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DEVELOPMENT OF VERTICAL GROUND REACTION FORCE AFTER HIP SURGERY

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SUMMARY

There has been a boom of diagnostic devices allowing objectification of walking quality recently.

This study is focused on the development of vertical reaction forces during the four months following total hip arthroplasty (THA – “total hip arthroplasty”).

The main objective of this work is to describe what walking dynamics of patients looks like after THA. Whether four months after surgery, when patients completed the rehabilitation and spa treatment and put support away, the vertical reaction forces of both the affected and unaffected limb reached the values common among the “healthy” population.

Another objective is to determine whether there have any walking dynamics changes occurred in four months after operation from the status before surgery and 2 months after the surgery. Information about the development of vertical reaction forces after THA can be used for correct timing of the rehabilitation process and can help the patient to return faster to normal life as well as extend the life of the implant.

Key words: walking, step cycle, walking phase, hip, total hip replacement, dynamic motion analysis, vertical reaction force

INTRODUCTION

Human walking as a method of locomotion, enabling individuals move from place to place, is completely unique throughout the animal kingdom and strictly specific to species Homo sapiens sapiens (Dungl, 2005). This study deals with the development of the vertical walking dynamics after hip surgery. Total hip arthroplasty is one of the most common orthopaedic surgeries, which is becoming more important with increasing life expectancy. Dungl (2005) states that there are more than 10 000 hip replacements implanted in our country per year and with the expected aging of the population, this number will continue to grow.

An essential role after the THA surgery is played by rehabilitation and work of the physiotherapist, which lead to improved physical condition of the patient. Information about the development of vertical dynamics of walking after THA can be used to correct the timing of the rehabilitation process and can help the patient to a faster return to normal life as well as extend the life of the implant. Most patients experience pain relief and improvement in joint function and mobility after THA. (McCrory, White, Lifeso, 2001) state that several studies have shown that hip movements do not return to normal within 6 months after surgery and in some cases not even in following months or years.

Measures due to reaction force of the pad can be used to quantify abnormal load of limbs of individuals before and after hip replacement. Reaction forces of the pad provide indirect information about the internal joint effort, because the maximum reaction force of the pad coincides with the maximum load of the femur and hip joint during walking.

This study deals with the dynamic analysis of walking in a period of four months after THA surgery, when the patients completed their rehabilitation. Information about the development of vertical reaction force can serve physiotherapists, doctors and orthopaedists as a suggestion of instructions and advice to patients in what period of time after surgery to start walking without support, how to choose physical activities such as walking, running, swimming and so on. Information about the development of vertical reaction force can thus be used to correct the timing of the rehabilitation process after total hip arthroplasty and can help the patient to quickly return to normal life.

Biomechanical monitoring of walking had been focused on the analysis of vertical reaction force of the pad. The work should provide the answer to the question whether there have any positive changes from the state before the operation occurred in the dynamics of walking 2 or 4 months after THA surgery.

METHODS

Set

Data were collected from 7 patients of Fifejdy Municipal Hospital in Ostrava (FMHO) who underwent THA. Patients were advised by orthopaedist to undergo this operation. However, there was a condition that the patient did not use any walking support before the surgery. The set consisted of 5 women and 2 men. Mean age of patients was 60.1 ± 5.4 (years), mean weight 80.4 ± 17.9 (kg), average height 1.67 ± 0.09 (m) and mean fat percentage 34.2 ± 4.9 (%). Mean age of women was 62.0 ± 5.1 (years), mean weight 70.8 ± 8.4 (kg), mean height 1.61 ± 0.04 (m) and mean percentage of fat 35.5 ± 5.3 (%). Mean age of males was 55.5 ± 3.5 (years), mean weight of 104.2 ± 8.2 (kg), mean height 1.80 ± 0.02 (m) and mean percentage of fat 32.1 ± 1.7 (%).

Measuring instruments

A special walkway was used for measurements with two Kistler 9286AA built in amplifier dynamometric platforms built in. The signal from the amplifier went through the AD converter to the PC.

