Bratisl Lek Listy 2008; 109 (10)
441 – 444

PERSPECTIVES

Biomechanical conditions for maintaining body balance in kinesitherapy of osteoporotic patients

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Abstract: Regularities of mechanical conditions of body's static and dynamic balance are applied not only in movement techniques of sports events, but also in setting up exercises for osteoporotic patients. It is important to set up exercises in which the patient takes such a position where the forces acting upon him (action forces) are in balance with the forces generated in the patient's musculoskeletal system (reaction forces).
On the basis of biomechanical analysis of conditions for maintaining a trainee's body balance in training position, we point out the importance of individual exercise in sitting and prone positions led by a rehabilitation instructor, aiming at the removal of muscular dysbalance, before including the patient in group exercise. Following the preparatory exercise, the patient gains greater muscular strength and is able to keep balanced positions easier while standing. The patient's performance in exercise increases and the risk of falling during group exercise diminishes.
The aim of the article is to motivate rehabilitation instructors to set up an erudite methodology of kinesitherapy while meeting the conditions of proportional load of musculoskeletal system of osteoporotic patients, based on the principles of biomechanics *(Tab. 2, Fig. 1, Ref. 10).* Full Text (Free, PDF) *www.bmj.sk.*
Key words: biomechanics, body balance, osteoporosis, methodology of kinesitherapy.

Kinesitherapy is an indivisible and successful part of complex therapy of osteoporotic patients; therefore it is important to pay attention to the methodology of kinesitherapy. A correctly chosen methodology of kinesitherapy has to pay regard to biomechanical regularities of weakened osteoporotic skeleton as well as body's muscular dysbalance, especially the torso. Regularities of mechanical conditions of body's static and dynamic balance are used not only in movement techniques of sports events, but also in setting up exercises for osteoporotic patients. It is important to set up exercises, in which the patient takes a position where the forces acting upon him (action forces) are in balance with the forces generated in the patient's musculoskeletal system (reaction forces) (1).

Training position has to be chosen so that the action forces acting upon the trainee do not exceed the effects of reaction forces generated in the musculoskeletal system, i. e., do not exceed a permitted load of osteporotic bones (proportional limit in tension and compression for bone) and muscles, weakened by muscular dysbalance (proportional limit in tension and compression for muscle) (2, 3).

As it is presently not possible to determine *in vivo* the current value of proportional limit for bones and muscles of the patient, in setting up the methodology of kinestherapy we have to apply general laws of biomechanics of loading brittle (bones) and tenacious (muscles) materials, as well as mathematic modelling of loading osteoporotic skeleton, especially the spine, entering different values of BMD (bone mineral density).

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Footnote: Figures are created by author.

Conditions for maintaining the trainee's balance Biomechanical analysis (4–8)

Minimum two of three equilibrium conditions have to be applied in any movement, if the trainee has to keep balance in different positions during exercise.

Three general conditions for equilibrium of plane system of forces in theoretical mechanics:

1. The sum of vertical forces in the plane equals zero.

2. The sum of horizontal forces in the plane equals zero.

3. The sum of moments of forces to a given point equals zero.

<u>Model example</u>

The task is to find out the way the trainee keeps balance in the position in the picture, i.e. to assess the forces acting upon the trainee, as well as the reaction forces generated in muscles and bones of the trainee.

