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THERAPY

Determination of the Centre of Gravity in the methodology of kinesiotherapy for osteoporotic patients

Wendlova J

Derer's University Hospital and Policlinic, Osteological Centre, Bratislava, Slovakia. **jwendlova@mail.t-com.sk**

Abstract: The article brings a biomechanical analysis of the determination of the position of gravity centre of trainee in plane, both graphically and by calculation.
The importance of determining the position of the gravity centre in different postures of a trainee should not be underestimated, as it belongs to the basic principles in the development of methodology of kinesitherapy for both healthy and ill people.
An erudite methodology of kinesitherapy for osteoporotic patients can be developed only on the basis of biomechanical analysis of each exercise element, i.e., it is necessary to have the knowledge of the position of gravity centre, support area and the distance of the gravity centre projection from the stability limit, magnitude of the stability angle, and regularity of mechanical stress acting upon weakened osteoporotic vertebrae. A correctly chosen methodology of kinesitherapy for osteoporotic patients prevents the development of vertebral microfractures, prevents the patient from falling during the exercise, and stimulates the bone neoformation with increasing the bone mineral density and periosteal apposition of bone, followed by the enlargement of the bone cross sectional area as well as that of the cross sectional moment of inertia.. The resulting effect is an improvement in bone quality and its mechanical resistance *(Tab. 2, Fig. 7, Ref. 11).* Full Text (Free, PDF) *www.bmj.sk.*
Key words: biomechanics, determination of centre of gravity, osteoporosis, methodology of kinesitherapy.

The knowledge of mechanical conditions of the static and dynamic balance of skeleton is an important factor in the development of the methodology of kinesitherapy, especially for osteoporotic patients. An incorrectly chosen methodology of kinesitherapy with improperly stressed osteoporotic skeleton may result in the development of vertebral microfractures and rib infractions. Ignorance of the regularity of shifting the point of gravity centre of the body during the changes in the body's positions may lead to the development of exercises during which the trainee acquires some postures with reduced stability and for an osteoporotic patient this represents a risk of falling during exercise and a consequent risk of fracture with low energy injury.

Biomechanical conditions of the static and dynamic balance of skeleton

In the performance of everyday movements during physical work and exercise, the gravity force (*G*) acts upon each material point of human body. To maintain a balance while standing or moving, it is necessary that the effects of all forces acting upon a man are mutually cancelled, i. e., they have to equal zero.

Derer's University Hospital and Policlinic, Osteological Centre, Bratislava, Slovakia

Address for correspondence: J. Wendlová MD, PhD, Krizna 30, SK-811 07 Bratislava, Slovakia.

*Definitions (*1–4)

Mass (*m*) is a feature of a material body, manifested in a gravitational field by force effects, i.e., the gravity.

The body mass in the biomechanics is represented by a specific amount of mass and is determined by weighting. It is marked by letter *m* and measured values are given in *kg* according to international units. It is directly proportional to the gravity force (*G*) and inversely proportional to the gravitational acceleration (*g*).

The force of gravity (***G***) is the force with which the Earth acts upon the body mass and its magnitude depends upon a distance of the body from the Earth's centre. It is directly proportional to the body mass and gravitational acceleration.

The force of gravity is determined by the place of its action, magnitude, direction, and sense.

Mathematical definitions

mass: $m = \frac{G}{g}$ (kg)

gravity force: $G = m \times g$ (kg.ms^2)

gravitational acceleration: $g = 9.80665$ ms^{-2}

From the mechanical point of view the **balance constancy** in any posture of a man is determined by:

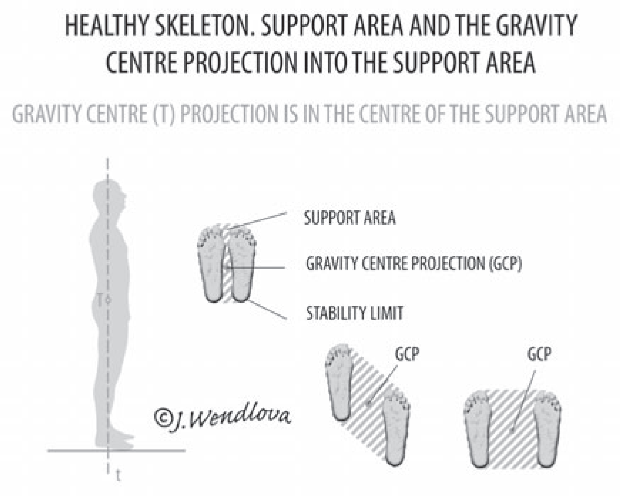

Figure 1

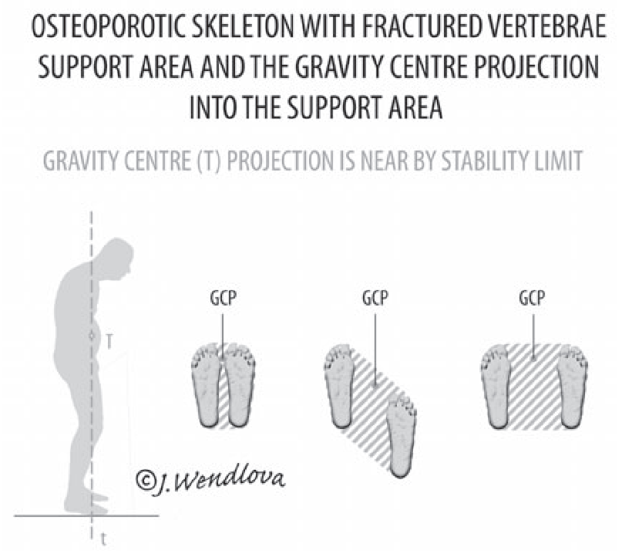

Figure 2

- the magnitude of the **support area**
- the position of the body's **gravity centre** in relation to the support area
- the distance of the body's median (the **gravity centre projection**) from the edge of the support area
- the magnitude of the **stability angle**

The **support area** of a man is represented by the area limited by the outer limit of the body's contact point with the ground. The outer limit of this support area is called the **edge of the support area** or the **stability limit**. The **gravity centre** (*T*) of the body is represented by a material point, concentrating the whole force of the body's gravity (the body mass). It is called also the mass centre. The body mass is equally distributed from this point to all sides. The **median** (*t*) is a vertical line passing through the gravity centre. The **gravity centre projection** (*PT*) is the point in the support area, crossed by the median (Fig. 1).

When the gravity centre projection in different exercise positions gets over the edge of the support area, i.e., beyond the stability limit, the trainee is in an unbalanced position and falls down to the ground. In patients with osteoporotic fractures of vertebrae the projection of the gravity centre into the support area gets close to the stability limit of the support area in the upright position, and so these patients are prone to falling when leaning forward or to sides (Fig. 2).

The gravity centre position depends upon

- the mass
- the form
- the length

] of the individual body parts

The **stability angle** is the angle formed by the median and the line passing through the gravity centre and the edge of the body's support area (Fig. 3).

The **stability of the skeleton** is increased by

- the enlargement of the support area
- the approximation of the gravity centre to the support area
- the approximation of the median (gravity centre projection) to the centre of the support area
- the enlargement of the stability angle

The gravity centre of different parts of the limbs lies upon the line joining the joint centres of a given limb part (the gravity centre divides the joining line into two parts in ratio of 4:5 in the direction from the proximal toward the distal joint). The position of the gravity centre is determined by the distance from the

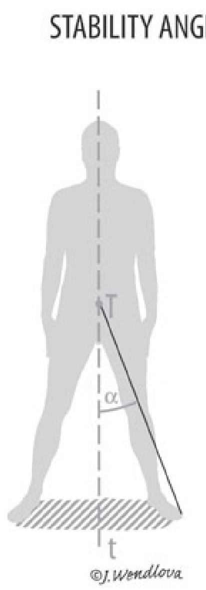

Figure 3

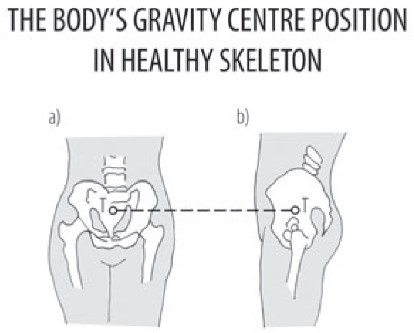

Figure 4

Tab. 1. The gravity centre positions of individual body parts expressed in % of the overall length of a given body part (Donskoy) (2).

