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The follow-up posturography in rehabilitation after total hip arthroplasty

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Purpose: Presentation of the results of clinical study on new supplementary method applied in the physical rehabilitation of patients who underwent total hip arthroplasty. The standard rehabilitation program was supplemented with the lower limb loading symmetry training based on the follow-up posturography with an adaptively modified visual biofeedback, performed on a double plate posturographic platform. *Methods*: The research involved 60 randomly selected patients included in prospective and comparative clinical study in the scheme of the parallel groups. The subjects were divided into two groups comprised of 30 patients each. In both groups a conventional 21-day rehabilitation was carried out. Additionally, in experimental group the limb loading symmetry restoration training based on the follow-up posturography with an adaptively modified biofeedback was implemented. The biofeedback coefficient reflected the distribution of loading exerted on a given patient's legs and was evaluated during the static posturography examinations carried out before each symmetry training session. *Results*: The eyes-open static posturography examinations indicated significant improvement in the lower limb loading symmetry in 29 (97%) patients from the experimental group ($p = 0.000003$). In the control group, such an improvement was observed in 20 (67%) patients ($p = 0.034796$). In the eyes closed examinations correction in the limb loading symmetry was evident in 23 (77%) patients from the experimental group ($p = 0.000247$) and 18 (60%) patients from the control group ($p = 0.043327$). *Conclusions*: Significant improvement in the lower limb loading symmetry was observed in patients who underwent rehabilitation supplemented with the herein discussed training method.

Key words: *rehabilitation, postural control, posturography, follow-up posturography, postural symmetry*

1. Introduction

In the literature, one can find a number of ideas concerning exercises performed on the posturographic platform. For example, the platform can be used for improvement of the balance control in patients after stroke [5] or the elderly people in general [4], [12]. There are also certain methods which utilize the platform with a biofeedback of some kind as a means for the proper posture restoration training [8], [11], [14]. Posturography in general is effective in diagnosing of both congenital and acquired postural deviations [5], [7], [10].

One of the goals of the rehabilitation following total hip arthroplasty is restoration of the proper body posture which involves symmetrization of the loading exerted on both of the lower limbs. In the process patients are often required to overcome certain habits acquired during the preoperative period as well as to eliminate certain associated psychological barriers. The symmetry training discussed in this article is an enhancement to the methods described in the literature which also implement a biofeedback of some kind [2], [3], [6], [13], [15], [16].

The ingenuity of the symmetry training utilizing the follow-up posturography results from a specific way in which the biofeedback is realized. The associated feedback coefficient evaluated by the software application imposes on the trained patient a certain biased loading of the lower limbs, stimulating him/her

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to shift their center of gravity towards the limb which is underloaded. Typically, in the initial stage of the rehabilitation there is a significant asymmetry in the loading of the lower limbs. In the herein studied approach this asymmetry is evaluated with the help of the static posturography examination carried out before each symmetry training session. As a result, the biofeedback coefficient is calculated determining a desired distribution of the body weight acting on the limbs during the symmetry training session. The limb which was underloaded in the static posturography examination becomes adequately overloaded during the symmetry training.

The article presents an outcome of the research conducted to examine the effectiveness of the follow-up posturography with an adaptively modified biofeedback coefficient as a supplementary method to a conventional rehabilitation program following total hip arthroplasty. The research has been approved by the Bioethics Committee at The Jerzy Kukuczka Academy of Physical Education in Katowice, Poland – Resolution No. 8/2009. All subjects participating in the study gave informed consent to the research.

2. Materials and methods

The research was performed as a prospective and comparative clinical study in the scheme of the parallel groups. It involved 60 randomly selected patients who underwent total hip arthroplasty. The group was divided into two sub-groups: A and B, each of 30 patients. The conventional rehabilitation methods (3 weeks of treatment involving conventional physical exercises) were used in the rehabilitation process of all the patients. The method for body posture symmetry restoration utilizing the follow-up posturography with an adaptively modified biofeedback coefficient was additionally implemented in the rehabilitation of patients belonging to group A. The study involved patients who met the following criteria:

- age up to 80 years,
- 3 to 6 months after the operation,
- first ever arthroplasty,
- equalized lengths of the lower extremities (e.g., using inserts),
- only one artificial hip joint,
- degenerative changes in the tissue being the reason for the total hip arthroplasty,
- walking with an arm crutch, a walking-stick or without any support,
- the ability to maintain an upright position without the crutch or walking-stick for at least 3 minutes.

