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THERAPY

Nordic walking – is it suitable for patients with fractured vertebra?

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Abstract: This article brings the biomechanical analysis of sport – Nordic walking – for patients with osteoporotic fractured vertebrae and shows that it is suitable for them.
Based on the biomechanical model of skeletal load we have developed a method of walking movement for patients, different from the method of walking movement for healthy people. And so came into being the „first sport" for patients with osteoporotic fractures. They can go for regular walks in easy terrains outdoors with friends and family, and so be liberated from social isolation. It requires only one-off financial costs of buying the poles and special footwear *(Tab. 1, Fig. 3, Ref. 14).* Full Text (Free, PDF) www.bmj.sk.
Key words: osteoporosis, fractured vertebra, biomechanics, exercise, Nordic walking.

Patients with fractured vertebra and sport?

I have put the question mark deliberately, as it could seem absurd to some people without it. However, I know from my clinical experience that most of these patients strive to defy the heavy odds and want to overcome their handicap by physical activity. Many patients are aware that inactivity will aggravate their health, their muscles will slacken and their efficiency will diminish, and the back pain will get worse. The patients will have to rely on the help of other people or a care service, which they often cannot afford for financial reasons. This is the reason why there is a growing interest in regular motion activities. I often hear in my surgery statements like "Could you advise me some group exercise for people with the same handicap I have?". The best exercise for patients with osteoporotic vertebra fractures is a regular group exercise lead by an experienced physiotherapist as well as exercise in a swimming pool (excluding swimming).

Unfortunately, there are not many towns and villages where the patients have the opportunity to participate in regular and long-term exercise organised by experienced physiotherapists. Other sport activities are not suitable for patients with osteoporotic vertebra fractures, either for the increased risk of injury or for increased strain on weakened skeleton.

When we pondered over the questions asked by my patients and considered what easy sport would be suitable for them, we have chosen – Nordic Walking. This assumption was confirmed by a biomechanical analysis. Based on the biomechanical model of skeletal load we have developed a method of walking movement for patients, different from the method of walking movement for healthy people. And so came into being the "first sport" suitable for patients with osteoporotic fractures. They can go for regular walks in easy terrains outdoors with friends and family, and so be liberated from social isolation. It requires only one-off financial costs of buying the poles and special footwear.

Nordic Walking – walking with supporting poles

Nordic Walking is a dynamic fitness walking outdoors in different terrains, using a pair of special telescopic poles with exchangeable tips for different surfaces. When walking on less concrete surfaces, such as grass or dirt, the poles with classical spike tips are used, on hard surfaces, such as asphalt, the poles with rubber tips are used. The stride rhythm is given by swinging opposite arms and legs alternately forward and backward.

The correct pole length should represent about 70–72 % of the body height and to calculate it there is a simple formula using one's own height multiplied by 0.66. The walker's elbow should be at approximately a 90° angle when holding the pole by the grip with the tip on the ground. We have chosen the Nordic Walking as a suitable sport for patients with osteoporosis, especially for patients with osteoporotic vertebra fractures. This conclusion was reached on the basis of biomechanical analysis of vertebra load. Firstly, we simulated the vertebra load as a patient with kyphosis walked with outstretched arms without supporting poles, to demonstrate the lever arms and components of the force of gravity of the upper part of the body acting upon the vertebra. Consequently, we unloaded the upper part of the body by poles held in arms extended forward during walking.

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Biomechanical analysis
Calculation of static load of vertebra during mild trunk bending without the support of the poles (1–8)

Model example No. 1

We are interested in static load, e.g., of the Th12 vertebra (12th thoracic vertebra) by the force of gravity of the upper part of the body above the mentioned vertebra, if both elbows of upper limbs are held at a 90° angle (i.e., without being supported by poles) (Fig. 1).

