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Ｂモード超音波検査における腹部脂肪量の測定

An Novel Method for Abdominal Fatness Measurement with the Help of B-Mode Ultrasonography

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Abstract: Subcutaneous and visceral fat acculmulation in abdomen has close relationship with of Metabolic Syndrome (MS) and other diseases, and therefore serve as important indicators of them. Abdominal computed tomography (CT) enables precise quantification of the Subcutaneous Fat Area (SFA) and Visceral Fat Area (VFA) and has been considered as the gold standard for body fatness assessment. In this paper, the distribution of fatness accumulation in abdominial area were studied and some principles have been discovered, and we develope a novel method to measure the SFA and VFA quickly and stably with ultrasound (US) and some drawbacks of existing methods have been overcome. Then, we evaluated the novel method on 100 patients. Strong correlation relationship between our method and CT method has been confirmed: For SFA and VFA, the mean deviation between US-method and CT-method was $33.5\,cm^2$ and $25.8\,cm^2$ respectively.

Key words: Visceral Fat Area, Subcutaneous Fat Area, Ultrasound Diagnosis, Abdominal CT Image.

1. Introduction

The term metabolic syndrome (MS), a combination of medical disorders that increases the risk of chronic diseases such as diabetes, hypertension, and cardiovascular disease, has been adopted by International Diabetes Federation (IDF) in 2006. MS is a major public health problem, the prevalence of which has increased worldwide. Despite differences in histology, physiology and gene expression profile among fat depots, it is generally believed that excessive fat accumulation in abdominal has similar negative health connotations. For example, both visceral fat and subcutaneous fat depots are related to insulin resistance and dyslipidemia, albeit to different degrees[5].

Abdominal obesity, colloquially known as belly fat or clinically as central obesity, is the accumulation of abdominal fat resulting in an increase in waist size. Abdominal obesity is thought to be a fundamental pathology for MS in particular and therefore, the accurate measurement of abdominal obesity represents an important tool in assessing the ocurring and developing of MS. There are two kinds of adipose tissue accumulation in abdomial obesity: subcutaneous fat and visceral fat. Subcutaneous fat is found just beneath the skin as opposed to visceral fat which is found in the peritoneal cavity. Visceral fat, also known as organ fat, packes in between internal organs and the torso, as opposed to subcutaneous fat which is found underneath the skin. Since subcutaneous fat and visceral fat cannot be observed directly, the accurate assessment of them has prooven to be challenging work.

Abdominal computed tomography (CT) has been considered the most accurate and reproducible technique of body fatness measurement, particularly abdominal adipose tissue. Abdominal CT enables visualization and accurate quantification of both subcutaneous fat area (SFA) and visceral fat area (VFA) and therefore serves as the gold standard for abdominal obesity assessment [1]. However, abdominal CT has many drawbacks, including exposure to radiation, lack of simplicity, high cost, and time-consuming. Due to these limitations, a variety of alternative methods are being used to assess visceral fat amount and distribution. Previous studies have shown that waist circumference (WC), and WC-based indices can perform as some indicators of the level of visceral obesity [2]. These measurements are recommended as a simpler and easier screening method. However, due to the lack of the individual visualization of internal adipose tissue, these methods have fatal drawbacks such as inability to distinguish subcutaneous fat from visceral fat, inability to take into account an individual's specific information, low level of reproducibility in the case of marked obesity, and most important, poor accuracy.

In recent years, simple methods for assessing abdominal fatness accumulation using ultrasonography (US) have been studied and were further confirmed by strong correlations with CT-detected VFA [3][4][6][7]. Ultrasound has many advantages such as non invasive to human bodies, low-cost, easy to be operated, real time and enables the visualization of adipose tissue. Therefore, US-based methods show a balance on simplicity and accuracy between abdominal CT and WC-based indices. However, the performance of the existing US-based methods depend seriously upon the quality of US image, which differs largely due to the diagnosis situations such as doctors experience and probe accuracy, and therefore the practical applications of these methods cannot be too highly expected under universal environment.