Stationary rehabilitation was carried out over the period of 21 days. The conventional part of the rehabilitation program (applied in patients belonging to both groups) involved:

- individual exercises in the gym encompassing active pulley system exercises, isometric exercises targeting quadriceps femoris and glueteal muscles, stationary bike and resistance training with Thera Band tape,
- water pool exercises,
- magnetotherapy with magnetic fields of low frequency (camera Magnoter D 56, duration of treatment = 10 minutes, frequency = 40 Hz, magnetic induction (field strength) = 4 mT),
- hydrotherapy (underwater massage),
- phototherapy (laser, Biotron),
- mechanotherapy (segmentary massage, lymphatic massage for the lower limbs),
- thermotherapy (cryotherapy).

Physical rehabilitation was adjusted to the current health state of a patient. It involved at least five treatments per day. In each case the treatment was matched to the symptoms identified during objective and subjective health evaluations and was taking approximately three hours a day. Kinesitherapy and Physiotherapy sessions were carried out 6 and 5 times a week, respectively. In group A, the conventional method of rehabilitation was supplemented with the lower limb loading symmetry training carried out twice a day. The training was based on performance of the visually stimulated exercises on a double-plate posturographic platform. While standing on the platform patients were supposed to sway their body in such a way that the scaled position of the trained person's Center Of Pressure (COP) visualized on the computer screen coincided as closely as possible with the moving point representing the visual stimulus. The COP constitutes a good approximation of the patient's center of gravity projected onto the supporting plane (the platform). During the training the position of the visualized COP marker is being scaled according to the value of the biofeedback coefficient evaluated in the static posturography examination just before the training session is started. If in such an examination a given limb is diagnosed to be underloaded, a correspondingly greater loading is imposed on it during the symmetry training session.

Over the course of the rehabilitation program the loading of the lower limbs was becoming more and more symmetrical in most of the cases under study. In turn, the scaling of the visual stimulation was adapting to these changing conditions. For example, let us assume that the average loading of the limb with an artificial joint is equal to 40% of the body weight and the loading of the limb with a natural joint is equal to 60% thereof. During the training session a patient is visually stimulated to load the limb with natural joint with 40% of the total body weight, whereas loading exerted on the limb with artificial joint is set to 60%. Performing exercises with such a reversed loading of the limbs allows for faster restoration and consolidation of the proper body posture. Explanation of the way in which the biofeedback mechanism works is illustrated in Fig. 1. The point C (not visible on the monitor) represents the real position of the COP for the sample case in which the average loading of the left limb is equal to 40% of the total body weight (CL = 40%) and the average loading of the right limb equals 60% of the total weight considered (CP = 60%). The loading of the limbs imposed by the symmetry training algorithm is represented by the point A. Its position indicates that during the training session greater loading is exerted on the left limb, namely the one which in the static posturography was diagnosed to be underloaded. The rehabilitated patient, however, does not see the COP at point A as the COP point visualized on the monitor is shifted to the position of point B – the starting point for the visual stimulus. To the patient it seems as if the limbs were properly loaded when in reality loading exerted on the limb with an artificial joint is greater than it would normally be desired.

Rehabilitation was performed in the group of 60 patients of which 37 were women and 23 men. The youngest and the oldest patients were 37 and 76 years old, respectively. The average age of the patient was 63.2 years (σ = 8.29 years) and was the same for the men and women. Of the whole group of patients the arthroplasty of the right hip joint was carried out in 35 cases. In the rest of the patients (25) the left joint was operated. In 49 (82%) cases an uncemented endoprosthesis was implanted whereas in the remaining 11 patients (18%) a cemented model was used. The average duration of an experienced hip pain sensation before the surgery (estimated using subjective methods) was 6.64 years (σ = 5.37 years). On average, the rehabilitation program was started 123 days after the surgery (σ = 32.36 days).

