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Anatomical criteria to measure the adult right liver lobe by ultrasound

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Abstract

Introduction.—This study aims to establish objective anatomical criteria to obtain accurate and reliable measurements of the right liver lobe (RLL) length by ultrasound while considering sex and anthropometry of the patient.

Methods.—Thirty-three (n = 33) adult participants underwent two-dimensional (2D) and panoramic (PAN) ultrasound imaging of the RLL in the anterior axillary region (AAR). Each measurement was performed in the standard oblique plane and in a tested craniocaudal (CC) plane by two independent observers. Pearson analysis was conducted to evaluate correlation between measurements and Intraclass Correlation Coefficient (ICC) for inter-rater reliability. Two-tail paired T test was used to compare groups. Statistical significance was attained at $p < 0.05$.

Results.—The proposed craniocaudal 2D RLL length was 13.0 ± 1.5 cm for females and 14.1 ± 1.3 cm for males whereas PAN RLL size was 13.7 ± 1.8 cm for females and 15.0 ± 1.1 cm for males. A strong correlation between the proposed 2D CC measurement of the RLL length with PAN CC measurements was found ($r = 0.87$). Inter-rater reliability for 2D CC measurements showed high reliability (ICC 0.96).

Discussion.—CC measurement of RLL by ultrasound in AAR is a precise and reliable measurement that may allow for the routine monitoring of RLL length across time.

Keywords

right liver lobe; anatomy of the liver; anterior axillary region

Introduction

It is a common clinical practice to first assess liver health through 2D ultrasound when the patient presents with right upper quadrant (RUQ) pain, RUQ inflammation, or elevation in liver enzymes [1,2]. Although the size of this organ can be estimated by palpation and percussion, diagnostic imaging studies have shown that physical examination underestimates liver size [3,4].

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Measurement of the right liver lobe (RLL) length by two-dimensional (2D) ultrasound is taken as an anatomical criterion to assess hepatomegaly, usually defined as RLL ≥ 16.5 cm [5]. Therefore, it is of pivotal clinical importance that sonographers and physicians feel confident about their assessment of liver health through 2D ultrasound. Whereas there is agreement in the imaging field about how to evaluate liver texture [6–8], there is lack of consensus on whether measurements of RLL through 2D ultrasound are accurate and reproducible between sonographers [9]. Moreover, there is also a wide range of RLL length values reported in medical textbooks and research publications to indicate normal liver length [5,10–12]. There is also the observation that the line most typically traced for RLL measurement is in the oblique rather than in the craniocaudal plane [13]. It is not surprising that some physicians, biomedical researchers and imaging technologists are left with the impression that assessment of liver health through 2D ultrasound is qualitative at best. But there is the cost-effective need to routinely monitor the liver in patients with chronic health conditions that eventually impact liver health; as in the cases of diabetes mellitus type 2 [14] and nonalcoholic fatty liver disease (NAFLD) [7]. The clinical challenge then, is to be able to detect changes in RLL length, accurately.

The aim of this study is to establish objective anatomical criteria to obtain accurate and reliable measurements of RLL length by ultrasound.

Methods

Recruitment of study participants took place from November 2015 to January 2018. Subjects were recruited from two clinical sites: Endocrinology Clinics at University Hospital of Puerto Rico and The External Endocrinology Clinics of School of Medicine at Medical Sciences of Puerto Rico, UPR. Adult participants were recruited at the clinics according to the following inclusion criteria: no clinical history of hepatic disease, no right upper quadrant trauma or surgery, no hyperlipidaemia, no morbid obesity, without diabetes and non-pregnant. Data on patient's age, sex, weight, height and medical history was recorded from all subjects. Height, body weight (body mass index; BMI = weight (kg) / height $(m)^2$) and waist circumference were used as anthropometric measurements. Waist circumference (WC) was measured at the navel level, where <88 cm was the normal reference value for females and <102 cm for males [15–17].

A real time abdominal sonogram was made to evaluate the RLL length, using a Logiq E9 ultrasound machine (GE Healthcare, Milwaukee, Wisconsin, USA) with a C1–6-VN 2D convex probe. The ultrasound images were obtained by one of the authors who has experience as a sonographer (BLRC), and were also independently evaluated by a radiologist who is the Director of The Ultrasound Clinic, School of Medicine-UPR (W.R-M.).