In this study, to overcome some drawbacks of existing methods, a novel method has been developed for abdominal fatness studies to provided an estimation of the abdominal SFA and VFA with the help of ultrasound diagnosis.

2. Diagnosis Method for US Probe

For providing repeatability and simplicity of operations, we plan to develop a measuring method for ultrasound image which is easy to follow. The measuring method must fulfill the requirements that: 1) Same positions and angles for ultrasound probe on different patients during diagnosis; 2) Distinct markers easy to be observable in US image; 3) Quantitive measurement on patients' curvature of abdomen. Unlike CT, the ultrasound can only provide a limited scope inside one patient's body. The diagnosing angle and position of probe may differ from doctor to doctor due to their own experiences. As a result, we must provide doctors a standard which is easy to operate.

Due to the swiftly distance-attenuation of ultrasound, the diagnosis from side-positions and behind-positions can hardly take aorta into view and as a result no other distinct marks can be observed. This will make the diagnosis process quite unreliable even impossible to be standardized. So, we chose our diagnosis positions in front side of one patient's body. Three kinds of US measurements of fatness are taken. A), Total distance: the distance between the anterior wall of the aorta and skin; B), subcutaneous fat thickness: the distance between anterior face of the rectus abdominis muscle and skin; C), visceral fat thickness: the distance between the internal face of the rectus abdominis muscle and the anterior wall of the aorta(**Fig.1.**). And these three kinds of distances are measured from the three diagnosis positions in order.

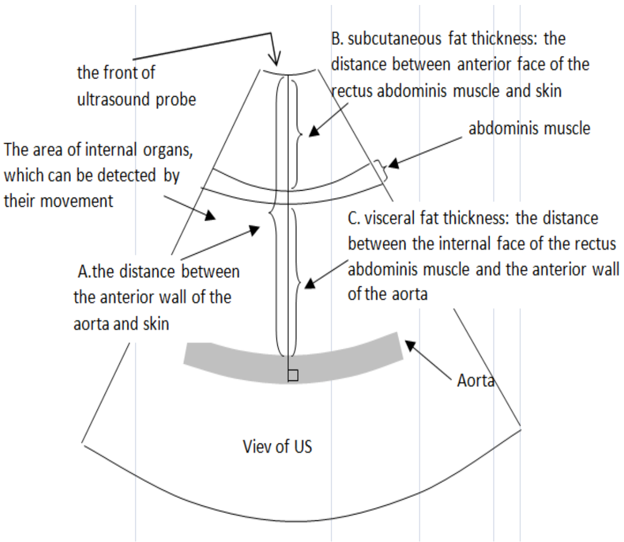


Fig. 1. Ultrasound diagnosis method. Totally nine distances will be measured from three diagnosis positions.

In [6], Y. Zhou *et al* came up with the idea of a belt-shaped ultrasound probe compatible device to provide a quick, easy-operated and accurate way to guide the ultrasonographic procedures. The probe was fixed at the same positions and angles by the belt when diagnosing and the images were taken from a horizontal direction. however, through our clinical experiments, we noticed that aorta, the most distinct mark in view mentioned in [6], was only a small faint circle which can easily be neglected sometimes. So we improved their idea and developed another design of compatible device which makes the US probe detect US image from a vertical direction(**Fig.2**).

In the visual field of an abdominal US, due to the Doppler Effect, the flow of blood in the aorta is nearly the most distinct marker for US. Thus, the belt-shaped device is designed to be fixed in the exact position from where the aorta can be observed most clearly. As a result, the diagnosis process will be finished in seconds, which is convenient for patients as well. With an elastic material, this belt-shaped device would bend smoothly and mold to patient's abdomen. It is easy to understand that: a patient with mild visceral obesity in normal range of waist circumference would have a 'flatter' shape in abdomen, which means that the belt-shaped device will be less bent when diagnosing. On the other hand, a patient with more serious abdomenial obesity would get a 'plumper' waist, and as a result more bent the belt-shaped device becomes when diagnosing. Hence, the curvature of the belt is proportional to the curvature of abdomen, which can serve as a valuable characteristic of individual seriousness level of visceral obesity and give a reasonable classification of patients. In the next sections, with the help of three probe-diagnosing positions rather than one, we will give a method to describe the curvature of abdomen quantitively.