Body parts	The gravity centre position to the proximal end of the body part (%)
upper arm	0.47
forearm	0.42
thigh	0.44
lower leg	0.42
foot	0.44
torso	0.44
head	0.44

proximal joint, which is given in *cm* or in percentage of the overall length of the limb part.

The gravity centre of the head and the torso lies in the saggital plane (in the vertical axis of the body) and is determined by the distance from the proximal part of the head and the torso, and is given in *cm* or percentage from the overall length of the torso and the head.

The gravity centre position of the individual body parts is determined, e.g., according to Donskoy, on the basis of the percentage expression from the overall length of the body part (Tab. 1).

The body's gravity centre position when standing upright is situated about five centimetres over the articulation coxae (hip joint) in the saggital plane (the plane of body's symmetry) in the pelvis behind the symphysis pubis (pubic bone). The gravity centre point is at 52 % of the overall height of the person calculated from the support area (Fig. 4). The body's gravity centre position depends upon many factors, primarily upon the body mass, its shape, the ratio of the mass of individual body parts to their length. The gravity centre position in women is about 0.5 to 2 % lower than in men.

Approximate determination of the gravity centre position in different body parts (Fig. 5)

- gravity centre of the head – situated inside the head behind sella turcica (Turk' saddle)
- gravity centre of the torso – situated at the frontal area of the first lumbar vertebra
- gravity centre of the torso with head – situated at the frontal side of the 11th thoracic vertebra
- gravity centre of the whole upper limb – situated at the elbow joint
- gravity centre of the upper arm – situated over the half of its length closer to the shoulder joint
- gravity centre of forearm – situated over the half of its length closer to the elbow joint
- gravity centre of hand – situated at the lower protuberance of the second wristbone
- gravity centre of the whole lower limb – situated at the rear side of the thighbone about 8 cm over the knee
- gravity centre of thigh – situated at the frontal side of the thighbone between the upper and the middle thirds
- gravity centre of lower leg – situated at the rear side of the shinbone between the upper and middle thirds
- gravity centre of foot – situated at the navicular bone.

The importance of determining the position of the gravity centre in different postures of a trainee should not be underestimated, as it belongs to the basic principles in the development of methodology of kinesitherapy for both healthy and ill people.