This study protocol was approved by the UPR Medical Science Campus Protection of Human Research Participants Office; IRB protocol A9000113. Written informed consent was obtained from all participants prior to recruitment.

Acquisition of ultrasound images for measurement of right liver lobe (RLL) length

To reduce bowel gas, participants were fasting or had taken a light meal for more than 4 hours prior to the imaging session. RLL images were obtained with study participants placed in a left anterior oblique position (15° – 20°), with the right arm placed above the head and with the skin exposed from the hip to the xiphoid process. Participants were instructed to take a deep breath and hold the air for a few seconds to displace the ribs and to facilitate the contact with the right upper quadrant for ultrasound visualisation of the liver.

It has been previously shown that, in cadaveric specimens, the craniocaudal (CC) RLL length was more accurate in the midaxillary line (MAL) rather than in the midclavicular line (MCL), when compared to *in situ* measurement of CC-RLL length [13]. With regard to surface anatomy, and for the purpose of this study, the transducer was placed longitudinally between MAL and anterior axillary line (AAL), an area that we refer to as the anterior axillary region (AAR; shown in Figure 1A). RLL 2D ultrasound images were acquired where greater visualisation of the right lobe was feasible. In addition, a panoramic image was acquired with study participants in the same anatomical position as for 2D imaging by using the Logic View application (GE ®). The panoramic, or extended, image allowed for the visualisation of adjacent structures that were used as anatomical landmarks to obtain the ultrasound image.

For the purpose of this study, the standard imaging trace that is commonly depicted in ultrasound and medical textbooks is defined as the oblique measurement of the RLL [12]. We tested a line that was traced craniocaudally for RLL length measurement (Figure 1B); from the uppermost right hemi-diaphragm visualised in the image to the inferior tip of the right lobe through a horizontal line as parallel as possible to the anterior liver wall [13]. As anatomical landmarks, both, the right hemi-diaphragm and the inferior tip of the right lobe were visualised in the ultrasound image. The goal was to trace the caliper's measurement line as high as possible and close to the diaphragm and as parallel as possible to the anterior wall of the liver. Figure 2 shows representative 2D and panoramic images of the RLL. As shown in these images, the measurement line was not always a perfect parallel trace. This was due, in part, to: the size of the liver, gases in the abdominal cavity, the anatomy of the base of the right lung and acoustic shadowing produced by the right ribs. To circumvent these caveats, the patient was placed obliquely to induce small rotations of the body wall along its axis to slightly displace the RLL medially and inferiorly within the cavity as well as to aid displacement of abdominal organs and gases. Intercostal spaces were widened by keeping the participant's arm above the head to reduce shadowing by the ribs and to facilitate visualisation of the liver parenchyma. In addition, when asking study participants to hold a deep inspiration, the hemi-diaphragm usually displaced inferiorly and the organ remained still while capturing the ultrasound image. For each study participant, measurements were performed twice by two independent observers whom traced the measurement lines as described here in 2D and PAN views. Reported values correspond to measurement means of both observers. Inter-rater reliability was calculated for RLL length in 2D CC, PAN CC and 2D oblique measurements. Inter-rater reliability agreement was classified as follows: < 0.7 poor, 0.7 – 0.8 strong and > 0.8 very strong.

Statistical Analysis

Data is expressed as mean ± standard deviation. Statistical analyses were performed with XLSTAT-Biomed software (Version 2018.5, Addinsoft, New York City, New York, USA). Shapiro-Wilk test was assessed for normality of the data and homogeneity of variance was evaluated according to normality results[18]. For all variables of interest, data was normally distributed. Kruskal-Wallis followed by multiple pairwise comparisons using Dunn's procedure were used to compare groups. Pearson analysis was conducted to evaluate correlation between measurements and Intraclass Correlation Coefficient (ICC) for inter-rater reliability. Two-tail paired t-test was used to compare groups. Statistical significance was attained at $p < 0.05$.