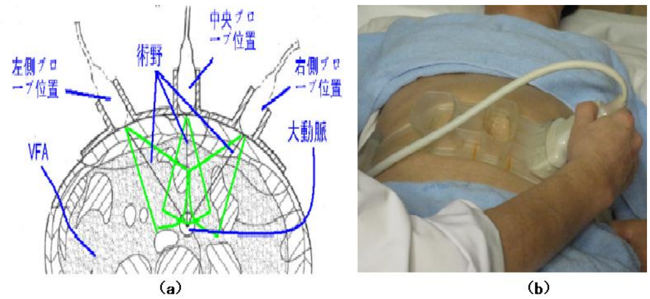


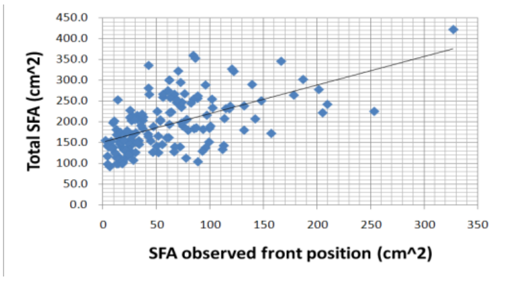
Fig. 2. Ultrasound probe compatible device. The distance between two adjacent probe positions is 50mm, and the angle between two adjacent probes is 40° in unbent situation. (a) Diagnosis method for the belt-shaped device. (b) Clinical experiment for the belt-shaped device on a patient.

3. An Analysis on Regional Fatness Distribution

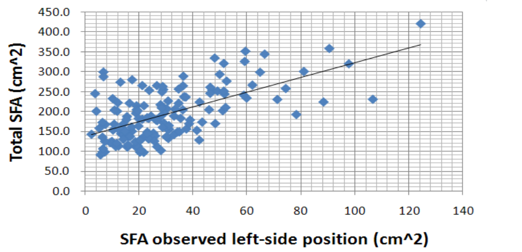
We want to discover some principles of the regional visceral fat distribution. For this analysis, 146 patients' abdominal CT cross-section images at navel level have been collected as materials from the same urban hospital. Abdominal cross-section by CT scanning was obtained in a single tomographic slice at umbilical level as ultrasound probe did. Abdominal cross-section by CT scanning was obtained in a single tomographic slice at umbilical level as ultrasound probe did. Portions with a CT number of −200 to −10 Hounsfield Units (HU) were separated as adipose tissue and their areas were automatically calculated.

We simulated the visual scope of US probe from three postions on these CT images and computed the visceral fat area in view. The Pearson's product-moment correlation and unpaired t-test between total SFA and SFA observed from those three positions was performanced. The results showed that there was strong correlation between the US observed SFA from these three positions and the total SFA of an individual patient. The coefficent was r = 0.647, 0.585, 0.635 for front-position, left-position and right-position respectively, and for all three of them, the level of significance was p-value < 2.2e-16 (**Fig.**

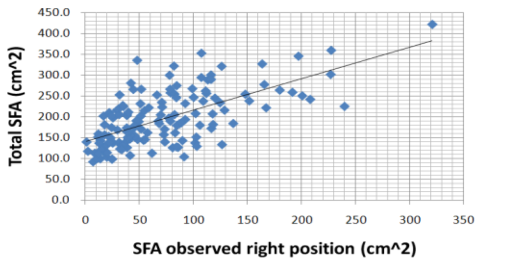
3(a)(b)(c)). This result shows that subcutaneous fat accumulates quite stably in every local regions in abdomen. Thus, there is some reasonability to use the limited-scoped US image to estimate the total SFA. As far as we know, this is the first attempt to analyze the regional distribution of subcutaneous fat accumulation in abdomen. Although this analysis may not be very exact for each individual patient, it provides us some detailed information on the volume of fatness accumulation at different regions in abdomen. And these information have been proofed to be quite helpful in the estimate next.