Protocol

Data were obtained in the biomechanical laboratory – Diagnostics Center of Human Movement (DCHM) 3 days before surgery, 60 days after surgery and 120 days after surgery. Three days before surgery, patients were not allowed to use support when walking, 60 days after surgery patients used support and 120 days after surgery patients were not allowed to use support again. Measurement of dynamic parameters of walking took place at a special pathway with a length of 5 meters and two dynamometric platforms built in (Figure 1). Data were collected from 7 patients of FMHO who underwent THA. The special way of walking the pathway were explained to the patients, a demonstration was carried out and time was then given to patients to get used to walking on the pathway. Once the patient managed to walk down the pathway, the dynamic measurement of walking parameters was carried out, which required ten valid attempts. The patients were walking along the pathway with natural speed, they were not allowed to shorten or extend the length of the step to match the deployment of platforms and it was also needed for the right foot to completely touch the platform first and left stayed outside and vice versa. If one of these three conditions had been violated, an attempt was marked as invalid. Furthermore, the somatometric measurement took place on patients using Tanita device and also measuring of postural stability.

Data Analysis

This study focuses on the individual dynamic parameters of walking:

- IInfluence of vertical reaction forces backing the affected limb during the stance phase of one step cycle before surgery, 60 days after surgery and 120 days after surgery.
- Influence of vertical reaction forces backing the unaffected limb during the stance phase of one step cycle before surgery, 60 days after surgery and 120 days after surgery.

Vertical reaction force is expressed in % of body weight in order to compare the tested persons among themselves.

Statistical Analysis

Normality of data distribution was assessed by the Kolmogorov-Smirnov test. Maximum force values during the step cycle were compared in terms of time of diagnosis using

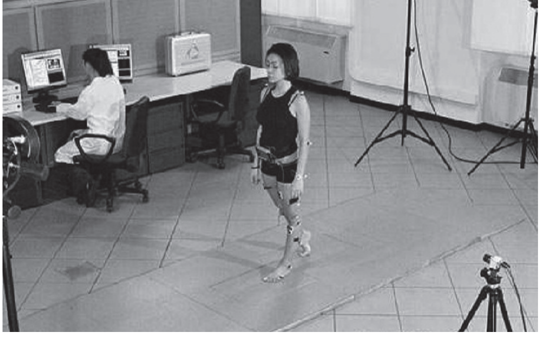

Figure 1. Special pathway with two force platforms (www.kistler.com)

single-factor analysis of variance for repeated measurements and subsequent Bonferri comparison of average values in the individual times of measurement. Force curves were normalized by interpolation to the duration of stance phase. A standard deviation was calculated for each subject as a function of time. Each entity then represented the average signal power versus time. For graphical comparison of the total vertical dynamics of force the average signal of all test subjects force was used as well as the standard deviation between subjects only.

RESULTS

A. Comparison of development of the average vertical reaction force of an unaffected limb of all patients with an interval of four months. (Figure 2)

There is almost no difference in the development of vertical reaction forces before surgery and two months after it, the curve of vertical reaction forces for two months after surgery (dashed curve) does not deviate from the standard deviation (grey area) of curve of vertical reaction forces before surgery (solid curve). Unaffected limb is therefore loaded by patients just as same two months after surgery as before surgery. A curve of vertical reaction force four months after surgery (dotted line) also does not deviate from the standard deviation curve of vertical reaction force before surgery with the exception of the minimum in the saddle, which is lower four months prior to surgery than immediately before the surgery and we can therefore say that at the end and inter-stance and at the beginning of the end-stance the unaffected limb is loaded less four months after the surgery than before the

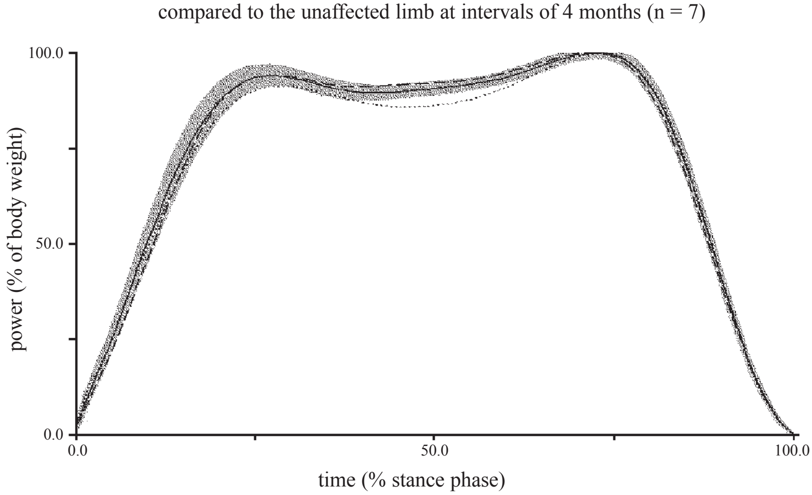

Figure 2. Dependence of the average vertical reaction force (% of body weight) of the unaffected limb during walking ± standard deviation between subjects (grey area) before surgery (solid curve), two months after surgery (dashed curve) and four months after surgery (dotted curve) at the time of stance phase (% of stance phase). (n = 7, mean of 10 attempts for each person tested).