Results

Thirty-three (n = 33) study participants between 23 to 69 years of age met inclusion criteria for this study; 20 females (48.9 ± 10.6 years of age) and 13 males (43.6 ± 14.7 years of age). Table 1 shows values of RLL length measurements according to sex as made by two independent observers in two-dimensional (2D) or panoramic (PAN) view and in a given anatomical plane; craniocaudal or oblique. 2D CC RLL mean length was 13.0 ± 1.5 cm for females and 14.1 ± 1.3 cm for males. PAN RLL mean length was 13.7 ± 1.8 cm for females and 15.0 ± 1.1 cm for males.

A statistical difference was noted between females and males for 2D CC measurement ($p = 0.04$) and for PAN CC measurement ($p = 0.03$) of the RLL (not shown). Therefore, it was of interest to determine whether sex of the patient could affect inter-rater reliability and whether craniocaudal measurements were more reliable than the traditional oblique measurement of the RLL. 'Very strong' (> 0.8) inter-rater reliability of these measurements was found (see Table 2). In addition, regardless of study participant's sex, the ascending order of Intraclass Correlation Coefficient (ICC) values according to ultrasound image and measurement caliper's trace was as follows: 2D Oblique > 2D Craniocaudal > Panoramic Craniocaudal.

Table 3 shows coefficient of determination (r^2) and Pearson correlation coefficient (r) analyses between CC and oblique RLL length measurements in 2D and PAN views. Whereas r^2 values reflect how successful a function can replicate results; r values represent the degree of relationship between two quantitative variables. These analyses revealed that, regardless of participant's sex, the CC measurement is similar between 2D and PAN views. But this was not the case for 2D oblique versus PAN CC comparisons.

With regard to the anthropometry of study participants, the mean value for body mass index (BMI) was 28.1 ± 4.9 kg/m^2 for females and 27.8 ± 4.7 kg/m^2 for males; with no statistical differences between these groups. Similarly, the mean value for waist circumference (WC) was 96.3 ± 13.8 cm for females and 99.7 ± 11.8 cm for males, with no significant differences between these groups. However, a sexually dimorphic difference in RLL length was noted in 2D craniocaudal and PAN craniocaudal measurements according WC categories (see Table 4). Namely, males with large WC have longer RLL than females with large WC.

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Discussion

Although diagnostic imaging of the liver by ultrasound is an inexpensive and efficient diagnostic tool that evaluates the liver in real time [4, 19], there are a wide range of RLL length measurements that indicate normal liver length [5, 10–12]. This can be due, in part, to various anatomical parameters that are taken into consideration to obtain the sonographic image and to trace the caliper's measurement line. In a routine abdominal sonogram, the length of the right liver lobe (RLL) is most commonly measured, and a length ≥ 16.5 cm is considered hepatomegaly [5]. Although hepatomegaly does not necessarily constitute liver disease, it may be indicative of hepatic pathology [20]. Therefore, this study aimed to provide a set of objective anatomical criteria to accurately measure the length of the RLL by ultrasound. The line traced for RLL measurement was not a steep oblique line, but rather, a line that was traced as high as possible and as close as possible to the right hemi-diaphragm along the superior border of the dome of the liver. In addition, the line was traced as parallel as possible to the anterior wall of the liver as visualised in two-dimensional (2D) and panoramic (PAN) ultrasound images. The goal was to reduce the angle that is produced between the standard oblique measurement of the RLL when extrapolated to a parallel line that is traced along the superior border of the dome of the liver in relationship to the anatomical plane of the anterior liver wall. Reliability between observers of this craniocaudal measurement were tested.

