultrasound Examination and Data Acquisition

Sonograms scans were obtained by using Sonosite M-Turbo Ultrasound Machine with a 2.5 -5.0 MHz curved transducer (DISS-Puerto Rico). All sonographic images were obtained by

one of the authors (BLRC), who has 12 years of experience in sonographic examination and eight years of experience as a sonography professor. In addition, images were independently evaluated and supervised by a second author (WR-M), who is the Director of Ultrasound at SoM-UPR since 1981. Ultrasound images of the liver were obtained with the specimen in a supine position. The right arm of each specimen was placed above the head to access the right upper quadrant. The first measurement was performed in the right midclavicular line. Liver longitudinal diameter was measured craniocaudally from the uppermost right hemidiaphragm to the inferior tip of the right lobe (whenever visible) or to the most inferior boundary of the lobe through a horizontal line parallel to the anterior liver wall (MCL CC). In addition, liver measurements were obtained obliquely for anteroposterior measurements (MCL AP). Each specimen was also placed in a left oblique position (15° - 20°) for right midaxillary line (MAL CC and MAL AP) measurements, where the approach described above was also followed.

After sonographic imaging, the anterior thoracoabdominal wall of each specimen was dissected by incising the wall with three cuts following a “Y” shape from the level of rib 1 to dermatome T 12. The anterior portion of the diaphragm was dissected for better visualization of the liver without reaching the triangular or coronary ligaments. *In situ* measurements of the RLL along the anterior and anterolateral margins were obtained from the top to the bottom edge of the lobe.

Statistical Analysis

Data is expressed as mean \pm standard deviation. The Shapiro-Wilk test for normality was employed to assess data distribution²². Two-tail paired t-tests were used to compare liver measurements. One-Way ANOVA and Tukey post-hoc test were used to assess the effect of anthropometric measures and BMI on liver length. Statistical significance was attained at $p < 0.05$. All statistical analyses were performed using the statistical program R 3.0.2 (Comprehensive R Archive Network, 2013, <http://cran.r-project.org>).

Results

Table 1 shows reported typical values for liver size according to clinical sonography and radiology textbooks. Given this lack of consensus, a study was conducted with twenty-one cadaveric specimens (3 females and 18 males) to measure liver length according to several measures. Individual values for each measurement, averages, and standard deviation values are shown in Table 2. Shapiro-Wilk test revealed that the data was normally distributed (analysis not shown). Specimens were between 18 to 98 years of age at the time of death (55 ± 21 years). The average liver size according to anterior *in situ* measurement was 12.7 ± 1.44 cm ($n = 21$). It was not possible to obtain accurate midclavicular line (MCL) measurements from 6 cadaveric specimens due to poor visualization of the organ. It was possible to obtain accurate measurements from all cadaveric specimens in midaxillary line (MAL).

MCL and MAL measurements

Figure 1 shows the approach taken to obtain 2-dimensional sonography measurements. Panels A and B show the positioning of the transducer for MCL and MAL approaches,

respectively. Panel C shows a diagrammatic representation of the ultrasonography measures that are typically taken to assess liver size as well as those that were investigated in this study. The craniocaudal and oblique measurements of the liver in MAL are shown in Panel D when the inferior tip is not visible. Panels E and F show craniocaudal and oblique measurements of the entire RLL for the same patient in MCL and MAL, respectively.

As expected, craniocaudal versus anteroposterior measurements were statistically different from each other for MCL ($p = 0.004$) and MAL ($p = 5.90 \times 10^{-10}$). In fact, correlation analysis for MCL and MAL revealed low correlation between these measurements (Table 3). The correlation between sonographic measurements for MCL versus *in situ* anterior showed low correlation as well; while the correlation between MAL and *in situ* anterior measurements was higher than the one obtained with MCL (Table 3). The strongest correlation was observed between MAL CC and *in situ* anterior measurements (Figure 2).