In group A there were 19 women (aged 41 to 75 years) and 11 men (aged 37 to 76 years). Group B was comprised of 18 women (aged 47 to 76 years) and 12 men (aged 51 to 76 years). The average age of patients in group A was 61.4 years (σ = 9.01 years) and

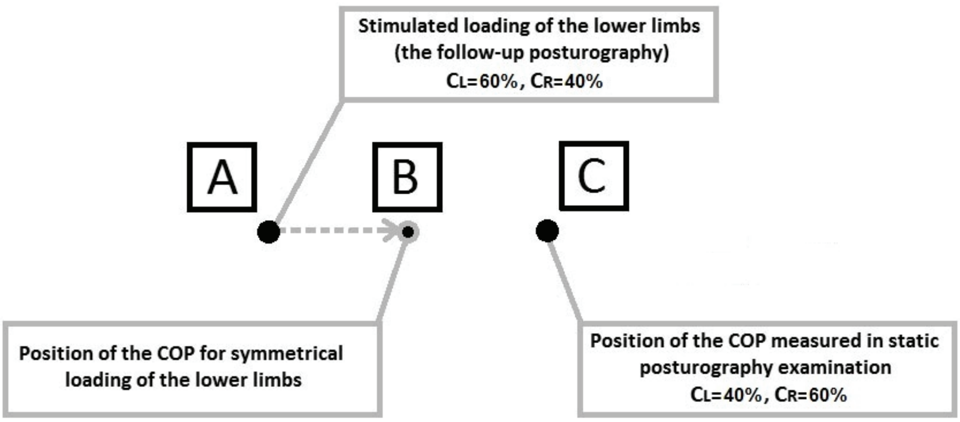


Fig. 1. Explanation of the way in which the biofeedback mechanism works

Table 1. General characteristics and baseline scores of the groups of patients under examination

Study groups	A	B	Total
Number of patients	30	30	60
Sex (number) Female Male	 19 11	 18 12	 37 23
Age (average value in years) (min; max; σ)	61.4 (37; 76; 9.01)	65.1 (47; 76; 7.18)	63.2 (37; 76; 8.29)
Time after surgery (average value in days) (min; max; σ)	112.03 (83; 189; 28.22)	133.5 (91; 204; 33.11)	122.8 (83; 204; 32.36)

was less than the average of 65.1 years (σ = 7.18 years) in group B. This difference was, however, statistically insignificant (p = 0.1048). The average duration of an experienced hip pain sensation before the surgery was 7.55 years (σ = 5.85 years) in group A and was greater than 5.73 years (σ = 4.78 years) evaluated for group B. The difference was also statistically insignificant (p = 0.2154). All the main features of the study groups of patients are summarized in Table 1.

Assessment of the lower limb loading symmetry was performed using double-plate posturographic platform designed and constructed at the Institute of Electronics of the Silesian University of Technology. The limb loading symmetry evaluation was carried out before and after 3-week hospital rehabilitation. Specialized software application communicating with the platform enabled calculation of the average loading of the limbs while performing static posturopraphy examinations. During the examinations patients were supposed to stand still on the platform for a period of 30 seconds (having left foot positioned on the left plate of the platform and the right foot on the right plate). The examinations were conducted in both open and closed eyes scenarios. The essence of the performed limb loading symmetry evaluation boils down to a precise measurement of the average weight exerted on each plate of the posturographic platform. Computation of loading coressponding to each of the lower limbs was based on the analysis of the COP trajectories registered individually for the left and right leg. Construction details of the posturographic platform as well as derivation of the utilized limb loading symmetry measures have been provided in [9].