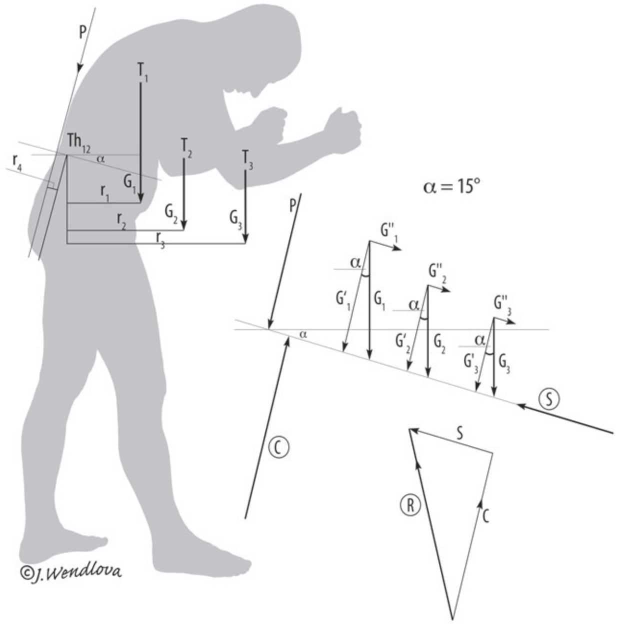

Fig. 1. Static load of vertebra Th12 during mild trunk bending without the support of the poles.

Mathematical definitions:

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

force of gravity: $G = m \times g$ ($kgms^{-2}$)

acceleration due to gravity: $g = 9.80665\ ms^{-2}$

gravity force moment $M = G \times r$

r – *arm, to which the force is applied.*

Solution

Static load will be calculated for the Th12 vertebra.

Patient's weight is m = 70 kg, his force of gravity is $G = m \times g \approx 700$ N
Bending forward, the spine is bent at a 15° angle.

When bending forward, there are four forces (G_1, G_2, G_3, P) acting upon the Th 12 vertebra:

1) G_1 – resultant gravity force of the upper part of the torso and head (over the Th12 vertebra), producing approx. 50 % of the body mass (Tab. 1)
G_1=350 N, is applied in the gravity centre of the upper torso T_1
2) G_2, G_3 – resultant gravity forces of both upper limbs stretched forward with elbows held at a 90° angle, producing 5.6 % x 2 = =11.2 % of body mass
G_2=39.20 N acting upon the gravity centre of the left upper limb (UL) T_2
G_3=39.20 N acting upon the gravity centre of the right UL T3
3) P – is force produced by the contraction of erector spinae muscles (consisting of muscles: – m. iliocostalis thoracis, – m. spinalis thoracis, – m. longissimus thoracis). The magnitude of the P force is unknown, we know only its direction and the point of application (it is an imaginary point in erector spinae muscles above the Th12 vertebra body).

Calculation of the P force magnitude

All four forces, namely G_1, G_2, G_3, P, are acting upon arms of different length (r_1, r_2, r_3, r_4) related to the imaginary point in Th12, producing four bending moments for this point.

Arms, on which the forces are applied, are real distances measured on the patient.

r_1=0.25 m, r_2=0.30 m, r_3=0.40 m, r_4=0.05 m

Explanatory note to symbols used in equations

The clockwise acting force moment is called a positive moment, marked by the symbol (+), the counter clockwise acting force moment is called a negative moment and marked by the symbol (-).

Forces of gravity G_1, G_2, and G_3 produce positive bending moments.

$M_1 = G_1 \times r_1$
$M_2 = G_2 \times r_2$
$M_3 = G_3 \times r_3$

Tab. 1. The Mass Ratio of Different Body Parts to the Whole Body in Precentage (body mass=100 %) (13).

Body part	The Ratio of the Body Part Mass to the Whole Body in % (according to Fischer)	The Ratio of the Body Part Mass to the Whole Body in % (according to Dempster)
Head	8.8	8.1
Torso	45.2	49.7
Thigh	11.0	9.9
Crus	4.5	4.6
Leg	2.1	1.4
Arm	2.8	2.8
Forearm	2.0	1.6
Hand	0.8	0.6

The contraction force P in m. erector spinae produces a negative bending moment

$-M_4 = P \times r_4$

Bending moment M_4 is the counterbalancing moment to bending moments M_1, M_2, M_3.