Anthropometric measures

The average body mass index (BMI) was $26.2 \pm 5.63 \text{ kg/m}^2$, and the average waist circumference (WC) was $86.5 \pm 24.1 \text{ cm}$ (Table 2). Figure 3A shows anterior *in situ* RLL length as a function of BMI (underweight, adequate weight, overweight, and obesity). Statistical analyses revealed that anterior *in situ* RLL length varies according to BMI ($F(2, 17) = 49.53, p = 8.11324 \times 10^{-08}$). Underweight was not included in the analysis because there was only one case ($n = 1$). Statistical difference was noted between adequate weight specimens and obese specimens ($p = 0.0159$, Tukey Test). Figure 3B shows that waist circumference measured at the navel level (in cm) varies according to BMI ($F(2, 17) = 7.54, p = 0.004$). With regard to waist circumference, statistical differences were noted between adequate weight specimens and obese specimens ($p = 0.005$, Tukey's Test), and between adequate weight and overweight specimens ($p = 0.05$, Tukey's Test). Last, analysis of anterior *in situ* RLL length as a function of waist circumference revealed that RLL length varies as function of waist circumference. Specifically, specimens with waist circumferences above 102 cm had larger RLL length than specimens with less than 102 cm waist circumference ($p = 0.003$, Figure 3C).

Discussion

There is lack of consensus on standard reference values for sonography measurements of the liver¹³⁻¹⁶. For instance, sonographic measurement of this organ is most commonly performed with the patient in the supine position, where RLL length is assessed longitudinally in the midclavicular line. Traditionally, this measurement is considered as being obtained in the craniocaudal plane⁷. But the line drawn for this measurement is oblique, which in many cases overestimates liver length. By using cadaveric specimens, this study demonstrates that the most accurate measurement of RLL length is obtained in the craniocaudal plane along a midaxillary line. When compared to *in situ* assessment of RLL, the concordance of RLL measurement in the craniocaudal plane along a midaxillary line is of 97%. In this study, RLL length was assessed from the uppermost right hemi-diaphragm to the inferior tip of the right lobe (whenever visible), or to the most inferior boundary of the

lobe through a horizontal line parallel to the anterior liver wall as shown in Figure 1, Panels D-F.

Collaboration of the patient is required to access the entire RLL for organ measurement by ultrasonography. For instance, gases in the cavity, the rib cage, variability in organ anatomy such as shape and size, its location in three-dimensional space, the anatomical boundaries of the organ, and breathing of the patient are some of the factors that can hinder a high-quality visualization of the RLL by ultrasonography. By studying the gross anatomy of the liver across cadaveric specimens, it was noted that the right lateral inferior tip of the liver in the sonographic image is the longest portion of the right lobe. This portion is surrounded by the lateral edges of the ribs, which makes it difficult for accurate measurement by sonography. In addition, as this portion of the RLL shows anatomical variations in terms of morphology and length, it should not be taken into account to determine liver length or weight.

Even though assessment of RLL in the craniocaudal plane along a midaxillary line is accurate, it is important to note that such measurement varies as a function of BMI and waist circumference. Specifically, obese specimens and specimens with waist circumference larger than 102 cm at the navel level showed larger RLL values. This suggests that abdominal shape affects liver length. At this time, it is not possible to make a sound statement with regard to RLL size and sex due to our small sample of female cadavers. It is interest for future studies to determine if there are sex differences in liver length. For instance, is it possible that disease processes affect liver size in a sex-specific manner?

It is of utmost clinical relevance to be able to detect early gradual change in hepatic size before the patient develops hepatomegaly by using the least expensive imaging technique. It is proposed that RLL with ultrasonography should be taken in the craniocaudal plane (from the uppermost right hemi-diaphragm to the inferior tip of the right lobe through a horizontal line parallel to the anterior liver wall) along a midaxillary line. In addition, it is proposed that standard reference values for liver length should be developed according to the anthropometry of the patient. A panoramic view of the organ is always desirable in spite of the inherent limitations that are usually confronted to access the liver by ultrasonography. But when the panoramic view is not feasible, the next best approach is to obtain measurement of the liver craniocaudally from the uppermost right hemi-diaphragm to the most inferior boundary of the right lobe through a horizontal line parallel to the anterior liver wall as shown in Figure 1D.

