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Original article

Pre-operative and post-operative kinematic analysis in total knee arthroplasty. A pilot study

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Summary. *Introduction:* Total knee replacement is the treatment of choice in knee osteoarthritis. Despite this, there is still a percentage of unsatisfied patients. Recently, prosthetic designs have been developed to improve the kinematics of the prosthetic knee. *Materials and methods:* Between June 2016 and November 2016 we enrolled 26 patients underwent to total knee arthroplasty divided in two groups (A and B) treated respectively with Journey 2 implant and the Attune impltant. Each patient was evaluated with functional scores (KOOS and KSS) and with kinematic analysis using the Bioval System. *Results:* In the group A, compared to the pre-operative, the flexion of the operated knees is significantly increased (31.27°±3.13° → 35.02°±2.1°) as well as that of the unoperated knee (34.34°±2.8° → 35.39°±3.5°). The pre/post-operative comparison of the muscles' activation timing showed an improvement for the unoperated side, which is closed to the physiological pattern, while the operated side showed an incorrect activation of all the investigated muscles. *Conclusions:* The Journey 2 prosthesis seems to reach better results in rotational flexion, rotational freedom and muscles activation during free walking. Furthermore, it seems that with this prosthesis the patient can feel his "new prosthetic knee" more similar and closer to the physiological one. More studies are needed to confirm these results. (www.actabiomedica.it)

Key words: knee, arthroplasty, kinematic, muscles activation

Introduction

The total knee arthroplasty is the treatment of choice in knee osteoarthritis. It has become a particularly frequent intervention, due to the increase of the average age of the people and the increase of the elderly population in our society, in fact the incidence rate of this intervention has increased from 6.3 out of 10,000 people to 11.0, with an annual rate of 5.1% (1).

The evaluation of the alignment of the prosthetic components is the subject of a great discussion: it's believed that the malposition of total knee arthroplasty is the main cause of early implant failure, as it would lead to the early appearance of knee pain and the mobilization of the prosthetic components, as well as the wear of the polyethylene insert and, therefore, at a higher rate of revision interventions. Up to 25% of patients who are subjected to knee arthroplasty have non-optimal functional results.

The alignment of the prosthetic components is generally performed along the mechanical axis of the lower limb. Several bio-mechanical studies have indeed shown that a misalignment over 3° of varus or valgus to this axis involves a change in the distribution of loads and a higher rate of prosthetic revision (2, 3). However, 98% of normal knees don't have a neutral mechanical axis and 76% have a deviation of more than 3° (4). The attempt to restore a mechanical 0° axis doesn't represent a return to normality but alters the normal kinematics of the knee (25, 26).

With this study we want to analyze the kinematics of deambulation before and after the surgery, in

order to evaluate any differences and the possible correlation to clinical disorders. The instrumental analysis of the movements allows to perform a quantitative assessment of the characteristics of posture and movement during walking or during functional activities (like taking the stairs, changing direction and running), evaluating everything with the Bioval System, concerning temporal-spatial, kinetic, kinematic and electromyographic parameters.

The arthrosis affects significantly the knee and the degenerative process involves all joint structures. The thinning of the cartilaginous layer, together with the meniscal degeneration and the formation of osteophytes, alters the mechanical congruence of the articular head and the degeneration of the ligaments alters the articular kinematics. The combination of these two elements causes the loss of the articulation's flexion-extension capacity. It has been studied the femoral rotation during flexion-extension under load in arthrosic knees: the results show a significant loss of external rotation at 20° of flexion compared to the healthy control group (1.6° vs 4.8°). The center of the femoral rotation tends to move anteriorly with the progression of the arthrosic process. These results suggest that the abnormal post-operative kinematics obtained with the traditional knee prostheses may are caused, in part, by the anatomical alterations that are already in the preoperative. Inadequate balancing of the prosthesis is the cause of the rigidity or the laxity in flexion or extension, depending on the case. It's therefore essential to perform the femoral and the tibial bone resection in respect of a correct mechanical alignment in extension and a correct femoral rotation in flexion.

