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Mid-vastus approach induces milder short-term effects on postural control compared to parapatellar approach in total knee arthroplasty.

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ABSTRACT

Background: Mid-Vastus and Medial Parapatellar techniques are used for total knee arthroplasty. Their short-term effects within the first month after surgery are yet unexplored. The purpose of this study was to compare Mid-Vastus and Medial Parapatellar effects on knee strength and balance control, at 5 days, 2 weeks and one month after surgery. It was hypothesized that Mid-Vastus would induce milder effects on the dependent variables due to its less invasive nature.
Methods: Twenty females, randomly assigned to either the Mid-Vastus or the Medial Parapatellar group performed knee flexion-extension force and 30 s of bipedal stance before, 5 days, 2 weeks and one month after surgery. Maximum force, weight distribution and travel distance of the Center of Pressure were calculated.
Findings: Both groups showed decreased force output at all post-measurements compared to before surgery. Medial Parapatellar group showcased significantly higher travel distance at the 2 weeks measurement ($Z = -2.268$, $p = .023$, $|r| = 0.507$) compared to before surgery. This result was also imprinted on the travel distance of the non-surgical knee limb in the post ($t = 3.259$, $p = .004$, $d = 1.456$), 2 weeks ($Z = -2.570$, $p = .009$, $|r| = 0.574$) and one month measurement ($t = 2.653$, $p = .016$, $d = 1.185$).
Interpretation: While force is affected for both approaches, Mid-Vastus approach does not affect postural control. Therefore, Mid-Vastus is a less invasive technique compared to Medial Parapatellar. This work highlights the differences between Mid-Vastus and Medial Parapatellar approaches at least until the first month of rehabilitation.

1. Introduction

Knee osteoarthritis (OA) is a degenerative disease characterized from changes in the joint articular cartilage affecting mostly older people (>60 years old) and especially women (Srikanth et al., 2005). Currently, knee OA affects more than 654.1 million people worldwide (Cui et al., 2020). Negative consequences of this disease include limited range of motion, pain and joint stiffness, deteriorated gait and balance, and overall reduced physical ability which leads to excessive risk of falling (Cubukcu et al., 2012; Jinks et al., 2007; Levinger et al., 2012; Tsonga et al., 2015; Yelin et al., 1987).

The treatment can be conservative or surgical. Surgery is used when conservative methods are ineffective. The most frequent treatment for end-stage knee OA is Total Knee Arthroplasty (TKA) which has improved the quality of life in many patients (Casazza et al., 2019). Following surgery, patients display significant deficits in muscle strength and balance. Knee extension strength is 50 % less 1 month post-operatively, 20–30 % less 3 months post-operatively, and after 6 months strength reaches its preoperative levels (Bade et al., 2010; Lorentzen et al., 1999; Mizner et al., 2005; Petterson et al., 2011; Stevens-Lapsley et al., 2010; Thomas et al., 2014; Yoshida et al., 2008). Yet, strength measures before 1 month post-surgery are scarce. It has been reported that after a TKA, knee extensors' strength showed a decrease by 54.1 %, 2 weeks after the surgery, and 43.9 %, 3 weeks after surgery (Iwata et al.,

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2019). Concerning knee flexion strength, research on the operated knee in comparison with the non-operated is limited and controversial. There is evidence suggesting that there are no differences between the two knees post-surgery, while other studies showed that the operated knee had less flexion strength compared to the other knee (Lorentzen et al., 1999; Stevens-Lapsley et al., 2010; Thomas et al., 2014). It is worth mentioning that the first study followed the same protocol with the other two in terms of measurements (the same instrument at the same angle) and rehabilitation.

There are various TKA approaches which aim to minimize the negative effects of surgery on muscle strength (Migliorini et al., 2020). The prevailing surgery procedure is the medial-parapatellar approach (PP) where the surgeon performs a longitudinal section of the quadriceps tendon (Berstock et al., 2018; Mehta et al., 2017; Tarazi et al., 2019; Zhao et al., 2022). This, however, damages the quadriceps tendon thus compromising the extension mechanism of the knee (Boerger TO et al., 2005). Another technique is the mid-vastus (MV) during which the surgeon access the knee through the vastus medialis (Engh et al., 1997; Guy et al., 2012; Hube et al., 2002; Mehta et al., 2017). This approach provides shorter recovery time compared to the traditional technique (Mehta et al., 2017) including an earlier improvement in the straight leg test score (Migliorini et al., 2020; Nutton et al., 2014) and a higher knee extension strength (Layher et al., 2016; Nutton et al., 2014; Stevens-Lapsley et al., 2012). However, the earliest comparative measurements found are at 4 and 6 weeks post-surgery (Bhave et al., 2005; Mehta et al., 2017; Nestor et al., 2010), indicating a lack of scientific evidence of the different acute effects imposed by the two approaches.