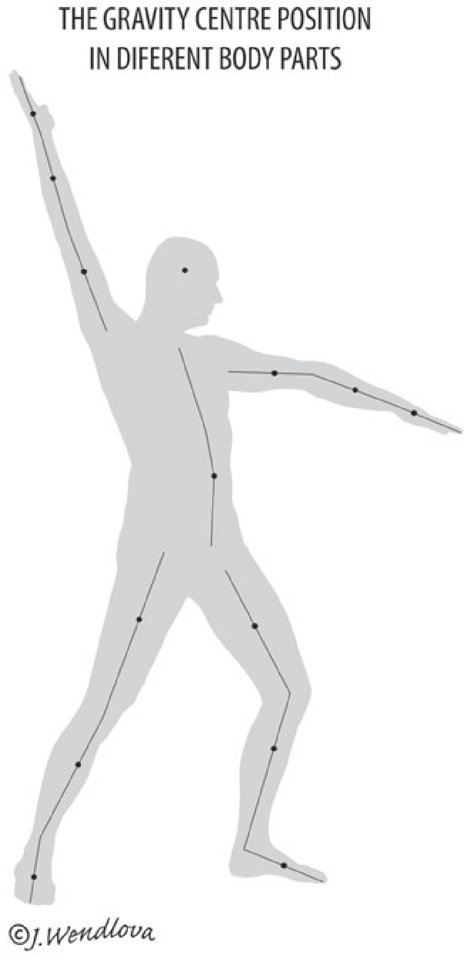

Figure 5

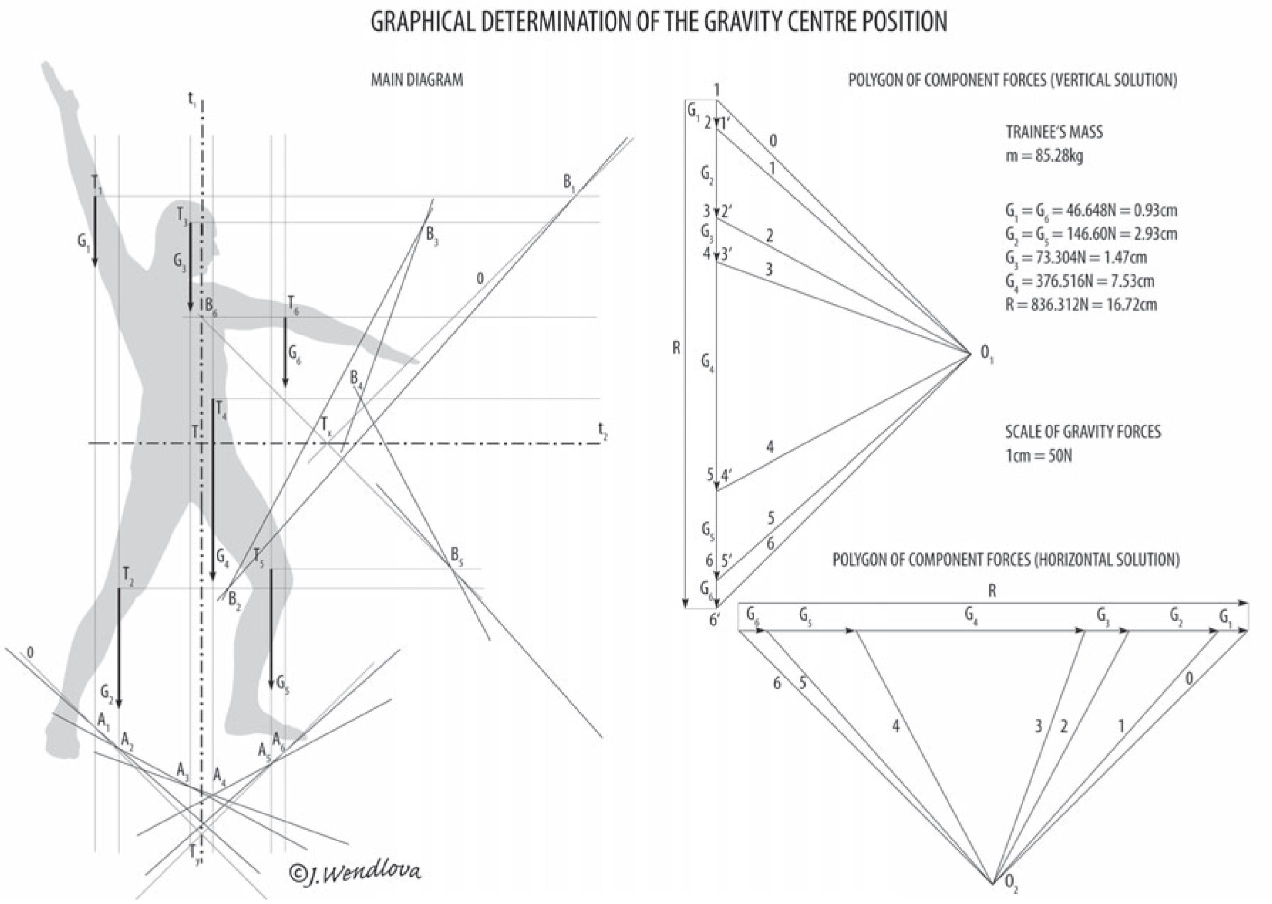

Figure 6

Therefore, we demonstrate a method of calculating the body gravity centre on a model example.

Determination of the body's gravity centre position of a trainee in plane

The body's gravity centre in plane can be determined in two ways:
1. graphically
2. by calculation

1. Graphical determination of the gravity centre position (Fig. 6) (5, 6)

The principal force acting upon each material point in the body of the trainee is the force of gravity *G.*

According to Tab1, in the trainee's photography we determine the gravity centres of different body parts in his exercise posture (the photography with gravity forces is called *the main diagram*). The following resultants of the gravity forces will be applied in the individual body parts *T1* to *T6*: The head – G_1, the right UL* – G_2, the left UL – G_3, the torso – G_4, the right LL** – G_5, the left LL – G_6, through which we draw the rays of the gravity forces.