With our study, we want to value the kinematic before and after total knee arthroplasty with two different implant: Journey 2 and Attune.

Journey 2 by Smith & Nephew (that has an asymmetric profile with articular rhyme at 3° of launch to the mechanical axis of the lower limb) and Attune by DePuy (that has a symmetrical profile with articular rhyme perpendicular to themechanical axis of the lower limb). Both implants are routinely used at our facility as well as internationally and are not to be considered extraordinary. At the moment, there are no direct comparative studies of the two implants.

Materials and Methods

Between June 2016 and November 2016 we enrolled 26 patients underwent to total knee arthroplasty divided in two groups. In the group A (12 patients) and group B (14 patients)

The patients have been evaluated subjectively and objectively, with the international KOOS and KSS scores, both in the preoperative and after 3 months from the surgery.

We have choosen patients with a diagnosis of gonarthrosis, requiring the placement of total arthroplasty. We decided to enrol two groups of 12 patients. Each patient was randomly assigned to group A or group B. Group A used the Journey 2 and Group B the Attune prosthetic implant. The inclusion rules were an age between 50 and 85 years, clinical and radiographic signs compatible with gonarthrosis and the presence of gonalgy and functional limitation caused by primary or secondary gonarthrosis. On the other hand, the exclusion rules were previous surgical operations on the lower limbs (including corrective osteotomies, unincompartimental prosthesis, osteosynthesis of femoral or tibial fractures, surgery at the ipsilateral ankle level), femoral or tibial fractures conservatively treated, severe pre-operative misalignment of the knee (beyond 15° in varus/valgus to the mechanical axis), very unstable knee before surgery, congenital hip dysplasia and patellofemoral misalignments.

As misurement tools we have used Bioval® inertial sensor system (Movea, France), a system with inertial sensors that allows the detection of the kinematic parameters of the body segments in the three planes of the space. This instrument consists of a software and four MotionPods with wireless sensors. Each MotionPod contains triaxial accelerometers, triaxial magnetometers and triaxial gyroscopes and is applied with adhesive tape or with elastic belts at certain points on the body without causing movement limitations to the patient. We also used Surface EMG TeleEMG®, 8-channel portable electromyograph (BTS s.p.a. Italia), then connected by means of optical fibers to the amplifiers.

The group A consisted of 12 patients, 8 females and 4 males, with an average age of 70.25 years (58-79). The group B consisted of 14 patients, 8 females

and 6 males, with an average age of 71.75 years (56-85). In Group A, 6 patients were operated on the right knee and 6 on the left one. In the Group B, 5 patients were operated on the right knee and 7 on the left one. The patients of the two groups didn't present statistically significant changes to the T-Student analysis. During follow-up, 2 patients belonging to Group B didn't make the planned three-Month post-operative check-up due to personal and health reasons. At the three-Month check-up, Group A included 12 patients and Group B 12.

Results

The pre and post-operative comparison within the group with KSS and KOOS scores values provided statistically significant results with $p<0.01$ for both Group A and B, however, a significant difference could be noted with regard to the "symptomatology" category. The direct comparison between the two groups at 3 months didn't show significant changes in terms of absolute articulation during static and kinematic tests. During the walk were recorded the data related to the angular variation on the 3 planes, relative to Flexion-Extension, intra-external rotation and abduction-adduction. The comparison has been done for each group, for the non-prosthesized side and for the prosthesized one, both in pre and post-surgery.

In the group A, compared to the pre-operative, the flexion of the operated knees is significantly increased (31.27°±3.13° → 35.02°±2.1°) as well as that of the unoperated knee (34.34°±2.8° → 35.39°±3.5°). The extension didin't show statistically significant variations, as well as the Internal rotation in the operated knee, but we saw a significant reduction in the un-operated one. The external rotation, on the other side, was unchanged in the un-operated knees and was significantly increased in the prosthetic ones. Adduction was reduced in both knees, while abduction didin't show significant changes.