A recent study [19] showed that three linear measurements of the right and left liver lobes, that included a craniocaudal measurement, can be converted to a liver volume [19]. This is of great clinical significance as it provides, for the first time, a valid and reliable reference range for liver volume in adults without liver pathology; that is 1060–2223 cm^3. We now found that the craniocaudal length, as defined here, of the adult RLL in a 2D sonographic image was 13.0 ± 1.5 cm for females and 14.1 ± 1.3 cm for males whereas PAN RLL length was 13.7 ± 1.8 cm for females and 15.0 ± 1.1 cm for males. Inter-rater reliability and correlation between 2D and PAN views for these measurements were, both, very strong. It is worth noting that in this sample, RLL length according to 2D views was approximately 1 cm smaller than for PAN views. It is clinically relevant that RLL length according to a non-panoramic 2D image is an underestimation of true length and that subsequent imaging with the same equipment and anatomical approach at various time points could assess changes in RLL length. We also found that the standard 2D oblique measurement of RLL length yielded a lower inter-rater reliability than the one with the proposed craniocaudal measurement. Nevertheless, this finding needs to be replicated by other research groups before it can be concluded that the proposed measurement is more reliable than the standard oblique ultrasound measurement of the RLL.

Similarly, a larger study sample will be required before an unequivocal statement can be made about plausible sex differences in adult RLL length according to the proposed craniocaudal measurement. We noted a significant difference in RLL length when males and females with large waist circumferences were compared, which adds to the complexity of these plausible sex differences when anthropometry is considered. This observation raises the possibility that reference values for normal RLL craniocaudal length may have to be defined, at least, according to sex.

We are certain that experienced sonographers readily recognise that factors such as anthropometry of the patient, normal variations in liver anatomy, anatomical boundaries within the abdominal cavity that limits visualization of neighboring structures, and breathing patterns of the patient can all affect measurement of RLL length. In this study, rather than providing reference values, it suggests several objective anatomical parameters to accurately measure the RLL by ultrasound. Since ultrasound is a non-invasive modality that does not use radiation, it definitively is a reliable tool that can be used to objectively monitor the liver as many times as clinically necessary for a given patient. In fast-paced clinical environments and in settings with limited financial resources, ultrasound measurement of RLL length as described here can significantly contribute to a first-line clinical assessment of liver health. In addition, accurate and reproducible ultrasound measurement of the RLL opens up the possibility for evaluating changes in RLL length over time for the same patient.

Taken together, we conclude that it is possible to obtain accurate and reliable measurements of RLL length, in 2D or panoramic ultrasound views, while considering anatomical variations in the position of the liver within the abdominal cavity when scanning in the anterior axillary region. We propose that such ultrasound-based measurement should be performed craniocaudally; from the uppermost right hemi-diaphragm that is visualised in the ultrasound image to the inferior tip of the right lobe through a horizontal line as parallel as possible to the anterior liver wall.

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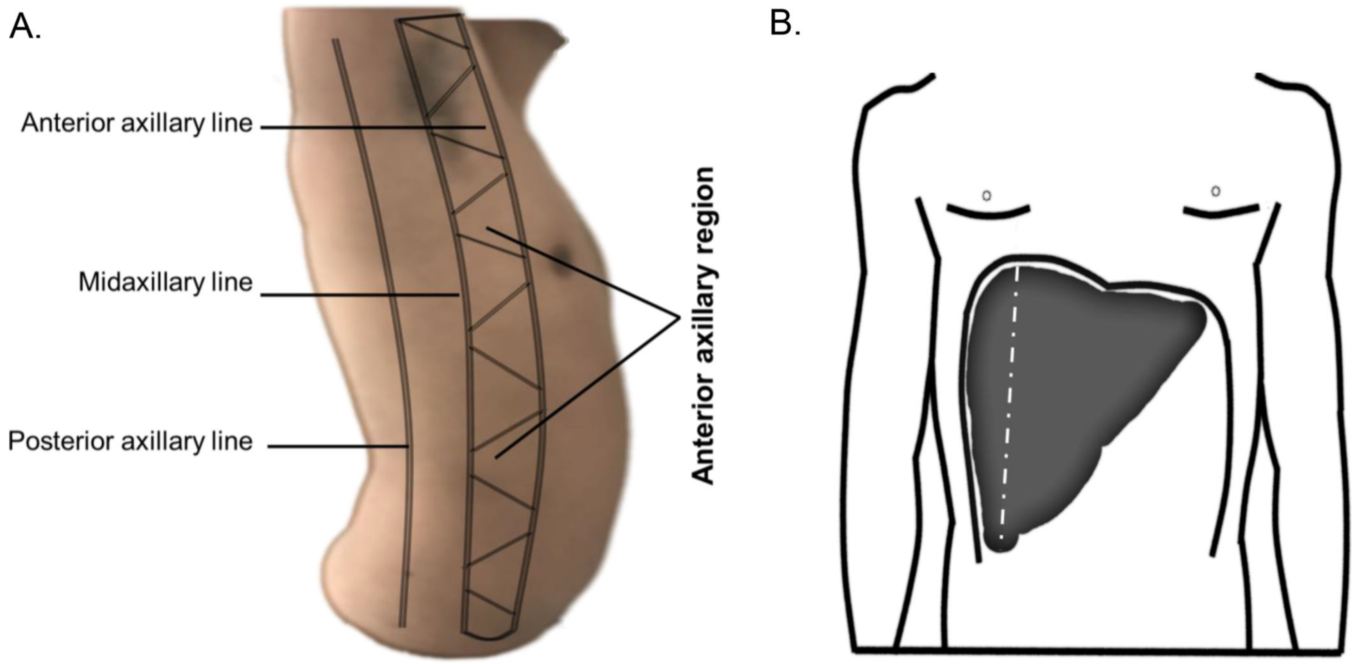