Conclusion

It is of great clinical importance to establish the most accurate way to assess liver length by sonography to establish ranges for normal values. Clinical follow up with ultrasound of those patients who may develop liver disease is warranted before the occurrence of major health complications. In the best clinical scenario, particularly for those cases where the tip of the liver can not be visualized in real-time sonographic images, panoramic views should be obtained for measurement accuracy. This study shows that the most accurate way to obtain measurement of the RLL was from the uppermost right hemi-diaphragm to the inferior tip of the right lobe through a horizontal line parallel to the anterior liver wall

through the midaxillary line. By using such a reliable approach, it is expected that intra- and inter-observer variability will be reduced. Moreover, the establishment of a conservative range of normal values for liver length by sonography according to the anthropometry of the patient would allow professionals to determine when a given measurement is indicative of liver pathology.

Acknowledgments

We acknowledge Diagnostic Imaging Supplies & Services (DISS-PR) and Ms. Angeles Pérez in particular, for providing the ultrasound equipment that was used in this study. We also acknowledge the enthusiastic collaboration of forensic pathologists, forensic autopsy technicians and auxiliary personnel of the Institute of Forensic Sciences of Puerto Rico throughout the data collection process.

References

1. Kratzer W, Fritz V, Mason R, Haenle M, Kaechele V. Roemerstein Study Group. Factors Affecting Liver Size: A Sonographic Survey of 2080 Subjects. *J Ultrasound Med.* 2003; 22:1155–1161. [PubMed: 14620885]
2. Sahani D, Kalva SP. Imaging the Liver. *The oncologist.* 2004; 9:385–397. [PubMed: 15266092]
3. Tchelepi H, Ralls P, Radin R, Grant E. Sonography of Diffuse Liver Disease. *J Ultrasound Med.* 2002; 21:1023–1032. [PubMed: 12216750]
4. Hung CH, Lu SN, Wang JH, et al. Correlation between ultrasonographic and pathologic diagnoses of hepatitis B and C virus-related cirrhosis. *J Gastroenterol.* 2003; 38(2):153–7. [PubMed: 12640529]
5. D'Onofrio M, Martone E, Brunelli S, et al. Accuracy of ultrasound in the detection of liver fibrosis in chronic viral hepatitis. *Radiol Med.* 2005; 110(4):341–8. [PubMed: 16292241]
6. Gomercic M, Duvnjak M, Barsi N. Ultrasonography in the diagnosis of nonalcoholic fatty liver disease. *Acta Med Croatica.* 2009 Dec; 63(Suppl 3):1–3. [PubMed: 20235368]
7. Rumack, CM.; Wilson, S.; Charboneau, WJ.; Levine, D. The Liver. In: Wilson, S.; Withers, C., editors. *Diagnostic Ultrasound.* 4th. Vol. 1. Philadelphia, PA: Elsevier- Mosby; 2011. p. 78-84.
8. Curry, RA.; Tempkin, BB. Sonography: Introduction to Normal Structure and Function. 3th. Missouri, United States: Elsevier Saunders; 2011. The Liver; p. 203-204.p. 212-214.
9. Fritschy P, Robotti G, Schneekloth G, Vock P. Measurement of liver volume by ultrasound and computed tomography. *J Clin Ultrasound.* 1983 Aug; 11(6):299–303. [PubMed: 6413535]
10. Hagen-Ansert, S. *Textbook of Diagnostic Sonography.* 7th. Vol. 1. Missouri, United States: Elsevier Mosby; 2012. The Liver; p. 220-223.
11. Castell DO, Frank BB. Abdominal examination: role of percussion and auscultation. *Postgrad Med.* 1977; 62(6):131–134. [PubMed: 928243]
12. Gosink BB, Leymaster CE. Ultrasonic Determination of Hepatomegaly. *J Clin Ultrasound.* 1981 Jan.9:37–41. [PubMed: 6792230]
13. [November 27, 2013] Fatty liver disease. Dr Ronald Hoffman. <http://www.drhoffman.com/page.cfm/623>
14. Moore, KL.; Dalley, AF.; Agur, AM. Clinically Oriented Anatomy. 6th. Vol. 2010. Baltimore, MD: Williams & Wilkins; Abdomen; p. 268
15. Kumar, V.; Abbas, A.; Fausto, N.; Aster, J. Liver and Biliary Tract. In: Crawford, J.; Liu, C., editors. *Robbins and Cotran Pathologic Basis of Disease.* 8th. Philadelphia, PA: Saunders; 2010.
16. [November 25, 2013] The Liver: Anatomy and Functions. The Ohio State University, Wexner Medical Center. http://medicalcenter.osu.edu/patientcare/healthcare_services/liver_biliary_pancreatic_disease/liver_anatomy_function/Pages/index.aspx
17. [November 25, 2013] Your Liver. American Liver Foundation. <http://www.liverfoundation.org/abouttheliver/>
18. [November 25, 2013] Anatomy and Physiology of liver. National Liver Foundation. <http://www.nlfindia.com/liverZone/functions.asp>