3. Results

Experiments have shown that the body weight of the patients examined had a serious impact on the values of certain posturographic coefficients [1]. The average weight of a patient before the rehabilitation was 80.95 kg (σ = 12.99 kg) and was significantly greater (p = 0.000010) than the average of 79.64 kg (σ = 12.46 kg) obtained after a three-week rehabilitation program. A significant decrease in the average body weight was observed in both groups of patients: A (p = 0.000067) and B (p = 0.0091). The intergroup comparison (based on the average values), however, indicated that changes in the body weight experienced over the course of the rehabilitation program in group A were not significantly different from the changes experienced by the patients belonging to group B (p = 0.9976).

In the case of significant body weight variations experienced over the course of the rehabilitation pro-

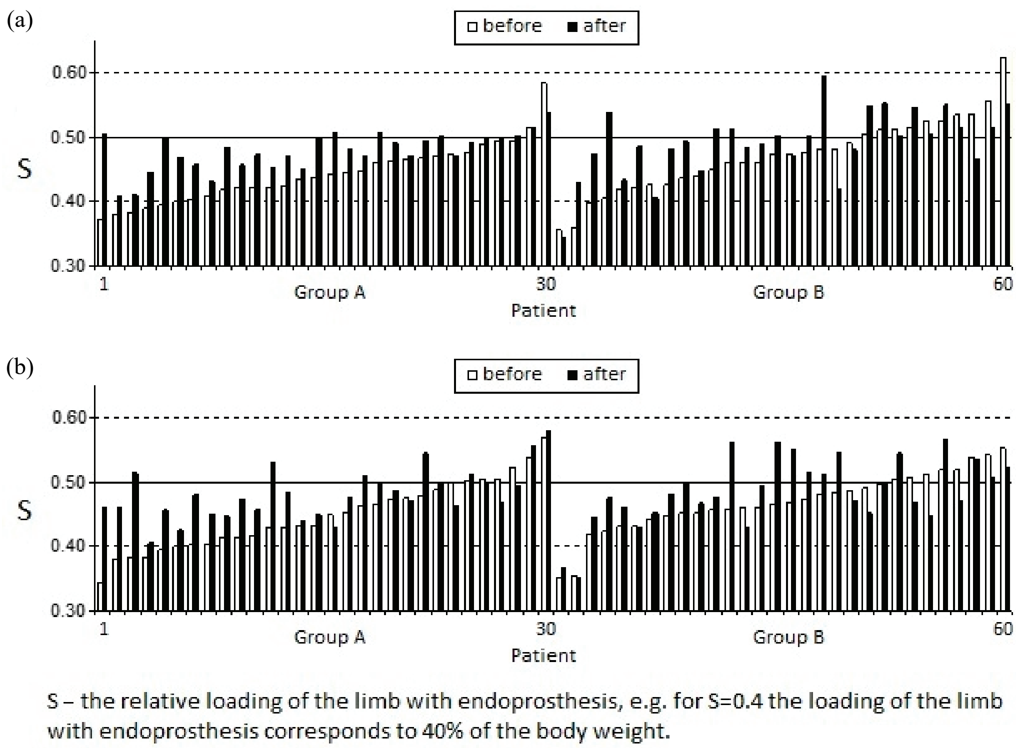


Fig. 2. The relative lower limb loading coefficient evaluated during the eyes-open (a) and eyes-closed (b) static posturography examinations carried out before and after the rehabilitation

gram the asymmetry of loading of the lower limbs can be effectively quantized by the relative limb loading coefficient (S) expressed as the ratio of the loading exerted on the limb with an endoprosthesis (E) and the total weight of the body (L + R). Figure 2 illustrates the values of this coefficient (S = E/(L + R)) assessed during the eyes-open and eyes-closed static posturography examinations carried out before and after the rehabilitation for both groups of patients. The symmetry training was applied in the rehabilitation of patients from group A whereas in group B only a standard rehabilitation program was followed. The data were sorted from the lowest to the largest values of the coefficient obtained before the rehabilitation was started. Values lower than 0.5 indicate a condition in which the limb with an endoprosthesis is underloaded. During the eyes-open static posturography examinations conducted before the rehabilitation such a condition was diagnosed in 48 patients (80%). Of this group, in 29 cases the relative loading exerted on the limb with an endoprosthesis was lower than 45% (S < 0.45). In 8 patients the value of the coefficient was even less than 0.4. Before the rehabilitation 12 patients (20%) were putting more weight on the limb with an artificial hip joint (the eyes-open static examination). In 3 cases (5%), the limb with an artificial joint was loaded with more than 55% of the whole body weight. The maximum value of the coefficient observed before the rehabilitation was equal to 0.62. Similar results were obtained in the case of the eyes-closed static posturography examinations (Fig. 2b).