operation, otherwise there was only negligible changes in the vertical reaction load. Neither the first nor the second peak of vertical reaction forces before the surgery, two or four months after the surgery is less than 110% of body weight. The second peak of vertical reaction forces is located above the top of the first, i.e. the unaffected limb is loaded by patients at the end of end-stance and in the beginning of zing up more than at the beginning of inter-stance. Minimum of vertical reaction forces before surgery, two months or four months after surgery does not reach the value of 80% of body weight, but it is above this threshold and the difference between the minimum and maximum vertical reaction force is less than 30% and can therefore be said that the course of vertical reaction forces before the operation, two and four months after surgery is not equal to vertical reaction forces of normal walking.

B. Comparison of development of the average vertical reaction forces of the affected limb of all patients with an interval of four months. (Figure 3)

The development of vertical reaction forces before surgery (solid curve) and four months after surgery (dotted curve) is almost identical, since the curve of vertical reaction force four months after surgery does not deviate from the standard deviation curve of the vertical reaction forces before surgery, so we considered the differences negligible and it can be stated that the affected limb is loaded four months after surgery just as before it. Neither the first nor the second peak of vertical reaction forces reaches 110% of body weight. The second peak of vertical reaction force is higher than the first, i.e. the patients load the affected limb just before the surgery and four months after surgery at the end of the end-stance and at the beginning of zing up more than at the beginning inter-stance. Minimum

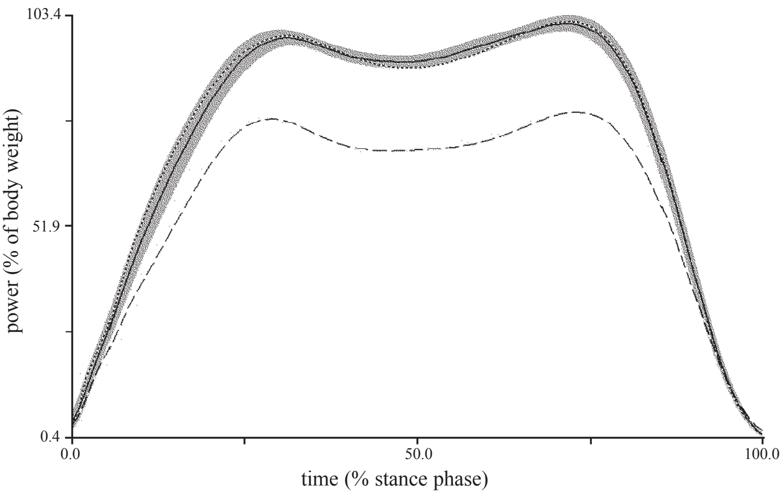

Figure 3. Dependence of the average vertical reaction force (% of body weight) of the affected limb when walking ± standard deviation between subjects (grey area) before surgery (solid curve), two months after surgery (dashed curve) and four months after surgery (dotted curve) at the time of stance phase (% of stance phase). (n = 7, mean of 10 attempts for each tested person).

of vertical reaction forces before surgery and four months after it is higher than 80% of body weight and the difference between minimum and maximum is less than 30% of body weight. The course of the vertical reaction forces before surgery and four months after surgery is consistent with normal walking. The curve shape of vertical reaction force two months after surgery matches the shape of the vertical reaction forces before surgery and two months after surgery, but of course does not acquire % values of body weight as these curves, because patients used walking support two months after surgery.

C. Comparison of average vertical reaction forces of affected and unaffected limbs before surgery. (Figure 4)

The course of the vertical reaction forces of the affected limb (dotted curve) almost does not diverge from the standard deviation (grey area) of vertical reaction forces before surgery (solid curve). The only exception is the first peak of vertical reaction force when the peak of vertical reaction force of the affected limb gets slightly above the peak of vertical reaction force of the unaffected limb. At the beginning of inter-stance the patients put more load on the affected limb than the unaffected limb. Otherwise, the differences are negligible and both legs are loaded equally for the rest of the stance phase. The values of neither the first nor the second peak of vertical reaction forces don't reach up to 110% of body weight and the second peak of vertical reaction force is higher than the peak of the first one which implies that both the affected and unaffected limb is more loaded by the end of the end-stance and at the beginning of zing up than at the beginning of inter-stance. Minimum of vertical reaction force in the saddle is over 80% of body weight, so the difference between maximum and minimum of vertical reaction force is less than 30% of body weight. This value is common in normal walking.