>Figure 1. Surface anatomy of the adult right liver lobe.

A. Anterior axillary region (ARR) in surface anatomy that was used to scan the RLL. **B**. Anatomical position of the RLL, the dash line represents the proposed craniocaudal measurement in AAR.

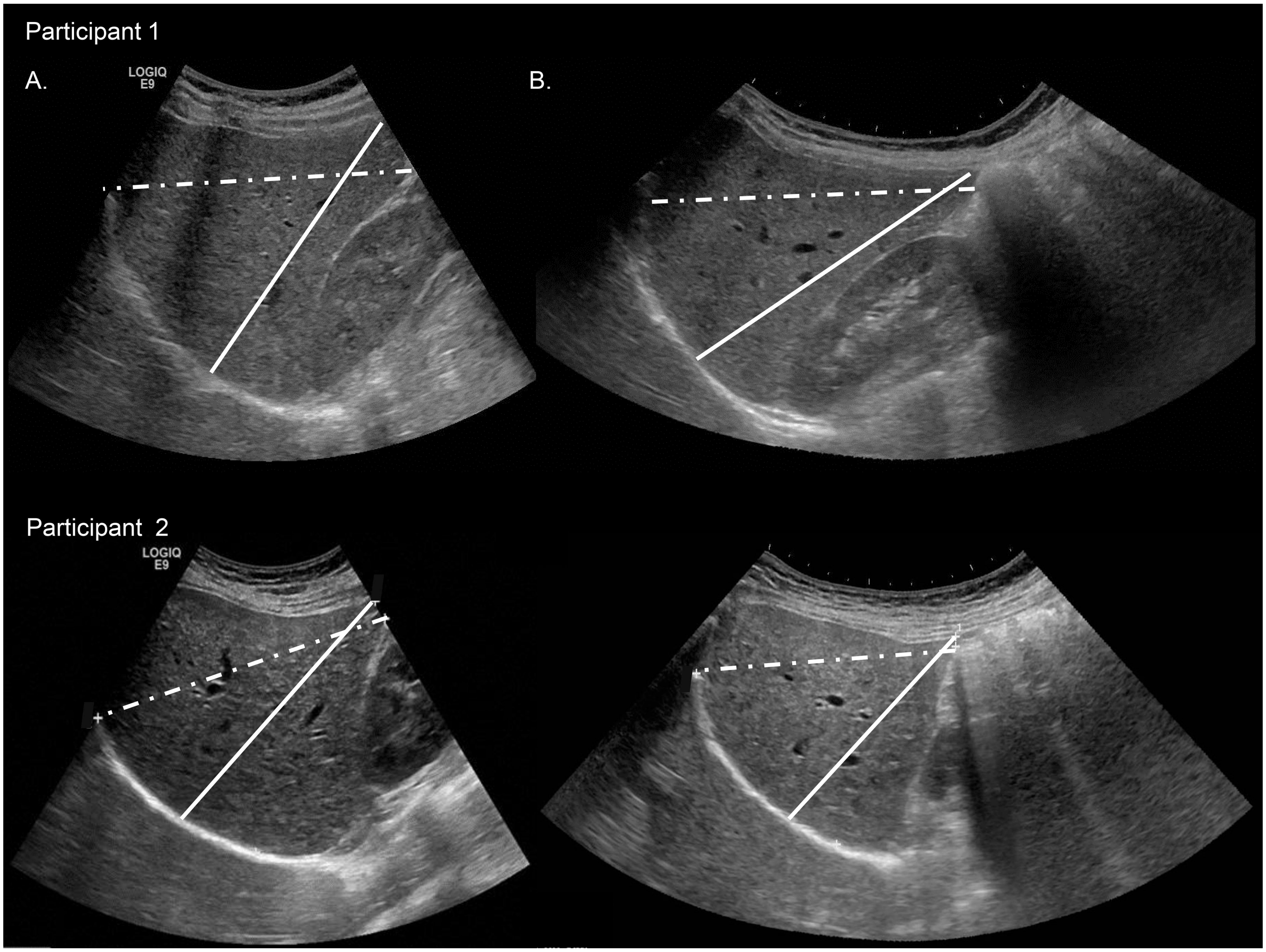

Figure 2. Right liver lobe (RLL) measurements by ultrasound.

Representative sonographic images that show RLL measurements in two-dimensional view (A) and in panoramic view (B) for two study participants. The solid line represents the standard oblique measurement. The dash line represents the proposed craniocaudal measurement that was taken from the uppermost right hemi-diaphragm visualised in the image to the inferior tip of the right lobe through a horizontal line as parallel as possible to the anatomical plane of the anterior liver wall (see text for details).

Table 1.

Right liver lobe length measurements according to sex

	Age			2D RLL CC (cm)			PAN RLL CC (cm)			2D RLL oblique (cm)		
	$\bar{x}$	95% CI	SD	$\bar{x}$	95% CI	SD	$\bar{x}$	95% CI	SD	$\bar{x}$	95% CI	SD
Females	48.9	43.9 – 53.8	10.6	13.0	12.3 – 13.7	1.5	13.7	12.9 – 14.5	1.8	12.8	12.3 – 13.4	1.2
