METHOD FOR DETERMINING THE HUMAN BODY-MASS CENTER

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ABSTRACT

It is described method for determining the center of the equal torques and the center of mass of the human body. The proposed method can be applied in the field of biomechanics of the human body, physiotherapy, dietetics, anatomy and in various fields of biomedical sciences.

Key words: human, method, body-mass center.

INTRODUCTION

The center of mass of a solid is called the geometric point in the body which characterizes the movement of the mass considered as a whole (material point) (1). If a mechanical system consists of N of bodies of masses $M_1, M_2, M_3, \dots, M_N$, which can be considered as material points with radius vectors $R_1, R_2, R_3, \dots, R_N$, the point determined by the radius vector is called the 'center of the masses':

$$R_M = (M_1 R_1 + M_2 R_2 + M_3 R_3 + \dots + M_N R_N) / (M_1 + M_2 + M_3 + \dots + M_N) \quad [1]$$

The center of gravity of a solid is called the geometric point in the body, which is considered as a whole (material point) has a radius vector:

$$R_G = (G_1 R_1 + G_2 R_2 + G_3 R_3 + \dots + G_N R_N) / (G_1 + G_2 + G_3 + \dots + G_N) \quad [2]$$

where $G_1, G_2, G_3, \dots, G_N$ represent the forces of the weights of the individual parts of the body with radius vectors R_1, R_2, R_3, R_N .

The center of gravity and center of mass of a system of bodies or body parts coincide only when the gravitational field operating on the system is homogeneous (Earth acceleration has same value with respect to the whole system).

In this case:

$$R_M = R_G \quad [3]$$

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The center of mass of a solid body is fixed to body parts, whereas the position of the center of gravity, when changing the body position may move relative to those parts. Because the length of the human body is in the range between 0.75m-2.25m (which is very small in comparison with the radius of Earth) in practice the gravitational field is homogeneous and the center of mass and gravity coincide.

METHODS FOR CALCULATIONS

1. Main equations describing the measuring device.

The measuring device is a bed formed as a horizontal equally-spaced lever of two equal parts (Figure 1) with the same weight, length and torques of the two parts. For the lever, the main ratios are (1, 2):

$$L_1 = L_2 \quad [4]$$

$$G_1 = G_2 \quad [5]$$

$$G_1 \times L_1 = G_2 \times L_2 \quad [6]$$

Figure 1. Geometric parameters of the measuring device

2. Method for calculating the equal moments of forces (torques) of the parts of the human body in horizontal position.

The examined person lies on the bed-lever and selects the position of the body, whereby the lever is balanced in horizontal position (**Figure 2**). In this case, the next ratios are fulfilled (1, 2):

$$G_{up} \times H_{up} = G_{down} \times H_{down} \quad [7]$$

$$G_{up}/G_{down} = H_{down}/H_{up} \quad [8]$$

From Eq.7 for the torques of the upper and lower part of the body it is seen that the ratio between weights of the upper and lower body parts (G_{up} / G_{down}) is equal to ratio of the lengths (H_{down} / H_{up}) against the central line 0 - 0' of the bed-lever.

Since the center of gravity and center of mass of given body in homogeneous gravitational field are equal, the Eq.8 can be transformed into Eq. 9:

$$M_{up}/M_{down} = H_{down}/H_{up} \quad [9]$$

The basis for the equation [9] the ratio between gravity (G) and mass (M) at the same Earth acceleration ($g = 9.80 \text{ m/s}^2$):

$$M = G \times g \quad [10]$$

and

$$G_{up}/G_{down} = (G_{up} \times g)/(G_{down} \times g) = M_{up}/M_{down} \quad [11]$$

Figure 2. Illustration of the torques of the body parts in horizontal position.

3. Calculation of the center of the mass of the upper and lower part of the human body in horizontal position.

To calculate where is placed the center of mass of the human body in horizontal position, we must calculate the extra mass ΔM that we must add or extract from M_{up} or M_{down} to obtain the point, that divides equal mass of the upper and lower body part (**Figure 3**).

Figure 3. Calculation the center of body mass

The extra mass ΔM is calculated by measuring the length (h) against the line 0-0'. We calculate the volume ΔV of the additional mass $\Delta M = \rho \Delta V$ at average body density $\rho = 1070 \text{ kg/m}^3$. Around the hip area the human body is considered as ellipsoid with a large and small half-ax ('a' and 'b'), and volume $\Delta V = \pi \times a \times b \times h$ (where h is the desired length in relation to the line 0-0'). In this case $\Delta M = \rho \Delta V = \rho (\pi \times a \times b \times h)$ and the desired length h is equals to:

$$h = \Delta M / (\rho \times \pi \times a \times b). \quad \text{The middle body mass is equals to:}$$

$$M_{middle} = M_{body} / 2 = (M_{up} + M_{down}) / 2 \quad [12]$$

The additional mass ΔM can calculate by absolute value of the differences:

$$\Delta M = |M_{middle} - M_{up}| = |M_{middle} - M_{down}| \quad [13]$$

To find the center of gravity (R_M) must add or remove the desired length h to H_{down} or respectively H_{up} :

$$R_M = H_{down} + h = H_{up} - h \quad [14]$$

4. Calculated examples.

Man with weight $M_{body} = 90 \text{ kg}$, $H_{down} = 0.66 \text{ m}$, $H_{up} = 0.99 \text{ m}$, $2a = 0.36 \text{ m}$ and $2b = 0.26 \text{ m}$.

Because of $M_{up}/M_{down} = H_{down}/H_{up} = 0.99 \text{ m} / 0.66 \text{ m} = 3/2$ we can calculate that 1 part body mass is equals to $M_{body} / (3+2 \text{ parts}) = 90 \text{ kg} / 5 = 18 \text{ kg}$. In this case for $M_{up} = 3 \text{ parts} \times 18 \text{ kg} = 54 \text{ kg}$, and for $M_{down} = 2 \text{ parts} \times 18 \text{ kg} = 36 \text{ kg}$. Because of $M_{middle} = M_{body} / 2 = 45 \text{ kg}$ for ΔM :

$$\Delta M = |M_{middle} - M_{down}| = 45 \text{ kg} - 36 \text{ kg} = 9 \text{ kg} \quad [15]$$

We can calculate for $\Delta V = \pi \times a \times b \times h = 3.14 \times 0.18 \text{ m} \times 0.13 \text{ m} \times h = 0.0734 h \text{ (m}^3\text{)}$. For $\rho = 1070 \text{ kg/m}^3$ we can calculate for ΔM :

$$\Delta M = \rho \Delta V = 1070 (\text{kg/m}^3) \times 0.0734 h \text{ (m}^3\text{)} = 78.538 h \text{ (kg)} \quad [16]$$

After alignment of Eq.15 and Eq.16 we can receive:

$$\Delta M = 9(\text{kg}) = 78.538h(\text{kg}) \quad [17]$$

From Eq.17 we calculate for $h = 9/78.38 = 0.1145\text{m}$. For mass-center we receive:

$$R_M = H_{\text{down}} + h = 0.99\text{m} + 0.1145\text{m} = 1.1045\text{m} \quad [18]$$

DISCUSSION

In medical practice the body characteristics such as mass, height, BMI, waist to hip and other body characteristics are often used (3, 4). But, these body characteristics do not give a good idea of the mass distribution in the upper and lower body part. The proposed method makes it possible to determine the centers of equal torques and the center of gravity/mass of the upper and lower part of the body and can be a good addition to the above-mentioned methods and body characteristics.

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