The P force magnitude is calculated from the first condition of equilibrium:

The sum of the moments in the plane acting upon a given point is equal to zero.

$$\sum_{i=1}^{4} M_i = 0$$

$$M_1 + M_2 + M_3 + (-M_4) = 0$$
$$G_1 \times r_1 + G_2 \times r_3 + G_3 \times r_4 = P \times r_4$$

$$P = \frac{(G_1 \times r_1) + (G_2 \times r_2) + (G_3 \times r_3)}{r_4} = \frac{(350 \times 0.25) + (39.20 \times 0.30) + (39.20 \times 0.40)}{0.05} = 2298.80 \text{ N}$$

P = 2298.80 N

Forces of gravity G_1, G_2, and G_3 are resolved in a polygon of forces into compressive forces G_1', G_2', G_3' and shearing forces G_1'', G_2'', G_3''. By both these forces the gravity forces G_1, G_2, and G_3 are acting upon Th12 vertebra at a 15° angle of bent back.

Calculation of reactive compressive force C in Th12 vertebra

Component compressive forces G_1', G_2', G_3' and the contraction force of muscles P, acting upon Th12 vertebra, condition the rise of the reactive compressive force C in the vertebra, which is in equilibrium with the forces G_1', G_2', G_3' and P (the equilibrium is upset in case of vertebra fracture).

The magnitude of the resultant reactive compressive force C in vertebra is unknown, we know only its direction and point of application. Its direction is opposite to the direction of G_1', G_2', G_3' and P forces, and its point of application is in Th 12 vertebra.

The C force is calculated from the second condition of equilibrium.

The sum of parallel forces in the plane is equal to zero.

$$\sum forces = 0$$

Magnitudes of component compressive forces G_1', G_2', G_3' are calculated from right-angled triangles by trigonometrical function for cosine:

$\alpha = 15°$

$\cos\alpha = \frac{G_1'}{G_1}$ $G_1' = \cos 15° \times G_1 = 0.966 \times 350 = 338.10$ N

$\cos\alpha = \frac{G_2'}{G_2}$ $G_2' = \cos 15° \times G_2 = 0.966 \times 39.20 = 38.87$ N

$\cos\alpha = \frac{G_3'}{G_3}$ $G_3' = \cos 15° \times G_3 = 0.966 \times 39.20 = 38.87$ N

$(\cos 15° \times G_1) + (\cos 15° \times G_2) + (\cos 15° \times G_3) + P + (-C) = 0$

$C = (\cos 15° \times G_1) + (\cos 15° \times G_2) + (\cos 15° \times G_3) + P = 338.10 + 37.87 + 37.87\text{N} + 2298.80 = 2712.64$ N

C = 2712.64 N

Calculation of reactive shearing force S in Th12 vertebra

Component gravity forces G_1'', G_2'', G_3'' are shearing forces acting upon the vertebra, where the reactive shearing force S comes into being, in equilibrium with the forces G_1'', G_2'', G_3'' (the equilibrium is upset in case of vertebra fracture). The magnitude of the reactive shearing force S in the vertebra is unknown; we know only its direction and a point of application. It acts in the opposite direction than forces G_1'', G_2'', G_3'' and its point of application is in Th12 vertebra.

Magnitudes of component shearing forces G_1'', G_2'', G_3'' are calculated from right-angled triangles by trigonometrical function for sine:

$\alpha = 15°$

$\sin\alpha = \frac{G_1''}{G_1}$ $G_1'' = \sin 15° \times G_1 = 0.259 \times 350 = 90.65$ N

$\sin\alpha = \frac{G_2''}{G_2}$ $G_2'' = \sin 15° \times G_2 = 0.259 \times 39.20 = 10.15$ N

$\sin\alpha = \frac{G_3''}{G_3}$ $G_3'' = \sin 15° \times G_3 = 0.259 \times 39.20 = 19.15$ N

The S force is calculated from the second condition of equilibrium.

The sum of parallel forces in the plane is equal to zero.

$$\sum forces = 0$$

$G_1'' + G_2'' + G_3'' + (-S) = 0$
$S = G_1'' + G_2'' + G_3'' = 90.65 + 10.15 + 10.15 = 110.95$ N
S = 110.95 N

We calculated the magnitudes of reactions (reactive forces) C and S in the vertebra to compressive and shearing components of gravity forces G_1, G_2, G_3.

Calculation of resultant reactive force R

As the forces C and S act perpendicularly upon each other, we can calculate the magnitude of their resultant R from the Pythagorean theorem:

$$R=\sqrt{C^2+S^2}=\sqrt{2712.64^2+110.95^2}=864.94\ \text{N}$$

$$R=864.94\ \text{N}$$

R is a resultant reactive force, produced in Th12 vertebra due to static load by the upper part of the body during bending the back at a 15° angle with upper limbs extended forward and elbows held at 90° angle. The direction of the action of the resultant force R is determined graphically by the combination of forces S and C.

The procedure for the calculation of static load for other dorsal vertebra is identical. The angle of action of component forces upon the vertebra changes as well as the magnitude of component forces depending upon the magnitude of resultant gravity force of the body part above the given vertebra. Less gravity force of the body acts upon proximally placed vertebra (upper vertebra) than upon distally placed vertebra (lower vertebra).

Forces transferred into poles during Nordic Walking (3, 4, 8–12)

Model example No. 2

We start from the identical position of the trainee as in the example No. 1 – the spine is at a 15° angle during trunk bending (identical picture).

The force of gravity of the upper part of the torso and the head G_1 (the point of application is in the centre T_1) and forces of gravity of both upper limbs G_2, G_3 (acting upon the centres T_2, T_3) are transferred into poles during walking with the poles held in extended arms. We consider two independent solutions – the trainee supported with one vertical pole and the trainee supported with one deflected pole.

Solution A

Transfer of forces into the right-hand vertical pole.

Solution B

Transfer of forces into the left-hand pole, deflected from the vertical at an acute angle.

Solution A (Fig. 2)

Transfer of forces into the right-hand vertical pole

To find out how the forces are transferred into the pole, at first we have to determine the magnitude, direction and the point of application of the resultant gravity force R and then add a couple of forces in the pole to the force R. These two forces are formed by two equally large forces acting in the same beam and point of application; they are of an opposite direction, while it applies that:

$$R=R'=R''$$

The equilibrium status of forces is not changed, as the effects of both added forces are cancelled mutually. Vertical distances of centres T_1 and T_3 from the pole are arms r_1, r_3, upon which act the gravity forces G_1, G_3. We calculated them in the

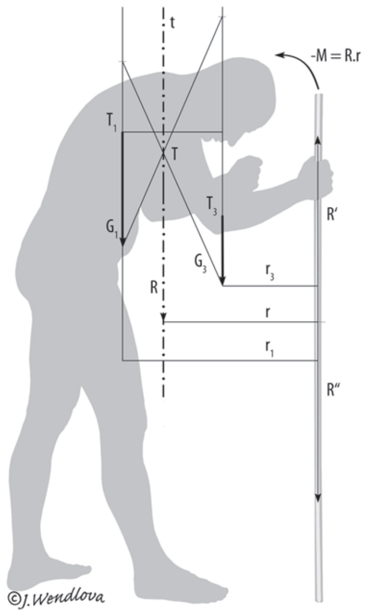

Fig. 2. Solution A.

Model example No.1. We find out the magnitude of the arm r, upon which acts the resultant of gravity forces R. The resultant of vertical gravity forces equals their sum.

$G_1=350$ N $\quad G_3=29.20$ N $\quad r_1=0.52$ m $\quad r_3=0.30$ m

$R=G_1+G_3=350+29.20=379.20$ N
$R=379.20$ N

From the condition of equality of moments we calculate the arm, upon which acts the resultant R: The moment of the resultant set of forces in the plane to a given point equals the sum of moments of individual forces for this point

$$G_1 \text{ x } r_1+G_3 \text{ x } r_3=R \text{ x } r$$

$$r=\frac{G_1 \text{ x } r_1+G_3 \text{ x } r_3}{R}=\frac{(350 \text{ x } 0.52)+(29.20 \text{ x } 0.30)}{379.20}=0.503\ \text{m}$$

$$r=0.503\ \text{m}$$

We know now the resultant R, arm r, upon which acts the R and its direction (in the picture we determined its direction graphically), but we do not know its point of application – the centre T. The centre of the resultant R can be determined graphically or by calculation. This mathematical process is not the target of this analysis, because for physicians it is important to explain in a simple way the principle of the transfer of forces into poles, and the position of the centre T affects neither the magnitude of moments of gravity forces, nor the magnitude of the compressive force R'' transferred into the pole.

The resultant moment M is produced by the gravity force R, acting upon the arm r.

$- M = R \times r = 379.20 \times 0.503 = 190.74$ Nm

In the course of walking with a pole in an outstretched hand, the total resultant of gravity forces R of the upper part of the body is transferred as the compressive force R'' (379.20 N). To provide stability, a couple of forces R, R' (negative bending moment, - M=190.74 Nm) are acting from the pole towards the upper part of the body against the forward inclination of the walker. Taking into consideration two vertical poles, while the distance of the centres of upper limbs from the poles is the same, a half of compressive force of the resultant gravity force R is transferred into each pole.

Solution B (Fig. 3)

Transfer of forces into the left-hand pole, deflected from the vertical at an acute angle.

The magnitude of the resultant force R of the upper part of the body is calculated in the same way as in Solution A, i.e., for an imaginary vertical left-hand pole.

$G_1 = 350$ N $\quad G_2 = 29.20$ N $\quad r_1 = 0.43$ m $\quad r_2 = 0.30$ m

$R = G_2 = 350 + 29.20 = 379.20$ N

$R = 379.20$ N

$G_1 \times r_1 + G_2 \times r_2 = R \times r$

$$r = \frac{G_1 \times r + G_2 \times r_2}{R} = \frac{(350 \times 0.43) + (29.20 \times 0.30)}{379.20} = 0.42 \text{ m}$$

$r = 0.42$ m

Equally as in the Solution A, we do not calculate the point of application of the force T, to make the analysis simpler. We know its magnitude, the arm, upon it acts and direction (determined graphically in the picture), which is sufficient for the explanation of application of forces.

The resultant force R is divided into two component forces R1 a R2.

The magnitude of component forces R1 a R2 is calculated from trigonometrical functions for sine and cosine of the angle:

$\alpha = 12°$

$$\cos \alpha = \frac{R_1}{R} \qquad R_1 = \cos 12° \times R = 0.978 \times 379.20 = 370.858 \text{ N}$$

$$\sin \alpha = \frac{R_2}{R} \qquad R_2 = \sin 12° \times R = 0.208 \times 379.20 = 78.874 \text{ N}$$

$R_1 = R_1' = R_1'' \qquad a = r = 0.42$ m

$- M = R_1 \times a = 370.858 \times 0.42 = 155.760$ Nm

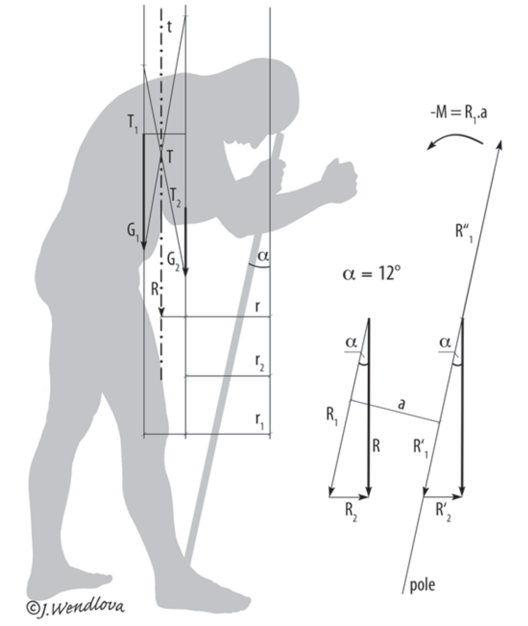

Fig. 3. Solution B.

The resultant force R, passing the axis of the gravity centre t, is transferred by its component R_1 at an 12° angle into the pole deflected from the vertical by 12°. We add to the component force R, of the resultant force R two forces in the axis of the deflected pole, both of equal magnitude, acting in one beam but in the opposite direction. The equilibrium of forces does notchange, because the effects of both added forces are mutually cancelled. The distance a is the distance of component force R_1 from the axis of the pole and simultaneously it creates the lever arm for two forces R_1 and R_1''. To provide stability, a couple of forces R_1 and R_1'' (negative bending moment, -M=155.760 Nm) are acting from the pole towards the upper part of the body against the forward inclination of the walker. The remaining force R_1' (370.858 N) is the compressive component force R_1 of the resultant gravity force R transferred into the pole. The horizontal component force R_2' (78.874 N) of the resultant gravity force R acts upon the pole by pressure, preventing its sliding (shear). If the two poles are deflected at the same angle and the axes of gravity force of upper limbs are at the same distance from the poles, then a half of the compressive component force of resultant gravity force R is transferred into each pole.

The conclusion of biomechanical solution of force transfer into the poles.

In the model example the Th12 vertebra of the trainee, bent in the spine at a 15° angle and stretching out the arms with elbows at a 90° angle, is loaded by a force of 864.94 N.

If in the same position we put vertical poles in the trainee's hands, then 379.20 N of the force of gravity of the upper part of the body is transferred into the poles; to provide stability two forces R and R' (negative bending moment) are acting from each pole towards the upper part of the body against the forward inclination of the walker. Using two vertical poles, the static load of the Th12 vertebra is reduced by 379.20 N and the vertebra is loaded by 485.74 N force.

If we put into the trainee's hands two poles, deflected from the vertical at a 12° angle, then 370.858 N of the force of gravity of the upper part of the body is transferred into the poles; to provide stability the two forces R_1 and R_1" (negative bending moment) are acting from each pole against the forward inclination of the walker. Horizontal component forces of the resultant gravity force R, transferred into the poles, are acting upon the poles by pressure in the horizontal direction, so preve nting their sliding. Using two poles, deflected from the vertical, the static load of the Th12 vertebra is reduced by 370.858 N and the vertebra is loaded by 494.08N force.

Effects of Nordic walking

Positive effects for osteoporotic patients with fractured vertebra:

- strengthening the muscles of shoulders, arms, breast, abdomen, spine, and upper and lower limbs,
- stretching the muscles of the neck, shoulders and trunk,
- enlargement of the support area and improvement of stability while walking (Fig. 5),
- partial relief of vertebra from the gravity force of the head and trunk,
- improvement of motion coordination → prevention of falls,
- improvement of muscle performance → improvement of mobility,
- sparing the knee and hip joints while walking,
- even longer walks do not worsen the back pain.

Overall effects upon the organism:

- up to a 20 to 50 % increase in energy consumption compared with ordinary walking without poles,
- 30 % less load on the locomotory system compared with slow running combined with walking (jogging),
- strengthening the cardiac muscle.

Differences in the walking methods between healthy persons and patients with osteoporotic vertebra fractures

Healthy person (Fig. 4)

The motion rhythm is given by alternate diagonal walking. The right upper limb is forward, the left lower limb is extended backwards, the left upper limb is stretched backwards, the right lower limb is extended forward and in the next step the positions of the limbs alternate. There is a rotation of the axis of the left (right) shoulder joint against the axis of the left (right) hip joint.