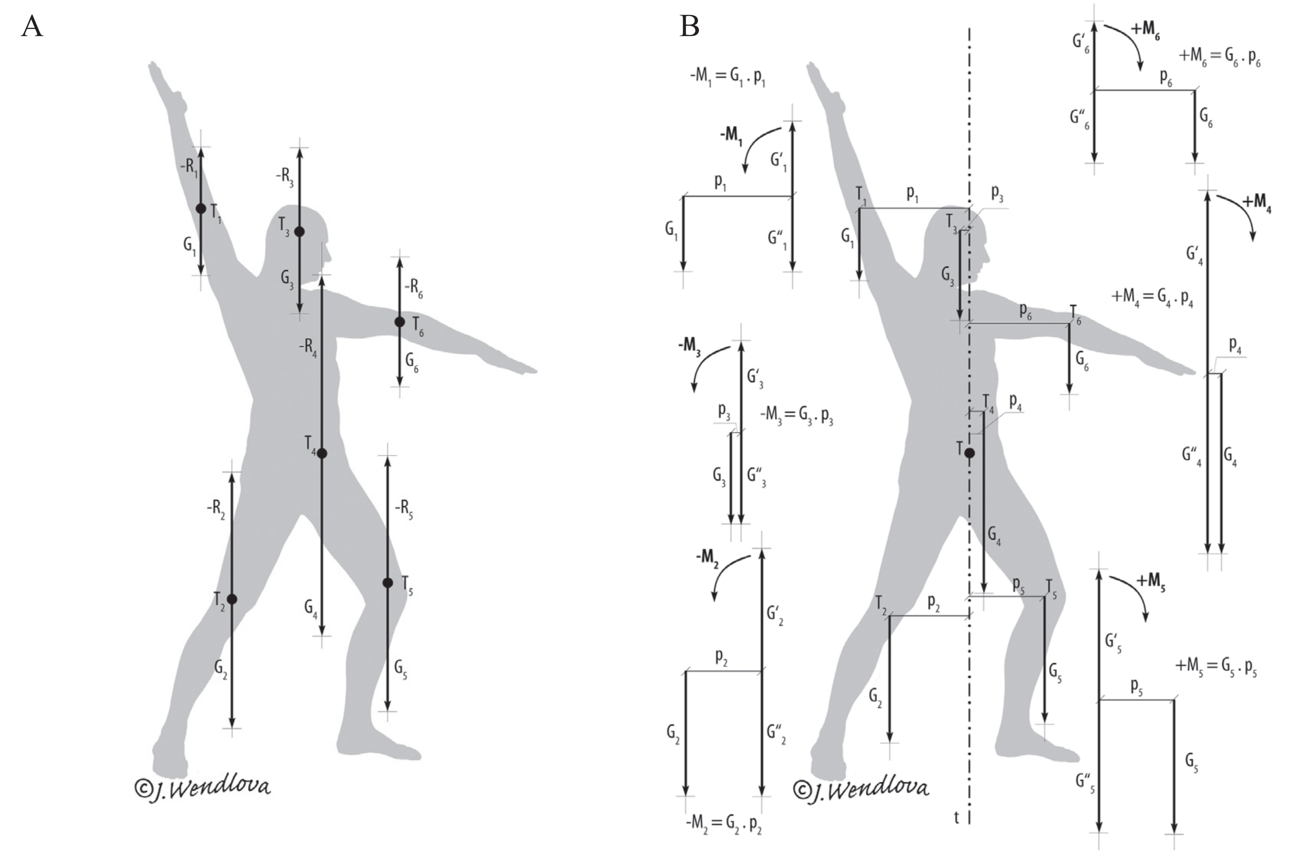

Fig. 1 a, b. Selecting a training position to be analysed and taking its picture.

Calculation of tasks for the example

1) determining the trainee's mass, m = x (kg)
2) selecting a training position to be analysed and taking its picture (Fig. 1a, b)
3) calculating masses of individual body parts ($m_1 – m_6$) from the trainee's mass according to Fischer (Tab 1), multiplying it by gravitational acceleration ($g = 9.80665\ ms^{-2}$) to get the gravity forces of body parts ($G_1 – G_6$)
   Upper limb (UL) .... $G_1 = G_6$
   Lower limb (LL) .... $G_2 = G_5$
   Head .... G_3
   Torso .... G_4
4) establishing the positions of gravity centres T1 – T6, e.g., according to Donsky (Tab 2)
   T_1, T_6 – gravity centre of the whole upper limb – situated at the elbow joint
   T_2, T_5 – gravity centre of the whole lower limb – situated at the rear side of the thighbone about 8 cm above the knee
   T_3 – gravity centre of the head – situated inside the head behind sella turcica (Turk's saddle)
   T_4 – gravity centre of the torso – situated at the frontal area of the first lumbar vertebra
   Magnitudes of gravity forces $G_1 – G_6$ act in the gravity centres $T_1 – T_6$.

Solution of the example

The starting point is Fig 1a with marked gravity centres $T_1 – T_6$ of individual body parts, where the gravity forces $G_1 – G_6$ are acting.

Any movement of the trainee means the emergence of reaction forces to gravity forces in each material point of bones, muscles, and tendons. In a balanced state of the trainee, the magnitudes of resultants of these reaction forces $R_1 – R_6$ (marked by symbol minus -), acting also in gravity centres $T_1 – T_6$, are identical with gravity forces $G_1 – G_6$, however, they are of opposite direction.

$G_1 = - R_1$, $G_2 = - R_2$, $G_3 = - R_3$ .... etc.

The solution has to be based on two conditions of the equilibrium of plane system of forces (1st and 3rd condition).

1st condition of equilibrium: (Fig.1a)

- *The sum of vertical forces in the plane equals zero*

$$\sum_{i=1}^{6} G_i + \sum_{I=1}^{6} R_i = 0$$

To maintain the trainee's balanced position in a given training position, the following formula has to apply:

G1 + G2 + G3 + G4 + G5 + G6 + (-R1) + (-R2) + (- R3) + (- R4) + (- R5) + (-R6) = 0

Tab. 1. 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 Fisher)	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

3rd condition of equilibrium: (Fig. 1b)

• *The sum of moments of forces to a given point equals zero.*

$$\sum_{i=1}^{6} M_i = 0$$

The gravity forces $G_1 – G_6$ do not act in partial gravity centres $T_1 – T_6$ only, but are transferred into the gravity centre of the whole body T, where they act as a resultant vertical gravity force G. To find out how the individual gravity forces $G_1 – G_6$ act upon the trainee in a training position, we have to add virtually to each gravity force a couple of forces in the median t (the couple of mutually cancelling forces). The couple of forces consist of two equally large forces acting in the same ray and point of application, however, they are of the opposite direction and sense, while it holds true that:

$G_1 = G_1' = G_1''$, $G_2 = G_2' = G_2''$, $G_3 = G_3' = G_3''$....., etc.