19. Walker, HK.; Hall, WD.; Hurst, JW. Evaluation of the Size, Shape, and Consistency of the Liver. In: Wolf, D., editor. *Clinical Methods: The History, Physical, and Laboratory Examinations*. 3rd. Boston: Butterworths; 1990. p. 478-481.
20. Okosun IS, Tedders SH, Choil S, Deve GEA. Abdominal adiposity values associated with established body mass indexes in white, black and hispanic Americans. A study from the Third National Health and Nutrition Examination Survey. *International Journal of Obesity*. 2000 May 24.:1279–1285. [PubMed: 11093289]
21. Janssen I, Katzmarzyk P, Ross R. Waist circumference and not body mass index explains obesity related health risk. *Am J Clin Nutr*. 2004; 79:379–84. [PubMed: 14985210]
22. Razali NA, Wah YB. Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling tests. *Journal of Statistical Modeling and Analytics*. 2011; 2(1):21–33.

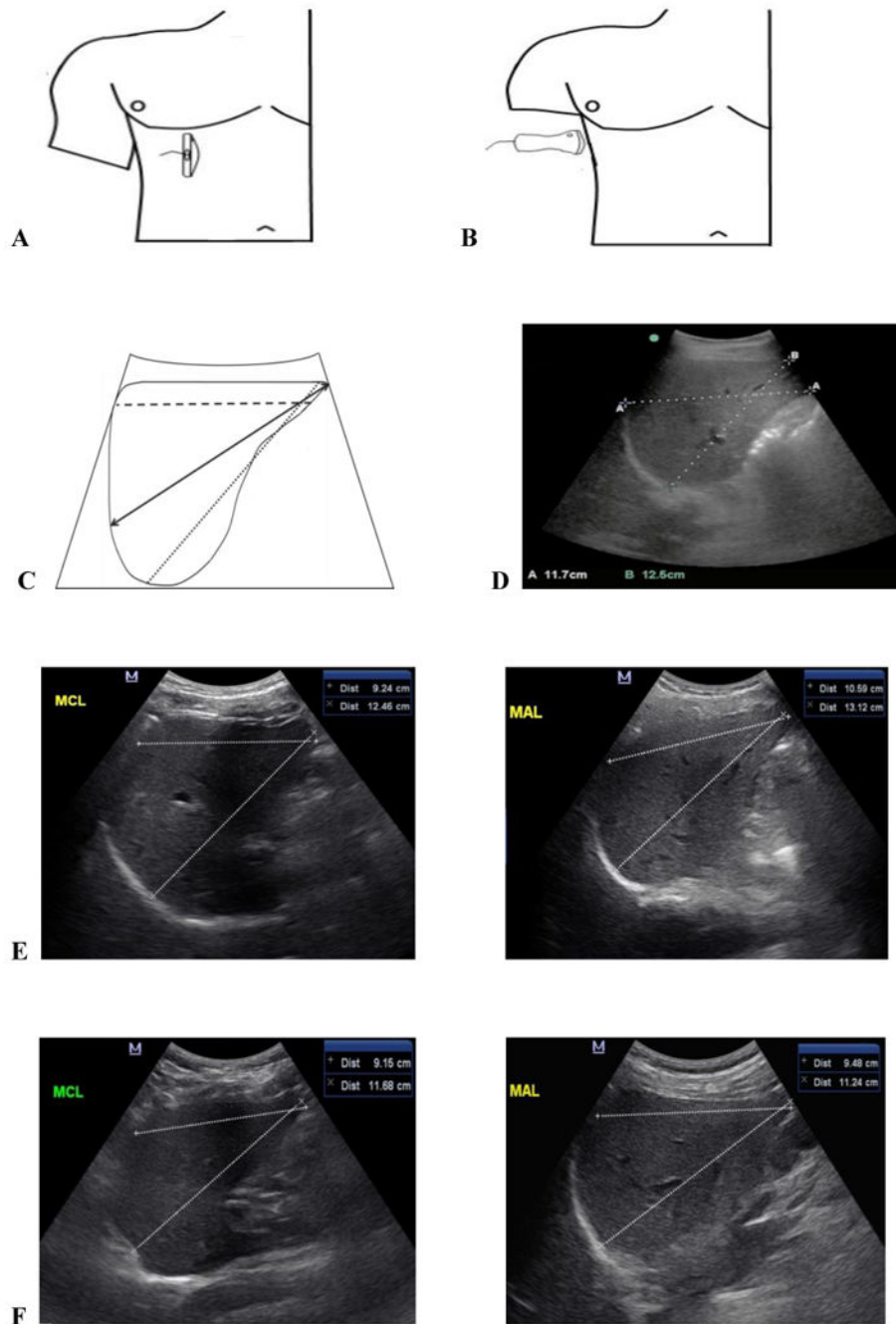


Figure 1. Liver measurements by sonography