Males	43.6	34.7 – 52.5	14.7	14.1	13.3 – 14.9	1.3	15.0	14.3 – 15.7	1.1	14.0	13.2 – 14.8	1.2

Table 2.

Inter-rater reliability of right liver lobe length measurements

	Interclass Correlation Coefficient		
	Females	**Males**	**Overall**
2D craniocaudal	0.95	0.97	0.96
PAN craniocaudal	0.98	0.98	0.98
2D oblique	0.91	0.85	0.90

Table 3.

Correlation analysis for right liver lobe length measurements

Measurements	n	r^2	r
Females 2D CC vs Pan CC	20	0.71	0.84
Males 2D CC vs Pan CC	13	0.81	0.90
Overall 2D CC vs Pan CC	33	0.75	0.87
Females 2D oblique vs Pan CC	20	0.31	0.56
Males 2D oblique vs Pan CC	13	0.51	0.72
Overall 2D oblique vs Pan CC	33	0.42	0.65

Table 4.

Sex difference on RLL length according to waist circumference

	Normal waist circumference							
	RLL length (cm) 2D view				**RLL length (cm) Panoramic view**			
	$\bar{x}$	95% CI	SD	p value	$\bar{x}$	95% CI	SD	p value
Females	12.5	11.14 – 13.8	1.1	0.36	14.1	11.3 – 16.8	2.2	0.72
Males	13.3	12.1 – 14.5	1.1		14.5	13.4 – 15.5	1.0	
	Large waist circumference							
	RLL length (cm) 2D view				**RLL length (cm) Panoramic view**			
	$\bar{x}$	95% CI	SD	p value	$\bar{x}$	95% CI	SD	p value
Females	13.2	12.3 – 14.1	1.6	0.02	13.6	12.6 – 14.6	1.8	0.01
Males	14.9	14.0 – 15.8	1.0		15.5	14.6 – 16.4	1.0	