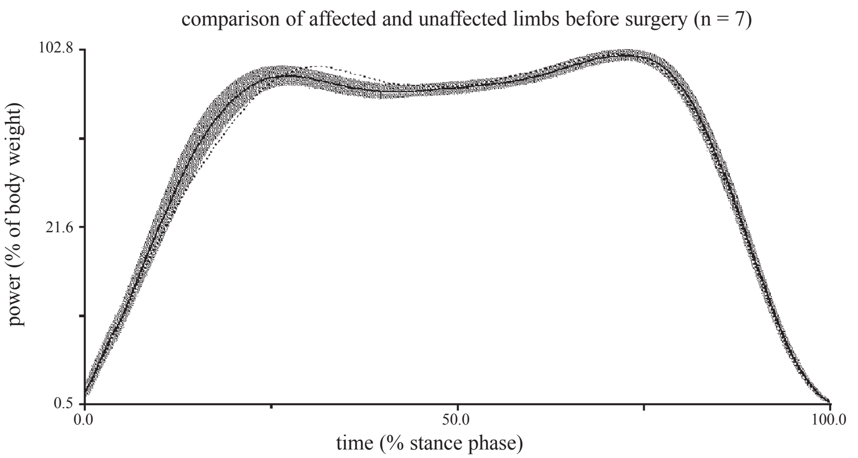

Figure 4. Dependency of the average vertical reaction force (% of body weight), the unaffected limb (solid curve) when walking ± standard deviation between subjects (gray area) and the affected limb (dotted curve) from operations during stance phase (% stance phase) (n = 7, average of 10 trials for each person tested).

D. Comparison of course of average vertical reaction force of affected and unaffected limb 2 months after surgery. (Figure 5)

Unaffected limb (solid curve) has the first peak of vertical reaction force two months after the surgery significantly below the peak of the second, indicating that the unaffected limb is more loaded by the end of the end-stance and at the beginning of the zing up than at the beginning of the inter-stance. Neither peak reaches 110% of body weight. Minimum vertical reaction forces in the saddle is above 80% of body weight, thus the difference between minimum and maximum is less than 30% of body weight indicating a normal walking. Vertical reaction force of affected limb corresponds by its shape to a normal walking, but does not reach percentage values of body weight in normal walking, because patients used support in this period.

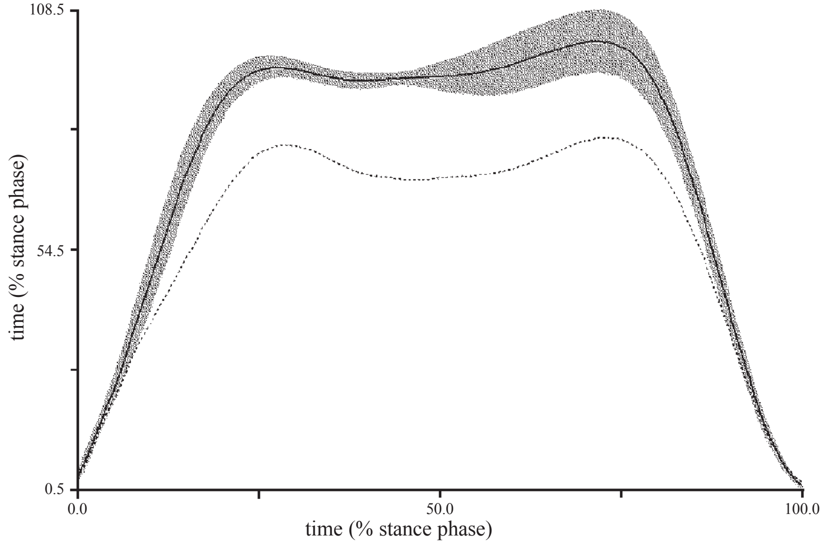

Figure 5. Dependence of the average vertical reaction force (% of body weight) of the unaffected limb (solid curve) when walking ± standard deviation between subjects (grey area) and the affected limb (dotted curve) 2 months after surgery at the time of stance phase (% of stance phase) (n = 7, mean of 10 attempts for each tested person).