A. Diagram shows the position of the transducer at midclavicular line. **B.** Diagram shows the position of the transducer at midaxillary line. **C.** Diagrammatic representation of right liver lobe measurements. Solid line and round dot usually termed as a craniocaudal plane, but the line drawn for measurement is oblique. Dash line represents craniocaudal measurement that must be taken from the uppermost right hemi-diaphragm to the inferior tip of the right lobe through a horizontal line parallel to the anterior liver wall. **D.** Sonographic image of the right liver lobe. The craniocaudal and oblique measurements are shown.

However, please notice that: (i) the inferior tip of the liver is not visible, and (ii) a rib overshadows part of the diaphragm dome. **E and F.** Sonographic images of the liver shows the craniocaudal and oblique measurements of the entire RLL in MCL and MAL. Each panel shows the measurements for the same patient.

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

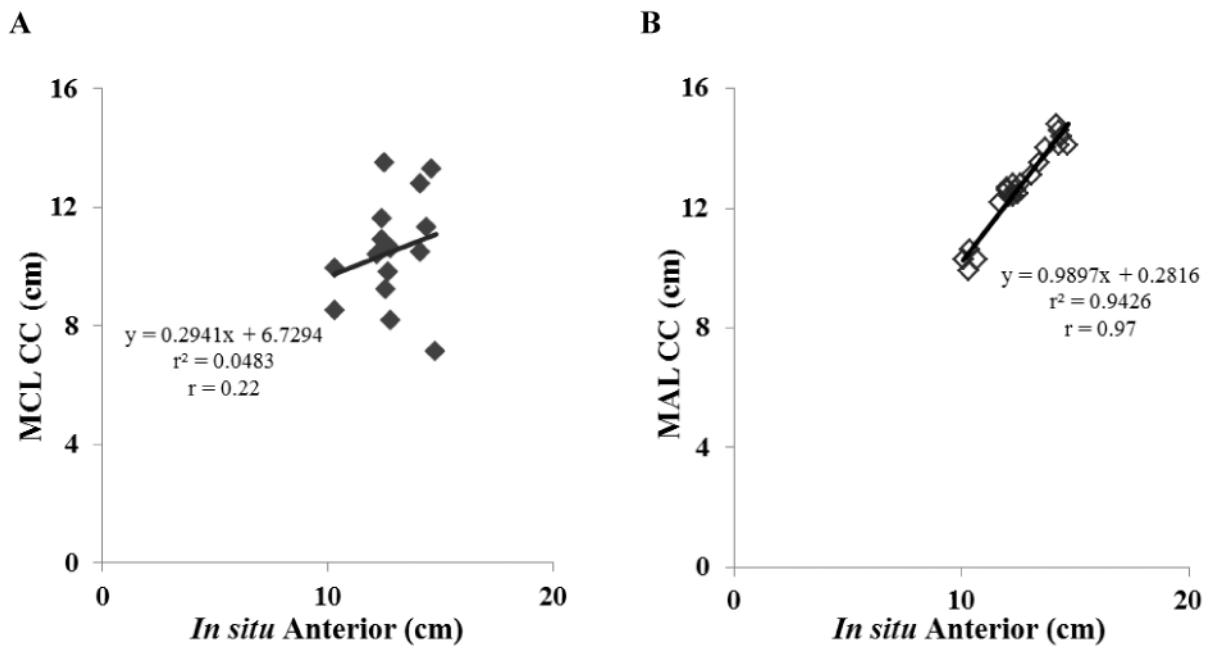


Figure 2. Regression and correlation analyses of the right liver lobe length

A. *In situ* Anterior versus Midclavicular craniocaudal (MCL CC) measurements. **B.** *In situ* Anterior versus Midaxillary craniocaudal measurements.