The ability to maintain upright stance also seems to be affected after TKA interventions, as 7 % to 33 % of individuals report at least one fall incident within a year after surgery (Bhave et al., 2005; Chan et al., 2018; Chan and Pang, 2015). Postural control is heavily dependent on proprioception that seems to be dysfunctional in osteoarthritic knees (Barrett et al., 1991). Joint sensation (Barrett et al., 1991) and balance (Gauchard et al., 2010; Isaac et al., 2007) are eventually improved in replaced knees after TKA, but postural deficits are still reported for the first 18 months after TKA (de Lima et al., 2021; Quagliarella et al., 2011). There is evidence that the center of pressure (CoP) displacement during a postural balance test 6 months after the operation remains higher compared to healthy age-matched adults (Bascuas et al., 2013; Clark et al., 2017; Fernandes et al., 2018; Hassan et al., 2001; Moutzouri et al., 2016; Stan et al., 2013). Minimal invasive techniques have fewer negative effects on postural compensation following a perturbation 3 months after surgery than PP approach (Pethes et al., 2015). However, these studies accounted for total CoP and did not capture unilateral postural control strategies, separately for each lower limb.

It is accepted that rehabilitation should start as soon as possible after surgery (Mizner et al., 2005). To plan rehabilitation properly it is important to be able to collect clinical data before that. Research, however, has mainly focused on changes in knee strength and balance after one month post-surgery, while limited studies applied measurements before one month (Chan and Pang, 2015; Stan et al., 2013). This is probably because isokinetic strength dynamometer measurements are almost impossible to measure in patients at the early stages of rehabilitation (Tashiro et al., 2007). Therefore, a comparison of knee extension and flexion strength and balance between various surgical techniques within the first month after surgery is yet to be explored.

The purpose of the present study was to evaluate the biomechanical characteristics of posture and knee strength after two different TKA approaches. Thus, this study compares the effects of PP and MV approaches on knee strength and postural control in TKA patients, measured prior to surgery, 5 days, 2 weeks and one month after surgery. The study was held in women since as foretold they are more likely to suffer from OA compared to men. Our hypothesis was that PP surgical intervention would inflict greater deterioration in the strength and balance variables compared to the MV approach. We also hypothesized that PP patients' rehabilitation of strength and balance over the course of the month will be slower compared to the MV patients.

2. Methods

2.1. Participants

Twenty female patients (68.5 ± 7.91 y, 160.6 ± 5.99 cm, 86.69 ± 11.67 kg, 29.58 ± 1.96 BMI) suffering from knee OA in one knee (level 3 or above on Kellgren-Lawrence grading scale) voluntarily participated in the study. The other knee suffered less from OA (below level 3 on Kellgren-Lawrence grading scale) or had undergone surgery three years ago or earlier. The inclusion criteria were: i) females, aged more than 60 years with a body mass index (BMI) less than 31, ii) no previous knee surgery (including meniscectomy) and local signs of knee infection, iii) without knee valgus deformity due to the possibility of needing a lateral parapatellar approach. The threshold for valgus knee was set to 15 degrees angle. Patients who met the criteria and were willing to participate gave their written consent. The study was approved by the ethics committee of the hospital (Approval Number: 2022-B2015–232). All patients followed a standard rehabilitation treatment after surgery consisted of muscle strengthening and joint mobilization. Patients were instructed to follow a standardized home-exercise program, before they left the hospital, focusing on increasing muscle strength and range of motion. A total of 24 participants matched the inclusion criteria, 20 of them participated in the study while the rest four dropped out during the process. This sample was a part of the total population 93 that visited the hospital and underwent TKA surgery within one year. The final sample was this convenience sample of 20 patients. Participants were randomly assigned to MV or PP group. The MV group underwent surgery with the MV technique while the PP group with the PP technique.

2.2. Surgical techniques

All surgical operations were performed by a single orthopaedic surgeon to minimize potential bias. The surgeon operated 93 patients during the one-year period that the study was conducted. The surgeon has 25 years of knee TKA surgical experience and operates on about 100 patients per year. About 70 % of the operations are performed using the PP approach and the rest using the MV approach. In both techniques, the incision of the skin and subcutaneous tissue is medium and 12–15 cm long. During the PP approach, the incision is made at the medial border of the quadriceps' tendon originating approximately 5 cm medial to the top of the patellar bone. It then extends peripherally to the medial border of the patellar bone and the patellar tendon until the tibial tuberosity. Following a medial parapatellar bursectomy, the patella is everted outward, and the knee is flexed as much as possible. During the MV approach, the incision is made approximately parallel with the vastus medialis oblique muscle fibers until it reaches the upper medial side of the patellar bone. The incision extends peripherally to the medial border of the patellar bone and tendon similarly with the PP approach (Scott et al., 2018). At all cases, operations were conducted using posterior stabilized arthroplasty since, as reported in the literature, differences between cruciate-retaining and posterior stabilized TKA are non-significant at short- and middle-term follow-ups (D'Ambrosi et al., 2022; Li et al., 2012). Patellar resurfacing was performed without the addition of implants.