UL* – upper limb
LL** – lower limb

Model example 1

Task assignment

According to Table 2 (Fischer) we calculate the masses of individual body parts; multiply them by the gravitational acceleration (g) and the results are the gravity forces of body parts.

The trainee's mass is m = 85.28 kg, G = 836.332 N

Head...................... 73.304 N
Torso .... 376.516 N
Thigh .... 91.36 N
Lower leg .... 37.485 N
Foot....................... 17.493 N

LL=thigh+lower leg+foot=146.608 N

Tab. 2. The ratio of the mass of different body parts to the whole body in percentage (Body mass = 100%) (2).

Body part	The ratio of the mass of a body part to the whole body in % (according to Fischer)	The ratio of the mass of a body part to the whole body in % (according to Dempster)
head	8.8	8.1
torso	45.2	49.7
thigh	11.0	9.9
lower leg	4.5	4.6
foot	2.1	1.4
upper arm	2.8	2.8
forearm	2.0	1.6
hand	0.8	0.6

Upper arm .... 23.324 N
Forearm .... 16.66 N
Hand .... 6.664 N
UL = upper arm + forearm + hand = 46.648 N

To transfer the gravity forces into a *polygon of component forces* we select a scale, for instance:

1 cm = 50 N

The aim of the solution

To determine the gravity centre position of a trainee in a chosen posture in a graphical way.

The solution of the example

As all forces are acting in the same vertical direction, we can compose them into one vertical line, referred to as resultant of the forces of gravity R. In the composition of forces of gravity each force is marked by its determination segment. The magnitude of the force G_1 is given by the determination segment 1; 1', G_2 – 2; 2', G_3 – 3; 3', G_4 – 4; 4', G_5 – 5; 5', G_6 – 6; 6'.

Polygon of component forces (vertical solution)

We select a pole O_1 at a random distance from the resultant R and from the latter we draw polar rays (marked 0 to 6). The ray 0 is drawn towards the beginning of the determination segment of the gravity force G_1 and the rest of rays towards the end points of individual determination segments. The picture with composed gravity forces and polar rays is referred to as *polygon of component forces.* We draw parallels with individual polar rays from the *polygon of component forces* into the *main diagram.* The line parallel to polar ray 0 crosses the vertical ray of gravity force G_1 in point A_1. From point A_1 we draw a line parallel to ray 1 from the component picture until it crosses the vertical ray of the gravity force G_2 in the *main diagram*. This forms the point A_2. From the point A_2 we draw a line parallel to the vertical ray 2 from the *polygon of component forces* until it crosses the vertical ray of gravity force G_3 and so we get the point A_3. We continue in the same way until we form the point A_6. The intersection of ray 0 passing through point A_1 with ray 6 passing through point A_6 forms the point T_y. The median (t_1) passes through the latter point, and is parallel to gravity forces G_1 up to G_6.

Polygon of component forces (horizontal solution).

We rotate the polygon of forces in the clockwise direction in plane by 90° and let the gravity forces act upon the same gravity centres but in the horizontal direction, i.e., in the perpendicular direction to the vertical gravity forces.

In the *main diagram* we produce lines parallel to individual polar rays from the *polygon of component forces*. The line parallel to ray 0 crosses the horizontal ray of gravity force G_1 in point B_1. From point B_1 we draw a line parallel to ray 1 from the *polygon of component forces* until it crosses the horizontal ray of gravity force G_2 in the *main diagram*. Thus we get the point B_2. From point B_2 we draw a line parallel to ray 2 from the *polygon of component forces* until it crosses the horizontal ray of gravity force G_3 and in this way produces the point B_3. We continue in the same way until we produce the point B_6. The point T_x, produced by the intersection of ray 0 with ray 6. The median (t_2) passes through the latter point and is parallel to the horizontal rays of gravity forces G_1 to G_6.