In group A, based on the results of the eyes-open static posturography examinations, a significant improvement in the lower limb loading symmetry was noticed in 29 (97%) patients, i.e., after the rehabilitation the loading of the lower limbs was more symmetrical than before the program was started (Fig. 2a). In group B, such an improvement was observed only in 20 patients (67%) (Fig. 2a). It is clear that the applied rehabilitation program has led to the amelioration of the lower limb loading symmetry in most patients in each of the groups examined. Significantly greater improvement was, however, observed in patients from group A. Thus, it is legitimate to assume that the follow-up posturography with an adaptively modified biofeedback coefficient significanlty influenced the limb loading symmetry restoration process.

As far as the eyes-closed examinations are concerned correction in the limb loading symmetry was evident in 23 patients (77%) from group A and just 18 patients (60%) from group B (Fig. 2b).

The difference between the average values of the relative limb loading coefficient obtained before and after the rehabilitation was very significant for each group both in the eyes-open and eyes-closed examinations. Statistical analysis proves it at the following levels of significance:

- Group A, eyes open: $p = 0.000003$,
- Group B, eyes open: $p = 0.034796$,
- Group A, eyes closed: $p = 0.000247$,
- Group B, eyes closed: $p = 0.043327$.

4. Discussion and conclusions

In order to prove the usability of the applied symmetry training approach the values of S coefficient were evaluated in both groups of patients (A and B) before and after the rehabilitation. The question was raised of how to proceed in a few cases where at the beginning of the rehabilitation program the weight put on the limb with endoprosthesis was greater than the loading of the limb with a natural joint. What should be the effect of the rehabilitation process in such cases? In the development of the training method it was assumed that the goal of the applied rehabilitation program was symmetrization of the loading exerted on both of the lower extremities. Thus, in the aforementioned cases, after determining a precise value of the biofeedback coefficient, the patient was stimulated to exert greater loading on the limb with a natural joint.

Due to the different limb loading distribution variants observed in both groups of patients, i.e., the value of the relative loading of the limb with an endoprosthesis was either greater or lower than 0.5 (which represents the ideal symmetry of the body weight distribution), the most advantageous way of assessing the obtained results was the analysis of S deviations from the value representing the ideal symmetry of loading. Such deviations were expressed as the absolute value of the difference between 0.5 and the relative loading of the limb with endoprosthesis (S), namely |0.5-S|. This kind of measure quantifies the quality of the limb loading symmetry irrespective of whichever limb was overloaded at the beginning of the rehabilitation program. Additionally, it allows for a direct assessment of the effects the symmetry training has on the rehabilitated patient's posture. If the difference between the coefficient values |0.5-S| obtained before and after the rehabilitation is positive, it means the limb loading symmetry was improved. Otherwise, if the difference between the coefficient values obtained before and after the rehabilitation is negative, it indicates deterioration in the limb loading distribution. Such a difference can be expressed as a separate coefficient using the following formula

$$K = \left|0.5 - \frac{E}{L+R}\right|_{\text{before}} - \left|0.5 - \frac{E}{L+R}\right|_{\text{after}}$$

$$= |\,0.5 - S\,|_{\text{before}} - |\,0.5 - S\,|_{\text{after}} .$$

Figure 3a illustrates the values of K calculated for both groups of patients during the eyes-open static posturography examinations. The data were sorted from the smallest to the largest values for each group, individually. In group A, there was only one patient for whom the rehabilitation process resulted in deterioration of the limb loading symmetry. In all other patients from this group the symmetry was improved. In 20 cases (67%) the improvement was greater than 2.5%. In group B, there were 11 patients in the case of which the limb loading symmetry deteriorated. In 5 of these patients aggravation exceeded 2.5%. Improvement in symmetry was observed in 19 patients, of which 13 experienced amelioration greater than 2.5%. Figure 3a clearly shows that the limb loading symmetry restoration effect was more pronounced in group A.