In the group B, compared to the preoperative, the flexion of the operated knee was not significantly changed (35.64°±2.4° → 32.1°±4.3°) while in the unoperated knee was decreased (38.8°±3.9° → 35.9°±3.6°). The extension didn't show statistically significant variations. The internal rotation showed a significant increase in the operated knee (4.77°±2.2° → 6.62°±1.2°). The external rotation didn't have significant variations in both sides. The prosthesized side showed a significant increase both in adduction and abduction, while in the unoperated they didn't change.

The comparison between the two groups was given by the difference between the Post-operative and the Pre-operative condition of each group. In the flexion, Group A achieved a significantly greater increase compared to Group B (3.76° Vs -3.58) while the extension didn't show statistically significant differences. For the rotations we saw a significant increase for the Group A in the external rotation. In both groups there weren't significant differences for abduction and adduction (Fig. 1-2-3).

The evaluation of electromyographic was performed for each group, for the non-prosthesized side (NPS) and for the prosthesized one (PS), both in pre

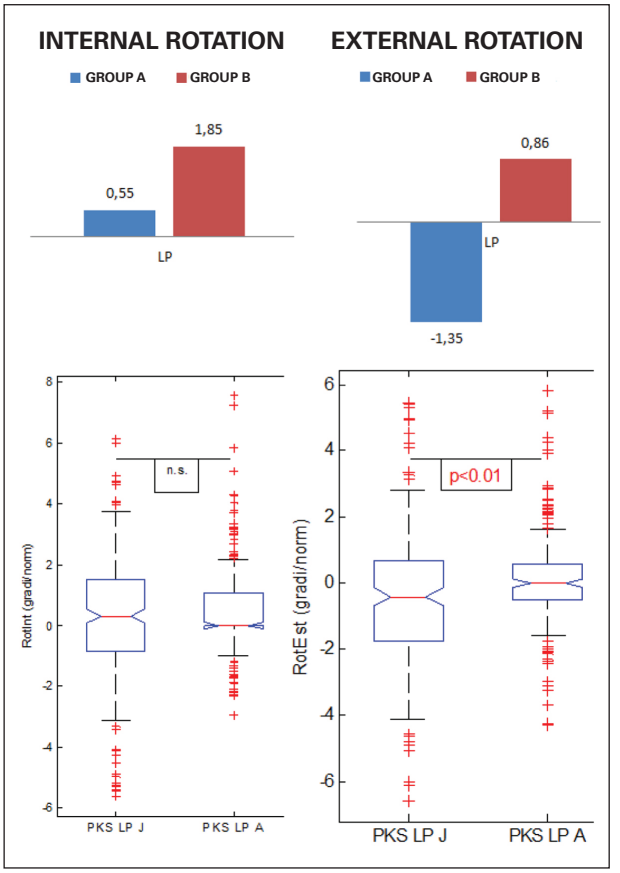

Figure 1. Comparison between Group A and B concerning internal and external rotation