E. Comparison of course of an average vertical reaction force of affected and unaffected limbs 4 months after surgery. (Figure 6)

The course of vertical reaction force of the affected limb (dotted curve) almost does not deviate from the standard deviation (grey area) of the unaffected limb (solid curve). The exceptions are two peaks of vertical reaction force when in the first peak of vertical reaction force the peak of the affected limb is above the peak of the unaffected limb. On the contrary, in the second peak the peak of a reaction force of the unaffected limb is slightly above. This means that at the beginning of the inter-stance the affected limb

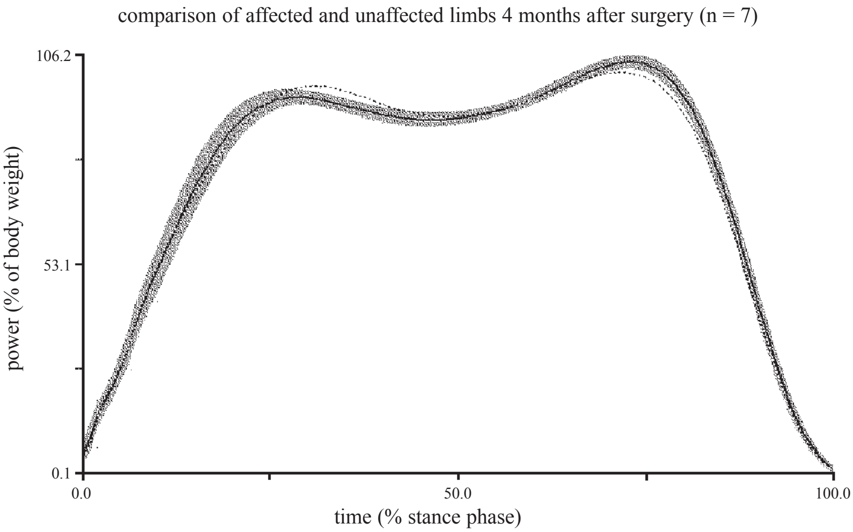

Figure 6. Dependence of the average vertical reaction force (% of body weight) of the unaffected limb (solid curve) while walking ± standard deviation between subjects (grey area) and the affected limb (dotted curve) 4 months after surgery at the time of stance phase (% of stance phase) (n = 7, mean of 10 attempts for each tested person).

is loaded more than the unaffected limb, while at the end of the end-stance and at the beginning of zing up the unaffected limb is loaded more. The first peaks of the vertical reaction forces of both legs are higher than the peaks of the second, which means that both limbs are more loaded by the end of the end-stance and at the beginning of the zing up than at the beginning of inter-stance. Neither one of the peaks of the vertical reaction forces reaches 110% of body weight and a minimum vertical reaction forces in the saddle has values greater than 80% of body weight. So the difference of 30% of body weight is not reached again between the maximum and minimum vertical reaction forces indicating normal walking.

DISCUSSION

The value of the first and second maximum (peak) of vertical reaction forces in a healthy population is 110% of body weight (Perry, 1992). Patients did not reach this value in the affected and unaffected limbs before, two months or four months after surgery. Unaffected limb was loaded most heavily two months after surgery, when the value of the maximum of vertical reaction force was 105.89% of body weight and the least loaded before the surgery, when the vertical reaction force was 103.31% of body weight. The difference between maxima of vertical reaction forces was 2.58% of body weight, which is a negligible value. Four months after surgery, the value of the maximum vertical reaction force was 104.49% of body weight. So there is no significant difference between before and four months after surgery (taking the measurement error 1.41% into account, the unaffected limb was loaded equally before and after surgery). The affected limb was loaded most heavily four months after the surgery when the maximum vertical reaction force was 103.95% of body weight. Least loaded it was of course two months after surgery, when the peak value of vertical reaction force was 87.34% of body weight. Before surgery, the value of the maximum vertical reaction force was 102.91% of body weight. Four months after surgery it increased by 1.04% of body weight in the vertical loads, but this value is also negligible (taking a typical measurement error 1.41% into account again, the value of the maximum vertical reaction force was the same before and four months after surgery).