Figure 3b presents the values of K coefficient obtained during the eyes-closed static posturography examinations carried out for both groups of patients. The data were also sorted from the smallest to the largest values of the coefficient, individually for groups A and B. For 8 patients (27%) from group A no improvement in the lower limb loading distribution was noticed. In 2 of these patients (7%) deterioration by more than 2.5% was observed. All other subjects from group A experienced improvement which in 20 cases (67%) exceeded 2.5%. In group B, the limb loading symmetry deteriorated in 14 patients (40%), of which 8 (26.7%) experienced aggravation exceeding 2.5%. Improvement in the symmetry was noticed in 16 patients (63%). In 8 of these patients (27%) the effect was greater than 2.5%. The data illustrated in Fig. 3b evidently shows that the rehabilitation of patients belonging to group A was more effective as far as the lower limb loading symmetry restoration is concerned.

Intergroup comparison (Student's t test for independent variables) proves there is a high statistically significant difference between the average values of the coefficient K obtained for groups A and B ($p = 0.0136$ and $p = 0.00743$ for the eyes-open and eyes-closed static posturography examinations, respectively). It is indicative of the positive effect of the applied follow-up posturography training on the symmetrization of the body weight distribution. The box plots of the average

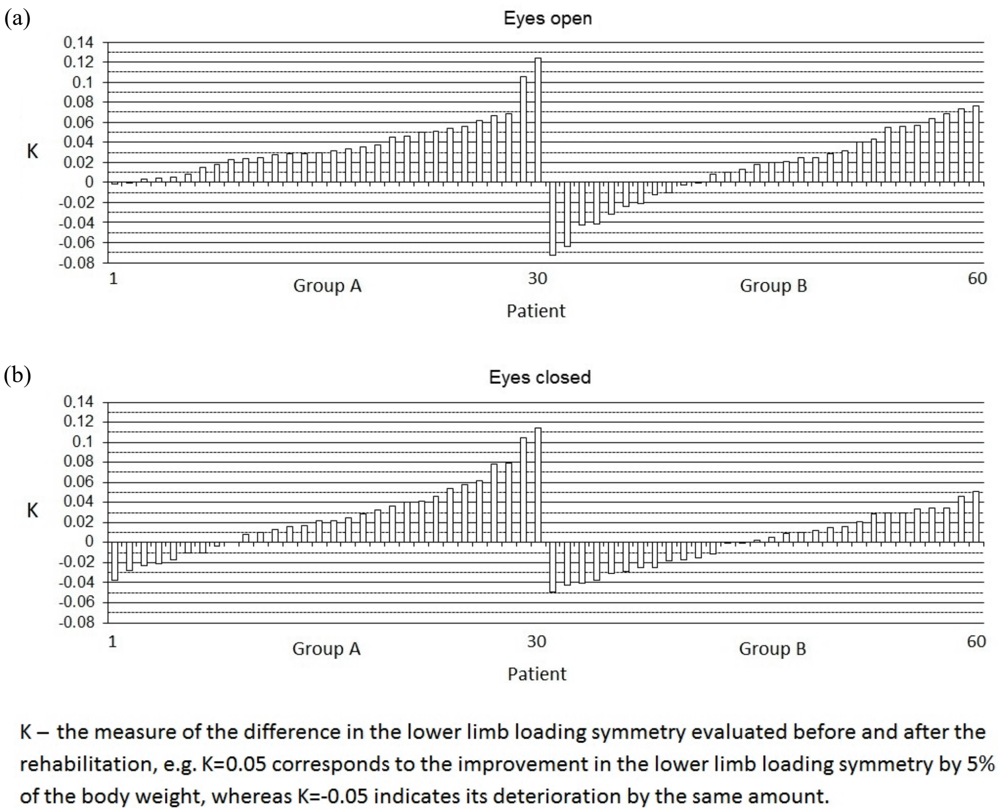
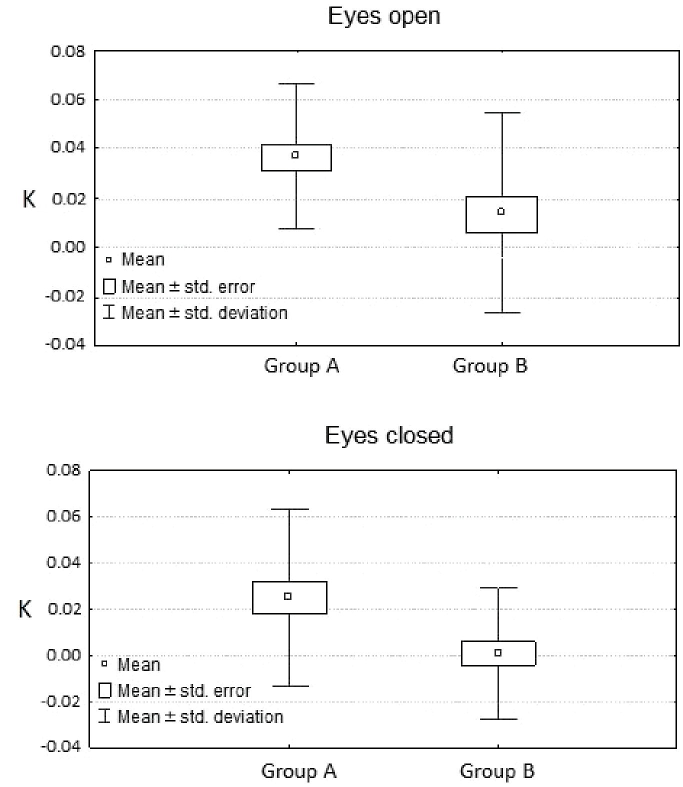