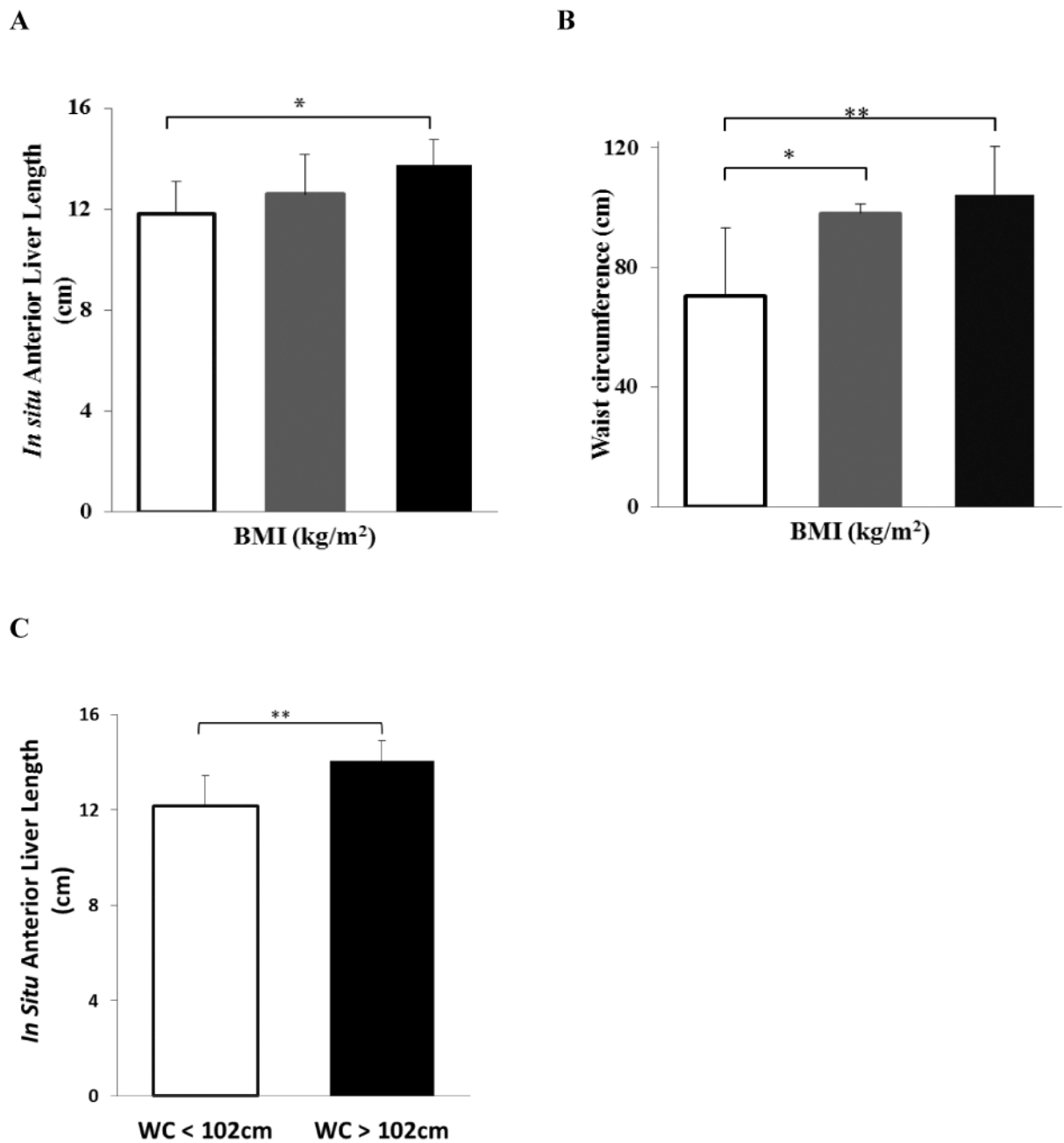


Figure 3.