The equilibrium status of forces does not change, as the effects of both added forces are mutually cancelled. The generation of the couple of forces helps to explain the strain of the trainee's body by individual gravity forces $G_1 – G_6$ in the median t, and finally even in the gravity centre T.

Distances of gravity forces $G_1 – G_6$ from the median t are marked as $p_1 – p_6$. These distances are arms, upon which act the couples of gravity forces $G_1 – G_1'$, $G_2 – G_2'$, $G_3 – G_3'$, $G_4 – G_4'$ etc.

The trainee's body part, crossed by the median t, is loaded by:

a) bending moments

and

b) vertical compressive forces

a) Bending moments of gravity forces

$-M_1 = G_1 x p_1$

$-M_2 = G_2 x p_2$

$-M_3 = G_3 x p_3$

$+M_4 = G_4 x p_4$

$+M_5 = G_5 x p_5$

$+M_6 = G_6 x p_6$

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

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

Values of gravity forces $G_1 – G_6$ are known, calculated according to Tab 1. The arms of gravity forces $p_1 – p_6$ are real distances of gravity centres $T_1 – T_6$ of the trainee from the median t, which have to be measured in the photograph (computer programs measure them automatically during recording the trainee's position by a movie camera and telescopically determine the position of the gravity centre). The values $G_1 – G_6$ and $p_1 – p_6$ are set into equations for the calculation of bending moments.

Explanatory note to symbols used in equations
The clockwise acting force moment is called a positive moment, marked by the symbol (+), the counterclockwise acting force moment is called a negative moment and marked by the symbol (-).

To maintain the trainee's balanced position in a given training position, the 3rd equilibrium condition has to apply, namely that the sum of moments of gravity forces in the plane equals zero.

$(-M_1) + (-M_2) + (-M_3) + M_4 + M_5 + M_6 = 0$

b) Vertical compressive forces

Gravity forces marked as G_1'', G_2'', G_3''..... G_6'' are vertical compressive forces from virtually added mutually cancelled forces in the median. These vertical compressive forces are put together into a resultant vertical gravity force G.

$G_1'' + G_2'' + G_3'' + G_4'' + G_5'' + G_6'' = G$

The resultant gravity force G acts in the gravity centre T as a vertical compressive force. In the same way the reaction forces R_1, R_2, R_3.........R_6 are transferred into the median t and put together into the resultant force R, acting also in the gravity centre T, equally large as the resultant gravity force G, but of opposite direction (Fig. 1a).

It holds true that:

$G = (-R)$

After meeting the equilibrium conditions, the trainee is in a balanced state in the training position given in Figures 1a and 1b. The solution of the example explains that if an osteoporotic trainee has to maintain balance even in the most demanding training positions, it is necessary that he develops in his muscles equally large reaction forces against the gravity forces acting upon partial gravity centres of individual body parts. This is possible only after regular training and strengthening of the muscles of the whole body. It is not acceptable, however, for the osteoporotic trainee to increase the magnitude of reaction forces by, e.g., using dumbbells or lifting weights due to the risk of vertebral microfractures.

Conclusion

On the basis of biomechanical analysis of conditions for maintaining a trainee's body balance in training position, we recommend to begin with individual exercise in sitting and prone positions led by a rehabilitation instructor. The latter exercise is aimed at the removal of muscular dysbalance, before including the patient in group exercise. Following the preparatory exercise, the patient gains greater muscular strength and is able to keep balanced positions easier while standing. The patient's performance in exercise increases, and the risk of falling during group exercise diminishes.

Based on the analysis of conditions for maintaining balance in any training position, we point out two principal requirements in setting up exercises for osteoporotic patients:

1) to load osteoporotic skeleton proportionally according to measured BMD values and patient's muscular strength
2) to balance the muscular dysbalance (strengthening weakened muscles and stretching shortened muscles)

Kinesitherapy helps to increase the strength of patient's musculature and bone strength (BMD increase, increase in cross section moment of inertia – CSMI) and so to increase the potential of reaction forces in the musculoskeletal system allowing for a better resistance to loading by external action forces (physical work, exercise, daily chores, fall, force acting during an accident…).

The increase in the potential of reaction forces allows increasing the potential of action forces, which is a case of positive potentiated dependence. The resistance of the musculoskeletal system to loading by external forces increases, and this is the main goal we want to achieve in the therapy of osteoporotic patients. The increase in muscular strength in osteoporotic patients improves the physical condition and contributes to their independence and better quality of life. The increase in bone strength diminishes the risk of fractures with low energy of traumatic force and reduces the risk of spontaneous vertebral fractures with subsequent disability of the patient (9).

The aim of the article is to motivate rehabilitation instructors to set up an erudite methodology of kinesitherapy based on the principles of biomechanics while meeting the conditions of proportional load of musculoskeletal system in osteoporotic patients.

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Received May 26, 2008.
Accepted August 20, 2008.