Fig. 3. Impact of the rehabilitation treatment on the lower limb loading symmetry restoration process evaluated in the eyes-open (a) and eyes-closed (b) static posturography examinations

(a)

(b)



K – the measure of the difference in the lower limb loading symmetry evaluated before and after the rehabilitation, e.g. K=0.05 corresponds to the improvement in the lower limb loading symmetry by 5% of the body weight, whereas K=-0.05 indicates its deterioration by the same amount.

Fig. 4. Improvement in the lower limb loading symmetry as a result of the applied rehabilitation treatment, verified in the eyes-open (a) and eyes-closed (b) static posturography examinations

values of K evaluated for both groups of patients during the eyes-open and eyes-closed static posturography examinations are shown in Fig. 4.

Analysis of the acquired data proves there is a significant difference between the results obtained for each group of patients under study. At the end of the rehabilitation program a significantly greater improvement in the limb loading symmetry was found in the group undergoing rehabilitation supplemented with the follow-up posturography training implementing the adaptively modified biofeedback coefficient. We should bear in mind, though, the effects observed in this group may not be long-lasting and could possibly diminish if the training is not continued for a longer period of time. Thus, it would be worthwhile to investigate changes in the values of the limb loading symmetry coefficient in a much broader time horizon. One could also look for a correlation between the quality of the lower limb loading distribution and the long-term benefits of the applied rehabilitation treatment, seeking an answer to the question if the limb loading symmetrization contributes to the minimization of possible future problems directly associated with the total hip arthroplasty (e.g., premature wear of the prosthesis, adverse effects to the healthy joint due to its overloading). There is no doubt, however, that patients undergoing rehabilitation supplemented with the herein discussed symmetry training method finalized the whole rehabilitation program with a more symmetrical loading of the lower limbs. Further research in this area should be concentrated particularly on the observation of the limb loading symmetry changes experienced over a longer period of time.