(a)



(b)



(c)

Fig. 3.(a). (b). (c). Scattergram between total SFA and SFA observed front, left-side, right-side probe position.

4. The Estimate of Subcutaneous Fat Area

In this and next sections, We tested our novel method of assessing SFA and VFA on 100 patients from the same community. All our ultrasonographic procedures were performed by the same examiner using a portable ultrasonography equipment (EUB-8500, HITACHI, Japan). The center of the belt-shaped device fixed exactly 2 cm left to umbilicus for each patient. Each patient assumed a supine position, and US data were measured at the end of expiration by a 6-MHz 2D abdominal probe, while the probe was making contact with patients' skin as slight as possible (**Fig.4**).For each patients, the total diagnosis procedures lasted about 200 seconds. This is quite an acceptable time during a medical examination. In addition, More quick diagnosis speed is also expectable in the future if doctors become more proficient in the operations of this novel method.

For a current patient, we assess the SFA based on an ellipse approximation for the shape of abdominal cavity with aorta as centre. The eccentricity of ellipse reflects the curvature of abdomen and therefore serves as a quantitive description of visceral obesity.

Fig. 4. Practical diagnosis procedures for a patient. (a) US Diagnosis. (b) Distance of visceral fat measured in US image.

The ultrasound probe were detecting from three positions by the belt-shaped device. The information we can acquire contains: b, denotes the distance between the internal face of the rectus abdominis muscle and the centre of the aorta detected from front, and is defined as semi-minor axis of ellipse; b', denotes the distance between front-end of ultrasound probe in the central diagnosing position and the centre of the aorta detected from front, r, denotes the same distance detected from one side; h', denotes the distance between two probes (50mm); h, denotes the curve length between b and r derived from h' by $h = h'b/b'$ as showed in **Fig. 5(a)**. Then, by ellipse circumference and ellipse parametric equation (**1**), we can calculate: a, denotes the semi-major axis; θ, denotes the angle between two probes. An follow these steps, all of the areas of four quarter-ellipse can be computed as showed in **Fig. 5(b).**

$$\begin{cases} h = \int_0^{\theta} \sqrt{a^2 sin^2 t + b^2 cos^2 t}\, dt \\ r^2 = a^2 cos^2\theta + b^2 sin^2\theta \end{cases} \quad (1)$$

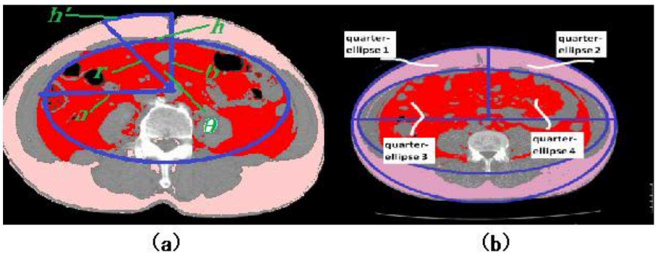


Fig. 5. Ellipse approximation of abdominal cross-section. (a) Parameters of ellipse. From our measured information *b,r,h,* the area of ellipse can be computed. (b) The areas of four quarter-ellipse can be approached.

Since the lack of distribution information from back-side of body, we cannot give an integral estimate of subcutaneous fat area. So, we define here that SFA= $A_1 + A_2 - A_3 - A_4$. And since abdominal CT holds the most accurate quantification of the fatness estimation, we treated it as the testing standard in our experiment for SFA this section and for VFA next section. The correlation between these two groups is also presented. The coefficent was r = 0.715, and the mean deviation between SFA measured by CT and our US method for each patient is $33.5\ cm^2$.

5. The Estimate of Visceral Fat Area

We have collected a database of 146 patients' abdominal CT images, VFA and the nine distances in which has been measured.