The gravity centre *T* of trainee is situated in the intersection of both medians t_1 and t_2.

2. Determination of the gravity centre position by calculation (Fig. 7) (5–8)

Let us situate the picture of the trainee, used in the example 1, with marked gravity centres and gravity forces of individual body parts, into a coordinates system of two, mutually perpendicular axes *x,y.*

Model example 2

Task assignment

The mass of the trainee is 85.28 kg (m = 85.28 kg), the resultant gravity force is *G* = 836.332 N

The gravity forces of individual body parts are calculated as in the model example 1.

UL .... $G_1 = G_6 = 46.648$ N
LL .... $G_2 = G_5 = 146.608$ N
Head .... $G_3 = 73.304$ N
Torso .... $G_4 = 376.516$ N

The aim of the solution

To determine the gravity centre position of the trainee in a chosen posture by calculation.

The solution of the example

We draw rays parallel to the axis *y* through the gravity centres T_1 to T_6 and gravity forces G_1 to G_6. We turn these forces by 90° and we draw rays parallel to axis *x* through gravity centres T_1 to T_6.

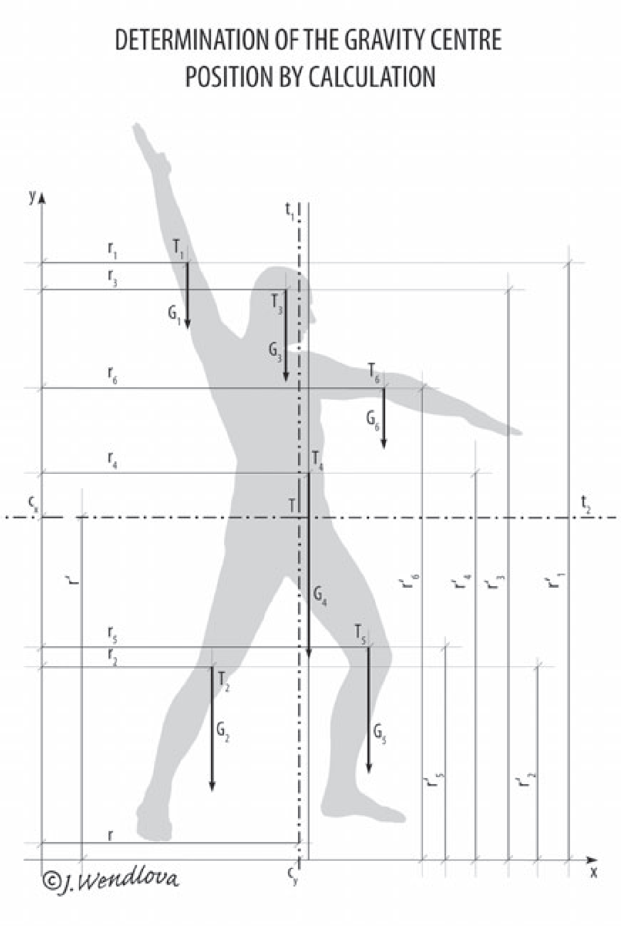

Figure 7

The calculation of the gravity centre position of the trainee is based upon two moment conditions:

1. The moment of the resultant gravity forces acting upon the axis ***y*** (M_y) equals the sum of the moments of individual gravity forces acting upon the axis ***y***.
2. The moment of the resultant gravity forces acting upon the axis ***x*** (M_x) equals the sum of the moments of individual gravity forces acting upon the axis ***x***.

The moment of the gravity force is given by the product of the gravity force and the arm (perpendicular distance to the axis *x* or *y*) upon which the gravity force is acting:

M = G x r

Perpendicular distances of partial gravity centres T_1 to T_6 from the axis y are arms of the forces r_1 to r_6 upon which the individual gravity forces G_1 to G_6 are acting.

