LipoTool: Evaluation of Tissues Compressibility

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***Abstract*—Nowadays undernutrition, overweight and obesity are very common health problems, with high impact in society at individual, social and economic levels. Therefore, the quantification and screening of body fat composition is very important in the health area. The assessment method based on skinfold measurement has well-defined protocols but the commercial equipment, considered in the literature, lacks technical evolution. Present technologies do not integrate devices with novel characteristics and are not adequate for large scale studies. They are also limited for efforts in developing new algorithms, namely, if based in dynamic tissue response. The integrated LipoTool system intends to contribute for those goals. Some novel features of LipoTool are presented, i.e., end tips alignment and acquisition of the tissue compressibility. The paper highlights innovative capacities of LipoTool, which transform it into a powerful tool for assessing and tracking, training, study and research, with the potential to develop new models and different application domains.**

Keywords-skinfold calliper; data recording, skinfold compressibility, skinfold measurement protocol.

I. INTRODUCTION

Changes in the nutritional status of an individual are one of the most common health problems and with high impact in society at individual, social and economic levels [1]. Malnutrition, obesity or even the co-existence of both are a major world health problem documented by the World Health Organization (WHO) [2].

According to the WHO, over 50 % of the European adult population is overweight or obese. In fact, excess body fat may lead to the increase of coronary heart disease, high blood pressure, type 2 diabetes, obstructive lung disease, arthritis, and some types of cancer [3]. Malnutrition is also related to other diseases generating costs to the European Health System comparable to those associated with overweight and obesity [4].

Malnutrition is a global issue that affects billions of people. The term malnutrition refers to both undernutrition and overnutrition. Traditionally, undernutrition is prevalent in developing countries and obesity is an epidemic in developed countries. Recently, obesity has been increasing in developing countries, leading to a double burden of disease, especially in urban settings [5][6].

Therefore, the quantification and screening of Body Fat (BF) composition is very important in the health area. For monitoring BF, several techniques are used being based the most usual on the estimation of Body Mass Index (BMI). BMI estimation is based on height and weight evaluation, although leading to very inaccurate results according to the literature [7][8]. The measurement of skinfolds using a calliper and the Bioelectrical Impedance Analysis (BIA) measurement based in body resistance and reactance are techniques widely used. The Dual-energy X-ray Absorptiometry (DXA) for image evaluation is considered a valid body fat measuring device [9].

The BMI calculation is a highly empirical method that only gives a rough idea of body fat. The DXA method has great accuracy, but is invasive and requires very expensive bulky type equipment, adequate facilities, and expert technicians, resulting in high cost/test rate [10].

The BIA is the technique that competes directly with the skinfold calliper. The BF is calculated based in correlating impedance and reactance values obtained by passing an alternating electrical current through the body [11]. It is a recent and widely used method requiring a convenient preparation not often respected. Individual preparation before the test typically includes several requirements:

- Avoid exercising within 12 hours of the test.
- No alcoholic drinks within 48 hours of the test.
- Do not drink coffee within 48 hours of the test.
- Avoid diuretics within 24 hours of the test.
- Urinate completely prior to testing.
- Abstain from eating and drinking within 4 hours of the test.

Failure to meet these requirements leads to very poor, inaccurate results.

Skinfold calliper methodology has advantages over other techniques because it is a simple method (portable, easy to use and not requiring special individual preparation), non-invasive and low cost; it provides reliable results compared with the DXA [12].

The measurement protocol prescribes a uniform distributed pressure of 10 gf/mm^2 [13] to be applied to the skinfold by the end tips. After positioning the end tips, three seconds should be counted (as recommended), and then, the skinfold thickness value may be recorded. With the value of skinfold thickness and with the individual anthropometric data, the percentage of BF is estimated by selecting an equation from a huge set of equations (more than 60) related with individual data.

In fact, the assessment method based on the skinfold measurement has a well-defined protocol but the commercial equipment, considered in the literature and available in the market, lacks technical evolution.

The challenge of this work starts precisely from the lack of progress and precision that this type of device has experienced since its development in the 1960s and aims at overcoming these limitations. We designed and tested a dedicated BF measurement system called LipoTool. The integrated LipoTool system intends to achieve all requirements for this method: the pressure between end tips should be uniform and constant (10 gf/mm^2) as established by the protocol, to guaranty and to improve the precision and measurement resolution, to offer a larger measurement range, to minimize or even to discard subjective operator errors (thickness reading and measurement time counting), to facilitate the recording and monitoring of patient results (data recorded in database), to guide the technician through the complete procedure, and to provide a database for large scale studies. Additionally, the system also intends to allow further studies in the health and nutrition fields and even for other applications in distinct areas (now, it is possible to record the dynamic tissue response during the skinfold compression interval).

The work aims at highlighting new studies and some results already available due to the device unique features. We believe that new algorithms, namely, based on dynamic tissue response will be possible to be developed with LipoTool. However, these studies will need samples referred to a standard method (for example, to DXA).

In the present work, Section II describes the integrated system LipoTool, comprising a digital skinfold calliper, named Adipsmeter, and its communication system with the LipoSoft application, highlighting the used technology. Section III provides details of the LipoTool performance, namely, the constant pressure between end tips according with the followed measurement protocol and its novel capabilities for evaluating tissue compressibility. This allows accurate studies on the effect of the time interval duration for skinfold measurement and its significance in the final evaluation of %BF. Finally, in the conclusions, it is stressed how it can be a powerful tool in the assessing and tracking, training, study and research domains, such as nutrition and health, forensic sciences, veterinary science and sports.

II. THE LIPOTOOL INTEGRATED SYSTEM

The technological solution of LipoTool, depicted in Figure 1, comprises a new digital skinfold calliper Adipsmeter (1), an antenna AirPCOn (2) for wireless communication with a computer and a software application LipoSoft (3).

A. The Adipsmeter digital skinfold calliper

The Adipsmeter mechanical design was studied, conceived and implemented in order to guarantee a constant pressure value of 10 gf/mm^2 between end tips, to increase the calliper measurement range and to reduce the measurement subjectivity due to five novel features: a constant force actuator mechanism, a cam to compensate changes in force, a controlled end tips articulation for keeping their clamping surfaces parallel to each other over all its opening range, a large jaws centre distance permitting greater openings without increasing the device size and, finally, a symmetric design to make it independent of the operator dominant hand.

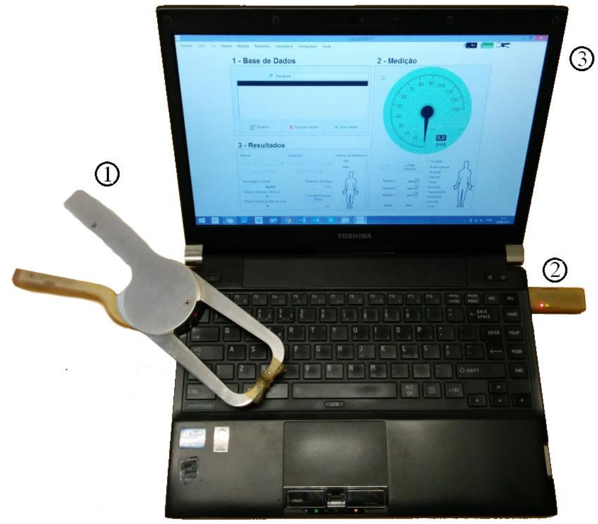

Figure 1. LipoTool system.

The entire mechanism can be seen in Figure 2. The two jaws (4) opening is accomplished by the operator through the manipulation of a fixed handle (1) and a lever (2). The simultaneous opening is achieved because the two jaws rotate around fixed axes and are interconnected by means of mechanical elements. Jaws closing action is operated by a transmission chain connected at the other end to a constant force actuator based on an elastic element. This actuator has the double effect of being the force element of the system while simultaneously eliminating all possible backlash in the transmission chain. The inclusion of a cam (3) whose profile compensates variations in the length of the applied force arm, guarantees the application of a constant force by the clamping surface of the end tips (5) to the skinfold under measurement. The end tips are hinged at the rotation axes in the extremities of the jaws, keeping their clamping surfaces parallel to each other at any opening level. This is achieved by a movement transmission mechanism that provides a constant and uniform pressure on the complete contact area between the end tip clamping surfaces and the skinfold.

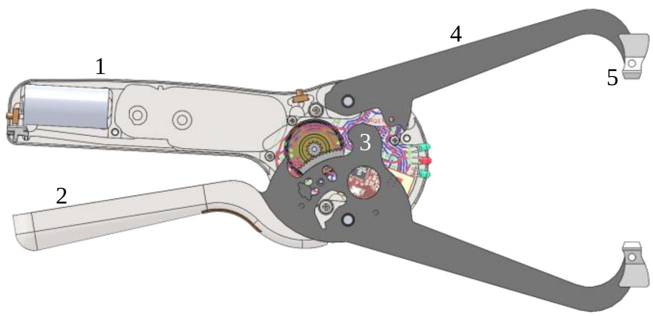

Figure 2. Schematics of the transmission chain.

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LipoTool is much more convenient and precise than any traditional skinfold calliper both in daily use and in large scale actions.

The integration of the mechanical design with electronics and informatics design enables to obtain a final resolution of 0.025 mm, to reduce the time measurement subjectivity, to reduce individual reading errors, to follow the tissue compressibility, to facilitate the use of the method by incorporation of all known equations, and also to integrate a database that enables the monitoring of individuals.

B. *The communication and the LipoSoft application*

The transmission rate for the wireless communication between the Adipsmeter and LipoSoft (60 samples/s) allows to register the dynamic tissue response for any skinfold under compression. It is also possible to monitor small changes in temperature during the compression process.

So, studies based on dynamic tissue response will be performed using traditional dynamic systems modelling techniques, such as time and frequency response, artificial neural networks, and genetic algorithms. We think that more flexible models could be achieved offering additional methods for BF evaluation, overcoming the use of more than 60 regression equations, at the present. In line with this idea, a study using neural networks has been reported by Barbosa, *et al.* [14].

The current electronic solution uses Microchip Technology Inc. [15] components for both processing and wireless communication. For the communication, data processing 8-bit microcontrollers were used. For the wireless communication, antennas were used with the communication protocol MiWi, based on the IEEE 802.15.4 standard for Wireless Personal Area Networks (WPANs) [16].

The digital measurement sensor of the calliper is an encoder of angular type and also includes a temperature sensor (miniaturized thermocouple bid). The angular encoder is connected directly to the microcontroller through two specific ports. The antenna and the temperature converter communicate with the microcontroller by Serial Peripheral Interface bus (SPI) and the set of buttons (included in the Adipsmeter) communicate through digital ports. In the AirPCOn antenna, two microcontrollers are used, communicating with Universal Synchronous/Asynchronous Receiver/Transmitter (USART) between them. One is used to communicate with the computer via Universal Serial Bus (USB) and the other with the antenna by SPI, as shown in Figure 3.

The LipoSoft application was developed in Visual Basic.NET and communicates with the antenna through the USB port. The interface is divided into three blocks: Database, Measurement and Results, as shown in Figure 4.

It is possible to introduce different settings through the LipoSoft user interface, as well as to turn off the Adipsmeter.

III. TESTING THE LIPOTOOL PERFORMANCE

This work presents two methods used for testing this novel calliper in terms of mechanical behaviour and dynamics evaluation of time interval during skinfold thickness evaluation.

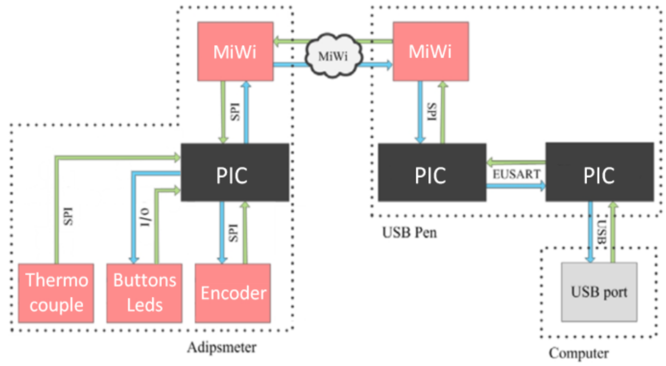

Figure 3. Communications diagram.

The first goal was achieved by comparing the pressure between calliper end tips within the measurement range for the Adipsmeter and the Harpenden calliper [17], the latter being the market reference. The second objective is to study the relevance of the protocol time interval value for measuring skinfolds.

A. *Constant pressure between end tips*

According to the protocol, the pressure between end tips should be 10 gf/mm^2 for the whole measurement range.