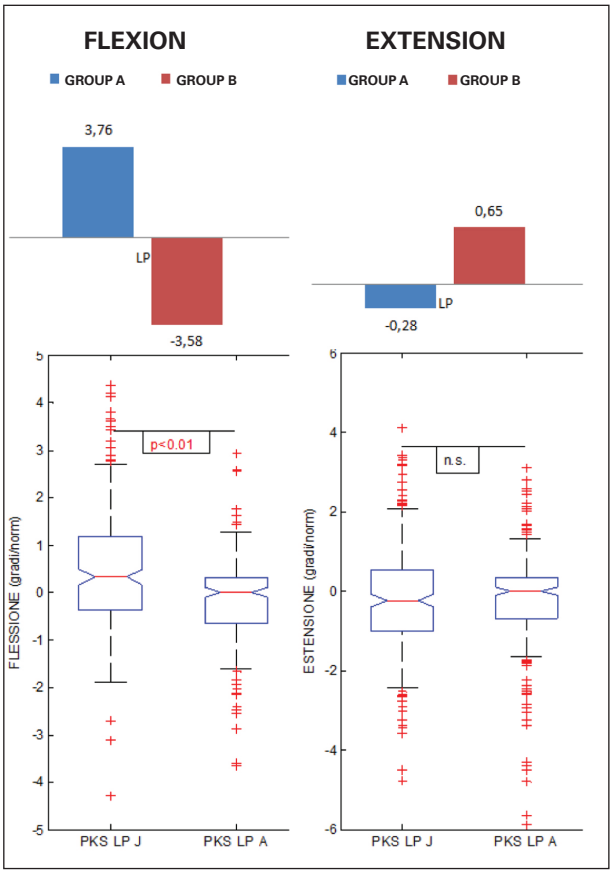

Figure 2. Comparison between Group A and B concerning flexion and extension

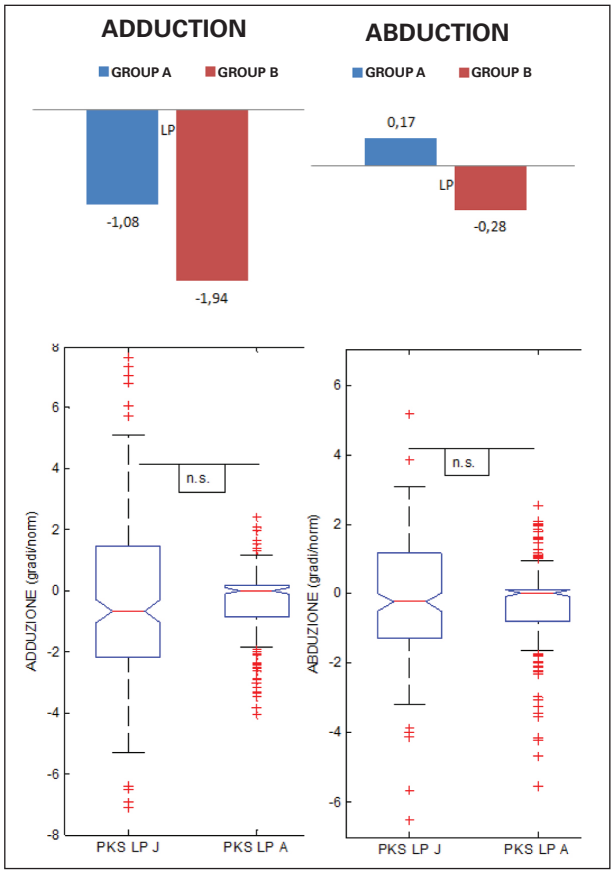

Figure 3. Comparison between Group A and B concerning abduction and adduction

and post-surgery. The analyzed muscles were: Rectus Femoris (RF), Vastus Medialis (VM), Vastus Lateralis (VL), Tibialis Anterior (TA), Semitandinosus/Semimembranosus (SEMI), Gastrocnemius Lateralis (GL).

In the group A, in the pre-operative evaluation, the knee to be operated didn't show statistically significant differences to the controlateral one. The same for the activation timing in both sides and it appeared the same as the physiological one. In the post-operative there was a general reduction for all the analyzed muscles, compared to the pre-operative condition, and that was more evident in the prothesized side. In the comparison between pre- and post-operative, there was a significant reduction for all the muscles of the prosthetic limb, especially in Rectus Femoris, Semitandinosus/Semimembranosus and Gastrocnemius Lateralis. The non-prosthetic limb has, but the Gastrocnemius Lateralis, a significant reduction for all the muscles, especially for the Quadriceps Femoris. The difference between the two sides in the postoperative period is however statistically significant for all the muscles investigated with RMS. The activation timing remains unchanged in both the conditions for both sides and is just like to the physiological one.