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References

[1] BŁASZCZYK J., CIEŚLINSKA-SWIDER J., PLEWA M., ZAHORSKA-MARKIEWICZ B., MARKIEWICZ A., *Effects of excessive body weight on postural control*, J. Biomech., 2009, 42(9), 1295–1300.

[2] CHENG P.W., WU S.H., LIAW M.Y., WONG A., TANG F.T., *Symmetrical body-weight distribution training in stroke patients and its effect on fall prevention*, Arch. Phys. Med. Rehab., 2001, 82(12), 1650–1654.

[3] DOZZA M., CHIARI L., CHAN B., ROCCHI L., HORAK F.B., CAPPELLO A., *Influence of a portable audio-biofeedback device on structural properties of postural sway*, J. Neuroeng. Rehabil., 2005, 2(13), 1–12.

[4] FAMULA A., NOWOTNY-CZUPRYNA O., BRZĘK A., NOWOTNY J., KITA B., *Telereceptywna i proprioceptywna sprawność regulacji równowagi a stabilność ciała u osób starszych*, Ortopedia, Traumatologia, Rehabilitacja, 2008, 10(4), 384–395.

[5] GEURTS A.C., HAART M., NES I.J., DUYSENS J., *A review of standing balance recovery from stroke*, Gait Posture, 2005, 22(3), 267–281.

[6] HELLER F., BEURET-BLANQUART F., WEBER J., *Postural biofeedback and locomotion reeducation in stroke patients*, Ann. Readapt. Med. Phys., 2005, 48(4), 187–195.

[7] KIDOŃ Z., *Cyfrowe przetwarzanie sygnałów stabilograficznych*, PhD Thesis. Silesian University of Technology, Gliwice 2003.

[8] KUCZMA W., SROKOWSKA A., OWCZARZAK M., HOFFMAN J., HAGNER W., SROKOWSKI G., *The Phenomenon of biofeedback in neurological rehabilitation traded on "Balance Trainer"*, Polish Journal of Balneology, 2007, 2(108), 79–85.

[9] ŁUKASZEWICZ T., KANIA D., KIDOŃ Z., PETHE-KANIA K., *Posturographic methods for body posture symmetry assessment*, Bulletin of the Polish Academy of Sciences – Technical Sciences, 2015, 63(4), 907–917.

[10] MRAZ M., CHAMELA-BILIŃSKA D., ZAWADZKA D., MRAZ M., SIPKO T., *Stabilografia w ocenie stabilności ciała w pozycji stojącej dzieci w wieku 9-12 lat z bocznym skrzywieniem kręgosłupa* I., Acta Bio-Optica et Inforamtica Medica, 2006, 12(4), 246–249.

[11] MUDIE M.H., WINZELER-MERCAY U., RADWAN S., LEE L., *Training symmetry of weight distribution after stroke: a randomised controlled pilot study comparing task-related reach. Bobath and feedback training approaches*, Clin. Rehabil., 2002; 16, 582–592.

[12] ROALDSEN K.S., HALVARSSON A., SAHLSTRÖM T., STÅHLE A., *Task-specific balance training improves self-assessed function in community – dwelling older adults with balance deficits and fear of falling: a randomized controlled trial*, Clin. Rehabil., 2014, 28(2), 1189–1197.

[13] SCHWARZ M., OLSON P.R., *A historical perspective on the field of biofeedback and applied psychophysiology*, [in:] *Biofeedback: a practitioner's guide*, Guilford, New York 2003, 3–19.

[14] WALKER C., BROUWER B., CULHAM E., *Use of Visual Feedback in Retraining Balance Following Acute Stroke*, Phys. Ther., 2000, 80(9), 886–895.

[15] WALL C., KENTALA E., *Control of sway using vibrotactile feedback of body tilt in patients with moderate and severe postural control deficits*, J. Vestib. Res., 2005, 15(5–6), 313–325.

[16] WALL C., WEINBERG M.S., SCHMIDT P.B., KREBS D.E., *Balance prosthesis based on micromechanical sensors using vibrotactile feedback of tilt*, IEEE Trans. Biomed. Eng., 2001, 48(10), 1153–1161.