Patient with osteoporotic vertebra fractures (Fig. 5)

We suggest the same motion rhythm, given by alternate diagonal walking; however, the upper limbs are bent in the elbows and stay outstretched during walking to reduce partially the gravity force of the head and trunk upon the spine. The right upper limb is forward, left lower limb is extended backwards, the left upper limb is forward, but with the pole closer to the body as the right upper limb, the right lower limb is stretched forward. In the next step the positions of the limbs alternate. There i s no counterrotation of the axes of shoulder and hip joints and so the osteporotic spine is spared the stress of the torsion forces.

Conclusion

Based on the biomechanical analysis we recommend Nordic Walking as a suitable sport for patients with osteoporotic fractures, under the conditions of the change of the method of motion rhythm, as suggested in the article.

Regular motion activities stimulate new bone formation. The bone mineral density (BMD) and also the periosteal apposition of bone increase. The periosteal apposition brings the bone mineral further away from the central axis, the cross – sectional area (CSA) of bone and following the cross – sectional moment of inertia (CSMI) enlarge. Increasing in BMD and in CSMI improve the bone strength. Less than 1 mm increase in outer diameter can compensate for 10 % loss in BMD (14).

There are now only two medicaments available for patients, which can stimulate simultaneously increase in the BMD and in the periosteal apposition: strontium ranelate and teriparatide.*

*Footnote: Figures are created by author.

References

1. Wendlová J. Biomechanika chrbtice a jej význam v pohybovej liečbe pri osteoporóze. Eurorehab 1999; 2 (3—4): 174—177.

2. Wendlová J. Odľaženie chrbtice o hmotnosť horných končatín v štádiu hojenia akútnej fraktúry stavca. Rehabil Fyz Lék 2004; 11 (2): 95—101.

3. Obetková V, Mamrillová A, Košinarová A. Teoretická mechanika.

Bratislava, Alfa 1990, s. 30—94.

4. Adamča LF, Marton P, Pavlík M, Trávníček F. Teoretickß mechanika. Bratislava, Alfa 1992, s. 27—37.

5. Homminga J, Van-Rietbergen B, Lochmuller EM, Weinans H, Eckstein F, Huiskes R. The osteoporotic vertebral structure is well adapted to the loads of daily life, but not to infrequent „error" loads. Bone 2004; 34: 510—516.

6. Bono CM, Einhorn TA. Overview of osteoporosis: Pathophysiology and determinants of bone strength. Europ Spine J 2003; 12: 90—96.

7. Lohfeld S, Barron V, Mc Hugh PE. Biomodels of bone: A review. An Biomed Engineering 2005; 10: 145—150.

8. Burr DB. Biomechanics. Clin Rev Bone Miner Metab 2006; 3: 112—117.

9. Bouxein ML. Biomechanics of osteoporotic fractures. Clin Rev Bone Miner Metab 2006; 3: 118—126.

10. Ferguson JS, Steffen T. Biomechanics of the aging spine. Europ Spin J 2003; Suppl 2: 167—169.

11. Ozkaya N, Nordin M. Fundamentals of biomechanics: Equilibrium, motion and deformation. New York, Springer Verlag 1999, s. 45—51.

12. Fernandez JW, Mithraratne P, Thrupp SF, Tawhai MH, Hunter PJ. Anatomically based geometric modeling of the musculo-skeletal system and other organs. Biomech Model Mechanobiol 2004; 3: 444—450.

13. Koniar M, Leško M. Biomechanika. Bratislava, SPN 1992, 37 p.

14. Faulkner KG, Wacker WK, Barden HS, Simonelli C, Burke PK, Ragi S, Del Rio L. Femur strength index predicts hip fracture independent of bone density and hip axis length. Osteopor Int 2006; 4: 593—599.

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