In the group B, in the pre-operative evaluation, the knee to be operated didn't show statistically significant differences to the controlateral one. In the side to operate was observed a prolonged activation timing for the Quadriceps and anticipated for Femoral Biceps and Semitendinosus/Semimembranosus in the last phase of the swing; there were also a tonic contraction of the Tibial Anterior and an incorrect activation of the Gastrocnemius Lateralis during swing. In the side not to be operated, there was a normal activation timing of muscles, with a slight anticipation in recruitment during the last swing phase for Rectus Femoris, Vastus Medialis,

Vastus Lateralis, Biceps Femoris and a co-contraction between Lateral Gastrocnemius and Tibialis Anterior during swing. In the post-operative there was a general reduction for all the analyzed muscles, compared to the pre-operative condition, and that more in the prothesized side. The difference between the two sides was significant for Semitendinosus/Semimembranosus, Tibial Anterior and Gastrocnemius Lateralis. The only exception was the Biceps Femoris, which showed a greater activity in the prosthetic knee. Comparing pre and post-operative, in the prosthesized side there was a significant reduction in the Rectus Femoris, Biceps Femoris, Semitendinosus/Semimembranosus, Tibialis Anterior and Gastrocnemius Lateralis. The non-prosthesized side showed a significant reduction in Vastus Medialis, Rectus Femoris, Biceps Femoris, Tibialis Anterior and Gastrocnemius Lateralis.

The pre/post-operative comparison of the muscles' activation timing showed an improvement for the unoperated side, which is closed to the physiological pattern, while the operated side showed an incorrect activation of all the investigated muscles.

In the operated side, Group A recorded a significantly a lower reduction than Group B for Biceps Femoris, Tibialis Anterior, Semitandinosus/Semimembranosus and Gastrocnemius Lateralis. ($p<0.01$). On the other side, Group B recorded a significantly lower reduction than Group A for Vastus Medialis ($p<0.01$). Concerning the unoperated side, Group A recorded a significantly lower reduction for Tibialis Anterior ($p<0.01$), while Group B for Vastus Medialis ($p<0.05$) and Biceps Femoris ($p<0.01$).

Discussion

The instrumental analysis of the movement (gait analysis) is a kind of study that has increased in the recent years, creating a great intersts among the orthopedic-rehabilitation sector (5).

In the Journey's prosthesis there is the ambitious goal of overcoming the standard prosthetic design by restoring a joint profile and with a kinematics that is similar as possible to the original one. To do this, have been made changes both to the femoral shield and to the tibial plateau. The shield is asymmetrical, with a more prominent medial condyle both distally and posteriorly, in order to restore the 3° of physiological varus. At the tibial level, the geometries follow the same philosophy. The insert seems to be more often laterally and with a slightly convex profile. Medially, it's more slim and concave. The point of the greatest concavity is in the middle third of the tibial plateau.

We have than summarized the clinical results concerning four categories: patient's satisfaction, articular ROM, articular kinematics and muscles activation valued with EMG.

In the "satisfaction" category of KSS questionnaire, out of 40 points, Group A reached 37.5 points and Group B 35.4. In the "quality of life" category of KOOS questionnaire, out of 100 points, Group A obtained 84.9 points and Group B 76.2. These results agree with the previous studies in literature (6,7). That suggests that the resolution of the knee's pain, the restoration of the physiological knee load axis and the increase of stability, due to the prosthetic are themselves enough to guarantee a good post-operative satisfaction of the patient. In our study, Journey 2 seems to be significantly better than Attune (22.75 vs 19.9, $p<0.01$).

Concerning the Articular ROM, the groups, comparing pre and post-operative results, didn't show significant differences. In the post-operative, both had a knee flexion of 108° with flexed hip, and that agrees with the literature's results (106°). In literatur it's now estabilished that post-operative ROM is directly proportional to the pre-operative articulation. A patient who, before the surgery, presents a deficit in flexion or extension will hardly recover the complete articulation (8). As far as the prostheses included in our study are concerned, the literatur shows good results: the Journey 2 has been shown to guarantee good results in terms of flexion-extension with an articular range of 0°-139° in cadaver laboratory tests (9) and, in vivo, of 0°-106° in the immediate post-operative (10) and 0°-116° after 2 years.

Also the Attune has obtained good results in the literature's studies: the design allows a gradual and soft transition from the greater curvature of the distal condyles to the smaller one of the posterior condyles. That helps to limit, although not eliminating it, the paradoxical anterior translation, giving a feling of stability (14, 15).