The arms of the forces r_1 to r_6 can be measured from the picture (in *cm*):

r_1=4.67 cm, r_2=5.46 cm, r_3=7.80 cm, r_4= 8.53 cm , r_5=10.45 cm, r_6=10.91 cm

According to the 1st moment condition, it is valid that:

The moment of the resultant of forces acting upon the axis *y* (M_y) equals:

$M_Y = G_1 \text{ x } r_1 + G_2 \text{ x } r_2 + G_3 \text{ x } r_3 + G_4 \text{ x } r_4 + G_5 \text{ x } r_5 + G_6 \text{ x } r_6 =$ 46.648 x 4.67 + 146.608 x 5.46 + 73.304 x 7.80 + 376.516 x 8.53 + 146.608 x 10.45 + 46.648 x 10.91 = <u>6842.759 N</u>

G = 836.332 N
M_Y = 6842.759 N

$$M_y = G \text{ x } r \qquad r = \frac{M_y}{G} = \frac{6842.759\ Ncm}{836.332\ N} = 8.18\ cm$$

The length of the arm to the axis *y,* upon which the resultant gravity force *G* acts, is 8.18 cm. We apply the length of the arm, i.e. *r* = 8.18 cm on the axis *x* and in the latter way we produce the point C_y. Through the latter point we draw a line parallel to axis *y* and refer to it as median t_1.

Perpendicular distances of partial gravity centres T_1 to T_6 from axis *x* are the arms of forces r'_1 to r'_6 upon which the individual gravity forces G_1 to G_6 act in case we turn the picture of trainee by 90°.

The arms of forces r'_1 to r'_6 can be measured again from the picture (in *cm*)

r'_1 = 19.07 cm, r'_2 = 6.16 cm, r'_3 = 18.16 cm, r'_4 = 12.32 cm, r'_5 = 6.8 cm, r'_6 = 15.06 cm

According to the 2nd moment condition, it is valid that:

The moment of the resultant of forces acting upon the axis *x* (M_x) equals:

$M_X = G_1 \text{ x } r'_1 + G_2 \text{ x } r'_2 + G_3 \text{ x } r'_3 + G_4 \text{ x } r'_4 + G_5 \text{ x } r'_5 + G_6 \text{ x } r'_6$ = 46.648 x 19.07 + 146.608 x 6.16 +73.304 x 18.16 + 376.516 x 12.32 + 146.608 x 6.8 + 46.648 x 15.06 = <u>9462.013 Ncm</u>

$$M_X = G \text{ x } r' \qquad r' = \frac{M_x}{G} = \frac{9462.013}{836.332\ N} = 11.313\ cm$$

The length of the arm to the axis x, upon which the resultant gravity force *G* acts, is 11.31 cm. We apply the length of the arm, i.e. r' = 11.31 cm on axis *y* and in the latter way we produce the point C_x. Through the latter point we draw a line parallel to axis *x* and refer to it as median t_2.

The trainee's gravity centre *T* is situated in the intersection of both medians t_1 and t_2.

Conclusion

Determination of the gravity centre position of trainee during sport performance is made by means of a film camera and special computer software, using biomechanical method of determination of the gravity centre position especially by calculation. It serves to educate sportsmen, because the watching of the film record and the analysis of the gravity centre positions enable them to rectify their faults in further performances and facilitate the drill of correct techniques of movement and maintaining stability during performances of different sport events. The analysis of the gravity centre position is also used in the methodology of developing new exercises in gymnastics, figure skating, aerobics, etc.; it also ensures the stability of trainee in any exercise positions.

The analytical method of determining the gravity centre position starts to be used also in the development of the methodology of kinesitherapy for patients with osteoporosis and other diseases of musculoskeletal system (9–10).

An erudite methodology of kinesitherapy for osteoporotic patients can be developed only on the basis of biomechanical analysis of each exercise element (i.e. it is necessary to have the knowledge of the position of gravity centre, magnitude of support area and the distance of gravity centre projection from the stability limit, magnitude of the stability angle, and regularity of mechanical stress acting upon weakened osteoporotic vertebrae). A correctly chosen methodology of kinesitherapy for osteoporotic patients prevents the development of vertebral microfractures, prevents patients from falling during exercise, and stimulates the bone neoformation with increasing the bone mineral density and periosteal apposition of bone, followed by the enlargement of the bone cross sectional area as well as that of the cross sectional moment of inertia. The resulting effect is an improvement in bone quality and its mechanical resistance (11).

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