Firstly, we denote the distance C from Front position as *Fc* and denote the distance C from Left position as *Lc*. Compare *Fc* of current patient with *Fc* of every CT images in database, and choose those images whose *Fc* are nearest with current patient (12 pieces). In those 12 pieces of images, then chose six pieces of images whose *Fc/Lc* are nearest with current patient's *Fc/Lc*. The reason we use *Fc/Lc* is that *Fc/Lc* can demonstrate the curvature of abdomen of one patient. Finally, define the VFA of current patient as the average of VFA in these six pieces of CT images.

By the diagnosis procedure mentioned in Section **2**, we tested our method on 100 patients from the same rural community and meanwhile abdominal CT were taken. Then, we compared the results of our US method with the(abdominal CT. **Figure.6** shows the comparisons of CT and our US-based method. The correlation coefficent between these two groups was r = 0.715, and the mean deviation between VFA measured by CT and our US method for each patient is $25.8\ cm^2$.

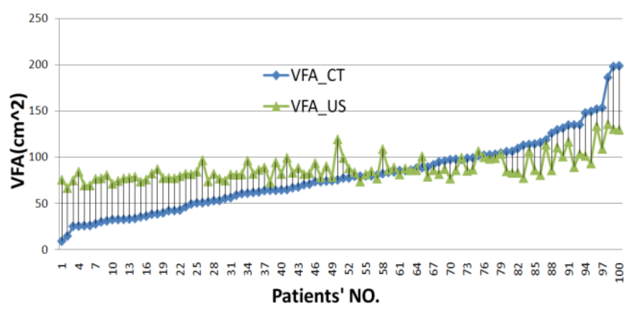


Fig. 6. Camprison of our US-based method and CT method.

6. Discussions and Conclusion

This paper proposes an analysis on the regional fatness distribution at navel level, and then based on this analysis, a novel US-based method for estimation of SFA and VFA has been developed. A fast and convenient diagnosis operation was introduced and a stable estimation method was proposed to estimate one patient's VFA from US data automatically. As far as we know, this is the first attempt to compute SFA by ultrasound, and our results were shown to be relatively correlated with CT measurements.

For VFA assessment, compared with existing simple US methods presented in [3][4][7], the accuracy of our method is extremely high, and it almost holds the same level of accuracy with the method in [6]. In addition, another main advantage of our method is its low level of dependency to the quality of ultrasound image. Compared with the complex VFA estimation method presented in [6], the information detected from US by our method is so stable that it is almost impossible to disturbed by unexpectable turbulence of image quality. As a result, our method can be easily used into more general clinical environment with a lower requirement on US device.

However, one main limitation of this present study is that all the data of patients were collected from the same ethnic group. For instance, the female body type in particular differs largely between Westerners and Easterners. Thus, the generalization of our results to other individuals of certain ethnic groups can hardly be approached directly and further discussions are needing. On the other hand, once the database of specified ethic group is established, our method can be soon applied.

Till now, we have developed a US-based method whose accuracy is approaching the level of abdominal CT. However, it is not an entirely impossible thing that the US-based method will become a more reliable indicator for MS than abdominal CT in the future. Due to the non-invasiveness and simplity of US, diagnosis at different levels of the abdomen will be accomplished without much difficulties. Consequencely, 3D individual visualization and estimation of visceral fat can be realized by US, while usually only one slice of abdominal cross-section image can be acquired by CT in medical examination due to the harmness of rediation. Secondly, due to its real-time characteristics, US allows us to detect visceral fat over a period of time. One patient's abdominal cross-sectional area when expiring will differ largely from inspiring. Abdominal CT cannot take this difference into consider and therefore would be less convincing than US in this respect. Further, by US, we may represent a useful method for monitoring weight loss, variations and transfer of visceral fat, which can be expected to indicate the associated risks of MS more accurately.

In conclusion, although its results are still rough and there are many details need discussing, the results of present US-based method is relatively correlated with results of CT method, and therefore has been proofed to be a considerably stable and accurate way for VFA and SFA estimation.

7. References

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