The level of significance α was set at level of 0.05. Typical maximum power measurement error before THA was 1.41 (% of body weight) and the inter-class correlation coefficient ICC = 0.85. A typical measurement error of power peak two months after THA was 4.34 (% of body weight) and the inter-class correlation coefficient ICC = 0.86. A typical measurement error of power peak four months after THA was 1.95 (% of body weight) and the inter-class correlation coefficient ICC = 0.85. From these results we can deduce the reliable measurement.

The value of local minima (in inter-stance and end-stance, called the saddle) is around 80% of body weight in a healthy population. Minima of vertical reaction forces of both affected and unaffected limbs gained greater values in patients, with the exception of the affected limb two months after surgery of course, when patients used support.

The first peak vertical reaction force was greater at the affected limb when compared to the unaffected limb before and four months after the surgery, two months after the surgery it was the opposite way because of walking with support. The second peak of vertical reaction force is greater in the unaffected limb in all the observed periods. This means that the affected limb is more loaded at the beginning of stance phase (with the exception of two months after surgery, when patients used support) than the unaffected limb. By contrast, at the end of the stance phase the unaffected limb is loaded more. Smaller values of minimum of vertical reaction force showed the unaffected limb, with the exception of two months after surgery of course, when the patient used support when walking. During inter-stance and end-stance the affected limb is loaded more.

The difference between maximum and minimum of vertical reaction force on the unaffected limb is larger than on the affected limb. The unaffected limb performs therefore a more dynamic movement with significantly alternating minima and maxima. Vertical reaction force increases steeply before and two months after surgery in the early stance phase in the unaffected limb. In the affected limb an increase occurs more gradually before surgery and two months after surgery to the first peak of vertical reaction forces. Four months after surgery the increase in vertical reaction forces at the beginning of the stance phase is identical in both affected and unaffected limbs. The second peak of vertical reaction forces at the affected and unaffected limb is higher than the first peak in all the observed periods with the exception of the affected limb two months after surgery, when the two peaks reach the same % value of body weight, but in this period patients used support when walking. Thus we may conclude that both the affected and unaffected limb is loaded less at the beginning of stance phase than at the end of stance phase.

CONCLUSION

Patients did not reach the vertical reaction force parameters of healthy population before surgery, two or four months after the operation. Abnormal walking may be caused by a practiced motion from the time before surgery. Individuals having problems with the hip joint can also usurp their way of walking, or the pathological walking may be caused by physiological or psychological deficiencies. Another argument might be that the joint substitutes were designed on the basis of normal walking studies, therefore prosthetic joint may not be designed for such a situation, when an individual practices abnormal walking. Although four months after surgery the values of the vertical reaction forces of both affected and unaffected limbs show no values of normal healthy population, it is positive that both legs are loaded almost equally. In the event of the unaffected limb being more loaded, this excessive load could lead to osteoarthritis. Conversely, if patients would unduly load the affected limb, it could lead to mechanical failure of the implant.

Learning whether the values of vertical reaction forces of both the affected and unaffected limbs reach values of normal walking in the longer term would be a matter for further research.

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VÝVOJ VERTIKÁLNÍ DYNAMIKY CHŮZE PO OPERACI KYČELNÍHO KLOUBU

RICHARD BILLICH, PAVEL DRDA, KAREL JELEN

SOUHRN

V poslední době dochází k rozmachu diagnostických přístrojů umožňujících objektivizaci kvality chůze. Tato studie zaměřena na vývoj vertikální reakční síly v období čtyř měsíců po totální endoprotéze kyčelního kloubu (THA – total hip arthroplasty).

Hlavním cílem této práce je popsat, jak vypadá dynamika chůze pacientů po THA, zda čtyři měsíce po operaci, kdy pacienti ukončili rehabilitaci, lázeňský pobyt a odložili oporu, dosahují hodnoty vertikální reakční síly jak postižené tak nepostižené končetiny hodnot, které jsou běžné u „zdravé" populace.

Dalším cílem je určit, zda nastaly čtyři měsíce po operaci v dynamice chůze pozitivní změny oproti stavu před operací či 2 měsíce po operaci. Informace o vývoji vertikální reakční síly po THA mohou sloužit

ke správnému načasování rehabilitačního procesu, mohou pomoci pacientovi k rychlejšímu návratu do normálního života i k prodloužení životnosti implantátu.

Klíčová slova: chůze, krokový cyklus, fáze chůze, kyčelní kloub, totální náhrada kyčelního kloubu, dynamická analýza pohybu, vertikální reakční síla

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