Comparison among anthropometrics measurement. **A.** BMI groups versus *In situ* anterior liver length. **B.** BMI versus Waist circumference. **C.** Waist circumference versus *In situ* anterior liver length. Errors bars show standard deviation values. Classification of BMI (kg/m²) as a following: Adequate (19.0 - 24.9) (white bars for Panels A and B, n = 9), Overweight (25 - 29.9) (grey bars for Panels A and B, n = 4) and Obesity (> 30) (black bars for Panels A and B, n = 7). * = p 0.01 – 0.005; ** = p 0.001 – 0.0001.

Table1
Typical values for liver size according to clinical sonography

References	Values for Liver Length	Location for liver measurement
Gosink & Leymaster, 1981	13.0 - 15.5 cm	Midhepatic line
Rumack et al., 2011	15.5 cm	Midhepatic line
Curry & Tempkin, 2011	13.0 – 17.0 cm	Longitudinal scan at midclavicular line
Hagen-Ansert, 2012	15.0 – 20.0 cm	Longitudinal scan under the costal margin from the inferior tip of the liver to the dome of the diaphragm in an oblique line.

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 2
Characteristics and Liver Measurements in Cadaveric Specimens

Specimen number	Sex	Age	BMI (kg/m ²)	Waist circumference (cm)	In situ Anterior (cm)	MCL CC (cm)	MCL AP (cm)	MAL CC (cm)	MAL AP (cm)
1	M	50	14.5	58.50	13.5	NV	NV	13.4	15.9
2	M	49	31.3	105.5	14.0	NV	NV	13.7	17.1
3	M	18	18.7	67.30	12.7	9.82	11.0	12.0	14.8
4	M	U	30.8	108.8	14.1	12.8	14.1	14.7	17.9
5	M	88	26.6	98.00	10.6	NV	NV	10.4	13.3
6	M	48	34.9	132.6	14.8	7.11	19.4	14.2	15.5
7	M	50	27.3	97.60	12.6	9.23	12.7	12.4	15.1
8	M	30	27.8	94.50	12.8	10.6	15.4	12.6	15.5
9	M	35	30.1	87.00	12.4	11.6	16.2	12.1	15.7
10	M	68	33.9	102.1	12.4	10.9	12.1	12.3	12.3
11	M	42	30.7	110.5	14.6	13.3	15.3	14.3	18.4
12	M	56	21.9	83.00	12.6	NV	NV	12.0	14.1
13	M	83	22.6	94.30	13.1	NV	NV	13.1	15.1
14	M	91	23.2	87.60	12.8	8.19	9.66	12.3	13.6
15	M	54	20.5	68.00	12.2	10.4	9.09	11.7	12.5
16	M	49	36.7	84.80	14.1	10.5	13.3	14.3	16.5
17	M	69	24.5	91.90	12.5	13.5	14.5	12.5	15.7
18	M	56	25.1	102.4	14.4	11.3	13.7	14.4	17.4
19	F	82	<u>21.4</u>	35.20	9.90	NV	NV	10.3	12.1
20	F	98	<u>24.2</u>	33.40	10.3	9.94	10.7	10.7	12.5
21	F	46	23.9	74.00	10.3	8.51	12.0	10.1	12.4
average		58	26.2	86.52	12.7	10.5	13.3	12.5	14.9
SD		21	5.63	24.07	1.44	1.84	2.71	1.41	1.94
NV= Not visible U = unknown Estimated measure									

Table 3
Statistical analysis for right liver lobe measurements

Measurements	n	r ²	r
MCL CC vs MCL AP	15	0.02	0.13
MCL CC vs in situ Anterior	15	0.05	0.22
MCL AP vs in situ Anterior	15	0.31	0.56
MCL AP vs MAL AP	15	0.36	0.60
MAL CC vs MCL CC	15	0.11	0.34
MAL CC vs MAL AP	21	0.76	0.87
MAL AP vs in situ Anterior	21	0.70	0.84
MAL CC vs in situ Anterior	21	0.94	0.97

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript