

Digital integrated instrument for measuring BMI and comparing to the ideal BMI for age as a guidance for Indonesian military recruitment

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Abstract. This study aimed to investigate body mass index (BMI) of 102 subjects to be Indonesian military officer candidates. To test the ideal body weight (IBW) used 2 methods for comparison, first from the calculation of IBW by Brodsky's and modified Broca's formula and ideal BMI from WPRO criteria and second from IBW of the Indian Navy and TNI/POLRI recruitment. A digital integrated instrument for measuring BMI was manufactured where BW and body height (BH) are measured using loadcell and ultrasonic sensor respectively and the result is processed by Arduino Mega 2560 microcontroller. From the separate measurement results there are BW error 0.96%, BH error 3.22%, and BMI error 2.88% compared to using digitally integrated measurement.

1 Introduction

Body Mass Index (BMI, kg/m^2) has long been used in US soldier selection criteria [1]. Individuals entering the US army must meet age and sex-specific weight for height screening criteria defined in Army Regulation 40-501: Standard of Medical Fitness [2]. A candidate to become a brigade of Gurkhas of the British army must meet minimum height and weight 158 cm and 50 kg respectively [3]. The Australian Army which used the PULHEEMS recommended BMI guidelines for entry into service i.e minimum and maximum BMI of male and female for age 18+ years are 18 and 28 kg/m^2 respectively, while for age 16 to <18 years are 17 and 27 kg/m^2 respectively [4]. The Indian Navy has published a correlation table between age, height and average weight for the guidance of candidates as shown in Fig. 1 [5]. It should be within permissible limits $\pm 10\%$ of the ideal weight given in the figure.

To pass the medical test in the Indonesian National Army (TNI) and the Police of the Republic of Indonesia (POLRI) a male candidate must meet the minimum height 165 cm and weight 50 kg [6]. TNI and POLRI have also published the ideal weight guidelines for being soldiers and officers based on the Western Pacific Region of WHO (WPRO criteria, 2000) [7], as shown in Fig. 2 [6].

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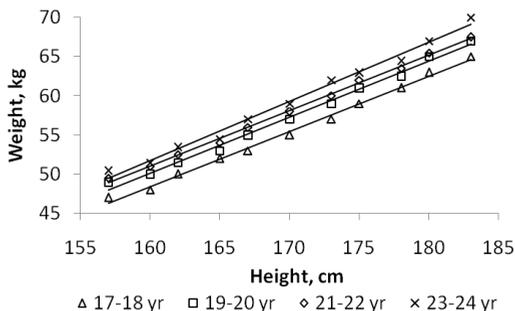


Fig. 1. The ideal weight guidelines for Indian Navy recruitment

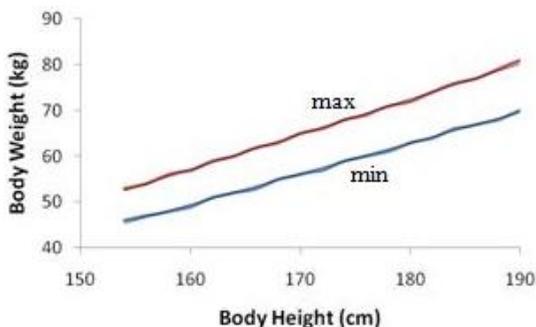


Fig. 2. The ideal weight guidelines for TNI and POLRI recruitment

There are many methods for calculating ideal body weight (BW) or BMI. The ideal BW (IBW) according to Robinson's formula is a 5 feet tall man should be 52 kilograms while that of a woman 5 feet tall should be 49 kilograms. For men who are taller than 5 feet, 1.9 kilograms should be added to get their IBW. In the case of women, 1.6 kilograms should be added for every inch above 5 feet [8]. The Miller's formula is based on the belief that the IBW of a man should be 52 kilograms at 5 feet. For every additional foot on top of the 5 feet, an additional 1.9 kilograms should be added. However, the IBW for women should be 49 kilograms and 1.7 kilograms added for every five inches more [9]. Another method was published by Brodsky et al. [10], which propose a simple approach to estimate IBW based on the BMI as shown in eq. 1. The IBW used by the TNI in candidate recruitment is the modified Broca's formula [11] (multiplied by 0.9, adjusted to Indonesian population BMI) which is calculated in Eq. 2 [6]. WPRO have also categorized BMI into 5 criteria i.e less than 18.4 kg/m² as underweight, 18.5 to 22.9 kg/m² as normal, 23.0 to 24.9 kg/m² as overweight, and over 25.0 kg/m² as obese [7].

$$BW \text{ (kg)} = 22 \times BH^2 \text{ (m}^2\text{)} \tag{1}$$

$$BW \text{ (kg)} = [BH \text{ (cm)} - 100] \times 0.9 \tag{2}$$

This study aimed to investigate BMI of 102 subjects to meet the ideal BMI criteria to be Indonesian military officer candidates. In order to obtain the comprehensive results it is necessary to compare the results of IBW calculations from Eq. 1 and Eq. 2, ideal BMI from WPRO 2000 criteria, and IBW of the Indian Navy and TNI/POLRI.

2 Methods

Generally, to obtain BMI of the subjects, BW and BH measurements are taken separately and then calculated the BMI value by dividing BW (in kg) to BH² (in m²). In this study have designed and manufactured digital integrated instrument for measuring BMI (Fig. 3). BW is measured using loadcell, BH is measured using ultrasonic sensor and age entered on touchscreen Liquid Crystal Display monitor (LCD, made by Orbital Matrix) 5 inch and the result is processed by using Arduino Mega 2560 microcontroller made in Italy.

The ultrasonic sensor used is HC-SR04 Micropik brand with the range of 2 to 400 cm and the accuracy can reach to 3 mm. The modules include ultrasonic transmitters, receivers and control circuits. The sensor placed in the upper frame above the subject head and ultrasonic wave reflections with a frequency of 40 kHz will be received at a speed of about 340 m/s. The microcontroller will calculate the time it takes to receive the wave and determine the distance between the sensor with the head as follows: Distance (S, m) = [time (s) x velocity (340 m/s)]/2. Thus the height of H (m) = 2 m - S (m).

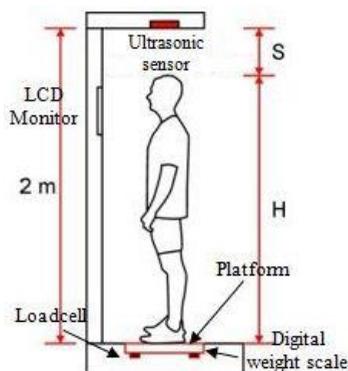


Fig. 3. Digital integrated instrument for measuring BMI

Digital weight scale with an accuracy of ± 0.2 kg (Xiaomi MI Smart made in China) with 4 loadcells (range of 20 to 80 kg) placed on the platform as shown in Fig. 3 and Fig. 4. Output loadcells in the form of analog signals forwarded to Arduino Mega 2560 microcontroller and converted into digital signals by analog to digital converter in microcontroller device. To see the display of weight value in LCD is by using TTL serial communication by entering a certain code.

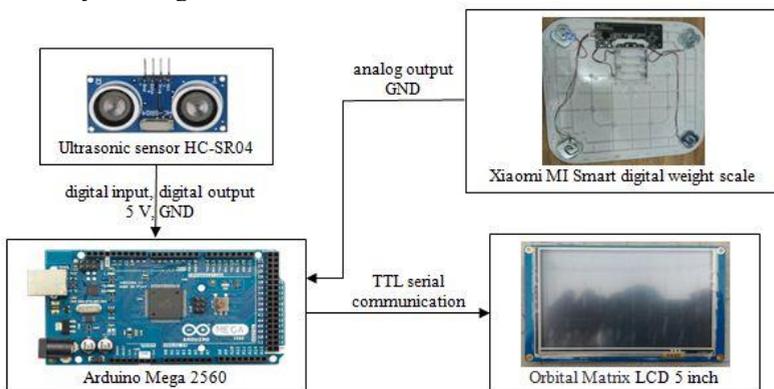


Fig. 4. The connection between hardware in the instrument to measure BMI

One hundred and two healthy students participated in this study (Table 1). Each subject was instructed to measure BW using Xiaomi MI Smart weight scale and BH using height measuring tape and measure BMI using a digital integrated instrument. The BW and BH measurement results separately will be compared to the digital integrated instrument to determine the percentage of error.

Table 1. Subject characteristics

	Age (year)	Gender (male:female)	Weight (kg)	Height (cm)	BMI (kg/m ²)
Range of Value	17 – 24		39 – 130	147 – 185	15.2 – 41.6
Mean and SD	20 ± 1.9	87 : 15	63.3 ± 13.8	167.3 ± 6.8	22.5 ± 4.2

In measurements using digital integrated instrument subjects were asked to use a swimsuit head cover (hijab for women), dressed in very light clothing, and bare feet standing on the platform and enter the age on touchscreen LCD monitor. Automatically displayed on the monitor BH (cm), BW (kg), BMI (kg/m²), comparison BW subject to Brodsky's and modified Broca's formula (eq. 1 and 2), and comparison BMI subject to WPRO 2000 criteria. Both for Brodsky's and modified Broca's formula the subject BW is an "ideal" category when the weight is still within the 10% bandwidth of the IBW.

To find out BW subject including the ideal category or not based on the Indian Navy and TNI and POLRI can be done by pressing the selection button available on the monitor. The IBW for age charts based on The Indian Navy recruitment (Fig. 1) obtained from correlation table between ideal height and weight for age range 17 to 24 years, which presented as linear regression equation (Table 2) [5]. The subjects who pressed this option on the monitor will show a linear graph of BH vs BW according to the age entered. The subject BW is an "ideal" when the weight is still within the 10% of bandwidth.

Table 2. The linear regression equation of IBW as the basis for recruitment of The Indian Navy

Age range (year)	Linear regression equation	Average ideal BMI (kg/m ²)
17-18	BW (kg) = 0.707 BH (cm) -64.75	19.1±0.2
19-20	BW (kg) = 0.713 BH (cm) -64.09	19.8±0.2
21-22	BW (kg) = 0.707 BH (cm) -62.06	20.1±0.1
23-24	BW (kg) = 0.754 BH (cm) -68.99	20.5±0.3

Conversely, if the subjects selected the IBW based on TNI and POLRI recruitment on the monitor will be shown two linear graphs BH vs BW showing the recommended limit of the maximum and minimum IBW (Fig. 2). These charts obtained from correlation table between ideal height and weight, which presented as a linear regression equation (Table 3) [6]. The subject BW is an "ideal" when the weight is within the recommended limit.

Table 3. The linear regression equation of IBW as the basis for recruitment of TNI and POLRI

Recommended limit	Linear regression equation	Average ideal BMI (kg/m ²)
Max	BW (kg) = 0.769 BH (cm) -65.95	19.1±0.2
Min	BW (kg) = 0.671 BH (cm) -58.02	19.8±0.2

3 Results and Discussion

From the separate measurement results there are BW error 0.96%, BH error 3.22%, and BMI error 2.88% compared to using the digital integrated instrument. This small

percentage error indicates that the digital integrated instrument can be used as an instrument to measure BW, BH, and BMI.

Based on Brodsky's formula (eq. 1) [10] there are 54% of subjects meet IBW criteria (93 male and 9 female), while 24% and 22% are below and above the 10% bandwidth respectively. Otherwise, from modified Broca's formula (eq. 2) [6] there are 57% of subjects meet IBW (96 male and 6 female), while 17% and 26% are below and above the 10% bandwidth respectively. From this result, the modified Broca's formula is more suitable for IBW identification shown by the number of subjects entering the ideal criteria are more than the Brodsky's formula. But for the IBW identification of women the Brodsky's formula is better than the modified Broca's formula, this is consistent with Brodsky et al's claimed that IBW is on eq. 1 applies also to female sex [10]. The use of Broca's formula (without multiplying 0.9) [11] is not suitable for IBW identification because only 37% of the study subjects entered the ideal criteria.

Based on WPRO 2000 [7] there are 56% of subjects in the normal BMI category, 8% underweight, 19% overweight, and 19% obese. These results are close to IBW from the modified Broca's formula which differ only 1% compared to normal weight.

Table 4 shows the average BW and BMI of all subjects for all age ranges. Only 48.1% of subjects who met the ideal criteria based on the Indian Navy recruitment [5]. Most of BW subjects who did not belong to the ideal category are above the 10% bandwidth, that are at the age range of 17-18 years 12 subjects, 19-20 years 19 subjects, 21-22 years 10 subjects, and 23-24 years 5 subjects.

Table 4. The average BW and BMI of all subjects for all age range

Age range (year)	Number of subjects	Average BW (kg)	Average BMI (kg/m ²)	Number of subjects that belong to the ideal category
17-18	21	65.22±16.83	23.09±4.89	9 (8.8%)
19-20	45	61.64±13.21	22.25±3.92	22 (21.6%)
21-22	23	66.64±12.80	22.94±4.17	12 (11.8%)
23-24	13	59.66±11.31	21.71±3.90	6 (5.9%)

Based on IBW of TNI and POLRI recruitment [6] there are only 41.2% of subjects who met the ideal criteria and 42.2% of BW subjects are above the maximum allowable IBW (Fig. 5). This result is close to the IBW on the Indian Navy recruitment for all age range where 45% of BW subjects are above the 10% bandwidth.

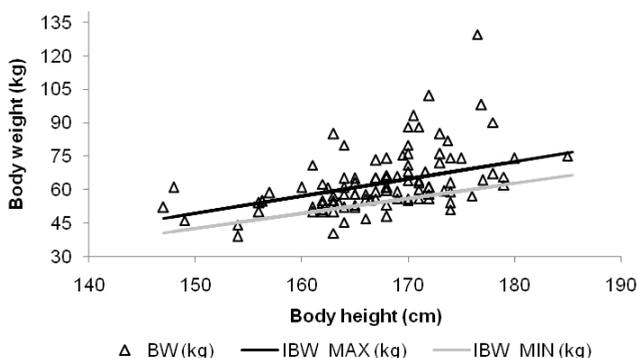


Fig. 5. The BW subjects compared to IBW recommended by TNI and POLRI

4 Conclusion

The digital integrated instrument designed and manufactured in this study can be used as an instrument to measure BW, BH, and BMI. This can be seen from the very small percentage of errors compared to the measurement of BH and BW separately.

The modified Broca's formula is more suitable for IBW identification of Indonesian populations than the Brodsky's formula, but for the IBW identification of women, the Brodsky's formula is better than the modified Broca's formula. The IBW found by modified Broca's formula approaches the normal BMI category of WPRO 2000 criteria.

Both IBW from the Indian Navy recruitment and TNI and POLRI recruitment can be used as medical criteria to determine IBW of the officer candidate.

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