In order to compare the pressure values between end tips, their area and the force between them were digitally monitored and measured. A mechanical structure able to ensure repeatability and the same conditions in force measurements for both devices (Adipsmeter and Harpenden) was developed integrating a load cell of 5 LBS measurement range. An aluminium structure was built for housing the load cell (ensuring the force discharge without friction) and room for gauge blocks in order to measure force for different skinfold callipers accurate opening, from 15 mm to 120 mm.

The Adipsmeter end tips are articulated; so their surfaces are always parallel for any opening. For that reason, the measurement process is simple to carry out. In other cases in which there is no parallelism between end tips (and so between skinfold contact surfaces), which is the case of the Harpenden calliper, it is essential to use special care by introducing additional calculations for compensating the lack of parallelism. Once the force is equally distributed by careful design of the mechanical test system, this leads to uniformity in the pressure distribution on the surface of the end tips, and therefore, in the skinfold surface.

Figure 5 presents the results from lab tests for comparing the Adipsmeter and the Harpenden callipers in terms of pressure between the end tip surfaces at different openings.

Figure 5 shows the evolution of the pressure between end tips for different jaw opening along the measurement range of each calliper - Harpenden: 0-80 mm; Adipsmeter: 0-120 mm. It also shows a non-constant pressure between end tips, i.e., Harpenden calliper does not accomplish the protocol requirement exhibiting a decreasing pressure with the opening increase. On the other hand, the Adipsmeter offers an increase of 50 % in the measurement range and a constant pressure between end tips.

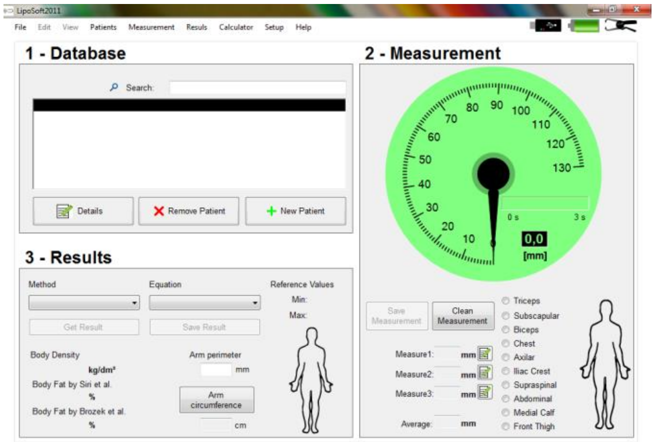

Figure 4. LipoSoft interface.

B. *Time interval for skinfold measurement*

LipoTool provides a unique ability by allowing to monitor and to register the skinfold behaviour along the skinfold measurement.

This LipoTool functionality permits to evaluate the time required for the skinfold measurement by observing the dynamic tissue response.

Studies of the protocol time interval have never been done based in an accurate procedure. The LipoTool system is able to read skinfold thickness and perform time evaluation in an intrinsic and precise digitally automatic way and to record them for later processing and evaluation. Nevertheless, Lohman [18] and Norton and Olds [19] have recommended the use of 2 s and 3 s after applying the callipers' end tips to the skinfold, as result of their empirical studies based in huge samples; but, it was impossible to read time and thickness with precision as it can be made by LipoTool.

In our study for evaluating tissue compressibility, the measurement procedure has followed the International Standards for Anthropometric Assessment recommendations [20]. A sample of 36 adults (50% women) aged between 21 and 49 years old was evaluated and all the participants were informed of the study purposes as well as the different procedures.

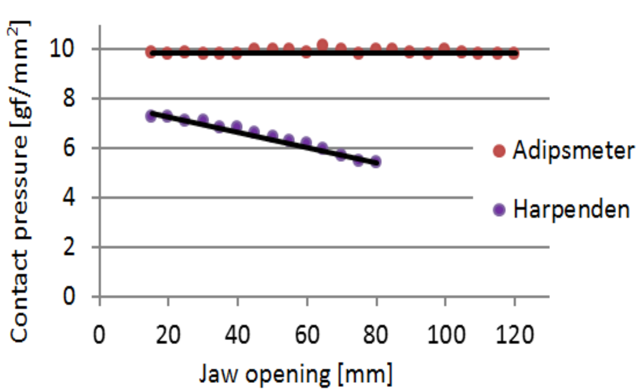

Figure 5. Pressure test between end tips for different jaw opening.

The tricipital skinfold was measured with the LipoTool system and the evolution of tissue compressibility during the initial 5 s was registered. The body density was estimated using the equations of Durnin and Womersley [21] and the % BF was estimated using the equation of Siri [22]. All these estimations were done in intervals of 0.5 s and the difference between these values in consecutive moments was calculated. The results are presented in Table 1.

Observing data from Table 1, it is evident that changes over 2.5 s are not meaningful when determining the % BF and this suggests the need for revision of the time interval for skinfold measurement.

Figure 6 shows an example of the information recorded during a skinfold measurement procedure for a heterogeneous set of 10 individuals. The data were processed in order to exhibit a normalized evolution of individual skinfolds during measuring time allowing a better comparison between individual skinfolds behaviour.

The dynamic evolution of tissue compressibility shows very different characteristics among individuals. We believe that for each individual it is possible to distinguishing two behaviours in the skinfold characteristic. One is related with the connective tissue and the other is related with the adipose tissue. The first decay rate is higher than the second one. For each individual, these decay rate values, respectively, must be related with his/her percentage of connective and adipose tissue, depicted in Figure 7.

Further studies may possibly conduct to offer a completely new functionality with skinfold callipers' measurement. However, for better characterization of these results, a higher resolution prototype must be used. These

TABLE I. BODY FAT PERCENTAGES FOR TRICIPITAL SKINFOLD

		Time [s]										
		0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5
%BF (Siri)	Men	27,1	26,1	25,9	25,9	25,8	25,8	25,7	25,7	25,7	25,7	25,6
% dif*			1,0	0,1	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,0
%BF (Siri)	Women	26,6	25,4	25,2	25,2	25,1	25,1	25,0	25,0	25,0	25,0	24,9
% dif*			1,3	0,1	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,0

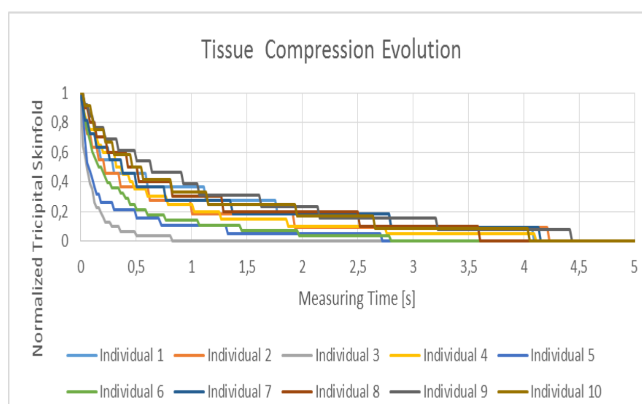

Figure 6. Normalized tissue compression evolution of tricipital skinfolds.

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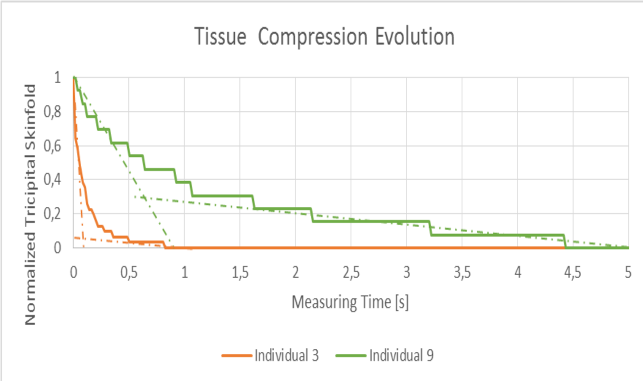

Figure 7. Decay rate for distinct behaviours of a skinfold.

studies also need data simultaneously obtained by this device and with a DXA system in order to develop validated models.

These capabilities have been already used in preliminary studies in Forensic [23][24] and in Nutrition areas [25][26].

IV. CONCLUSIONS

LipoTool presents innovations that allow its use for accurate and fast assessment of body composition by measuring skinfolds. While retaining the simplicity of any skinfold calliper, the innovative capacities of LipoTool transform it into a powerful tool for assessing and tracking, training, study and research, with the potential to help develop new models and different application domains which turns, once again, into additional innovation. To perform the associated research based on new studies, it is fundamental to get data not only from the LipoTool but also from a valid body fat measuring recognized standard systems. LipoTool is now under market development, which will bring later opportunities for new studies.

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