About articular kinematics, the differences depend mainly on the dynamic parameters recorded in the free walking. The internal Rotation increased significantly in Group B but not in Group A, while the external rotation increased in Group A and decreased in Group B: that suggests that prosthetic design may play an effective role in joint kinematics during walking, allowing Journey 2 a greater degree of rotational freedom. Compared to the pre-operative flexion, Group A recorded an average increase of about 4°, while Group B a reduction of 4°: Group A is so closer to the 55° of a physiological walk. However, in literatur there are numerous studies that don't show statistically significant differences in terms of kinematics and antero-posterior stability comparing the various models (like CR, CS and CP) (16-19). Our results sugget that prosthetic design can play an effective role in joint kinematics during walking, allowing Journey 2 a greater degree of rotational freedom.

Concerning the muscles activation valued with EMG, in direct comparison, we saw that Group A scored a lower reduction of activation in flexor muscles, Tibialis Anterior and Gastrocnemius Lateralis but, on the other hand, scored a lower decrease of the strenght for the Vastus Medialis. The activation timing was better in Group A, that was comparable to the physiological one, while in Group B all the muscles showed an anomalous timing (Fig. 4).

After implantation of a total knee prosthesis, the recovery of muscle strength is often difficult: compared to healthy subjects, the quadriceps strength decreases up to 60% in the first post-operative month and a deficit up to 30% can persist after two post-operative years (20, 21, 24). The same goes for the flexor muscles, that reuce their strength up to 50% in the immediate post-operative and a deficit up to 30% con persists after two post-operative years (21-24).

Concerning all these results, the Journey 2 prosthesis seems to guarantee a better articular synergy than the Attune prosthesis.

Our study certainly has limits, like the impossibility of kinematic sensors to evaluate rotations and translations of tibial and femoral components and even the short post-operative follow-up performed. The movement's sensors used for the recording, don't have the ability to discriminate between tibial and femoral rotation, so they indicate the rotation of the whole articulation. Than it's impossible to determinate whether pivoting is medial or lateral and to quantify the degree of femoral rollback.

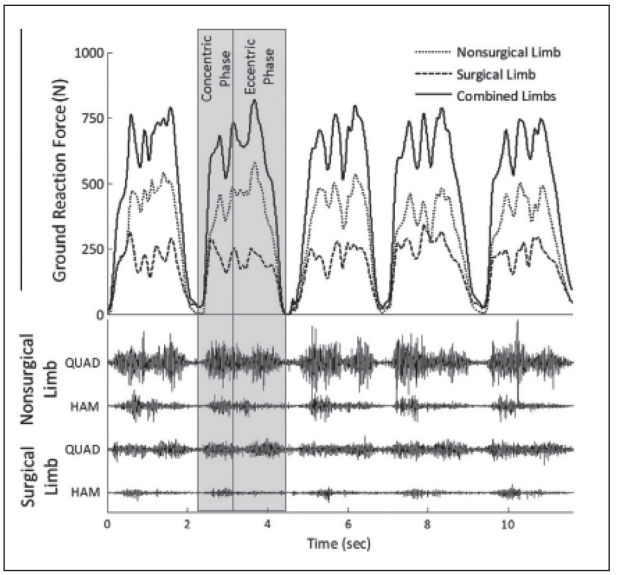

Figure 4. Ground Reaction Force and muscolar firing during 5 repeated Sit-to-Stand

Conclusions

Our study, although conduced in a short-term follow-up, showed significant results in both groups. The differences found are mainly due to the dynamic parameters recorded during the free walk in favor of the Journey 2 prosthesis. Also in the electromyography the Journey 2 prosthesis seems to guarantee better results, with a correct and physiological activation timing of most muscles and with a lower reduction for the flexor muscles. On the other hand, the Attune prosthesis allows a better preservation of quadriceps strength.

The Journey 2 prosthesis seems to reach better results in pain resolution, rotational flexion, rotational freedom and muscles activation during free walking. Furthermore, it seems that with this prosthesis the patient can feel his "new prosthetic knee" more similar and closer to the physiological one. These results can't therefore considered as definitive: a further 12 months post-operative evaluation will be necessary to confirm (or not) what we obtained.

Conflict of interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article

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