2.3. Measurement tools

Knee flexion and extension force at 60^o knee flexion as well as balance during bipedal stance were measured. The examiner that performed the tests was unaware of the surgical technique that was used in each patient. Strength (force) measurements were recorded using a hand-held dynamometer (Muscle Controller, @Kinvent, Montpellier, France). An IMU based sensor, (k-Sens, @Kinvent, Montpellier, France), was used to obtain knee flexion angle measurements. Lastly, a pair of portable force plates (k-Plates, @Kinvent, Montpellier, France) (330 × 175 mm each) was used for the CoP and weight distribution measurements. All measurement tools used were wireless and data was recorded using 75 Hz sampling frequency through the dedicated app (K-Physio, @Kinvent, Montpellier, France).

2.4. Data acquisition

All participants were hospitalized a day before the surgery and exited five days after the operation. The first measurement was conducted the day before the surgery (pre). Subsequent measurements were conducted five days (post), two weeks (2w) and one month (month) after. Two types of measurements were performed. Knee flexion and extension force were measured using Muscle Controller, placed at the anterior part of the ankle joint (lowest point of the shank) for the extension test and at the heel for the flexion test (Fig. 1a, Fig. 1b), synchronized with K-Sens, which was mounted to the participant's lower part of the shank, to determine the angle of the knee. The position of the dynamometer along the shank was measured and it was kept constant throughout the repeated measurement sessions. Each participant performed extension (Fig. 1a) and flexion (Fig. 1b) isometric trials of five seconds from the seated position with a knee flexion angle of 60° (knee flexion angle 0° = full extension). Each patient completed two trials of flexion and extension. For balance assessment the participants were instructed to stand in an upright bipedal position for 30 s on the two force plates.

2.5. Data analysis

Maximum flexion and extension force was used to quantify the strength measurement. A 0.5 s window at the highest area of the force curve was used and the mean value was extracted. The highest value of the two trials was selected for the analysis. Regarding the stance evaluation, the weight distribution was analyzed by the percentage of the total weight on each foot. The total sway length (travel distance) was extracted for both the total CoP and the CoP of each leg separately.

2.6. Statistical analysis

Shapiro–Wilk test was conducted to determine the normality of distributions. Force data presented normal distribution and a 2 × 2 × 4 analysis of variance was conducted with the independent factor being the surgical technique (MV and PP) and the repeated factors being knee (surgical and non-surgical) and time (pre, post, 2 weeks (2w) and one month (month) after surgery). Bonferroni correction was used as a post hoc analysis to investigate pairwise comparisons when significant interactions occurred. A 2 × 4 analysis of variance was also applied to examine the difference in weight distribution between surgical techniques at different time points. For non-normally distributed data, between groups (MV-PP) effects Mann-Whitney *U* test was used. To investigate within group (pre – post – 2w – month and surgical – non-surgical) effects, a Friedman test was used and if significant differences were observed, post hoc tests with Bonferroni correction were used for pairwise comparisons. Non-parametric tests were used for all postural balance variables as the normal distribution criterion was not met, except pairwise group comparisons of travel distance for the non-surgical knee at post and one-month measurements where independent *t*-tests where used. Effect size was calculated using Partial Eta Square ($\eta p2$) for analysis of variance, Cohen's d (d) for independent sample t-tests, Kendall's W (w) for Friedman's test and Cohen's r ($|r|$) for Mann-Whitney *U* test. The significance level was set to $a = 0.05$.

3. Results

The analysis of variance showed no significant effect of surgical type on knee extension force ($F_{(1,\,18)} = 1.291$, $p = .271$, $\eta_p^2 = 0.067$; Fig. 2a). Significant interaction was noticed between the Knee and Time factors ($F_{(3,\,54)} = 9.731, p < .001, \eta_p^2 = 0.351$). Upon analyzing the main effect of time for each knee, force was significantly higher in the pre measurement compared to post ($F_{(3,\,16)} = 2.099$, $p = .035$) for the non-surgical knee. For surgical knee, force was significantly higher in the pre measurement compared to post ($F_{(3,\,16)} = 29.425$, $p < .001$), 2w ($F_{(3,\,16)} = 29.425$, $p < .001$) and one month ($F_{(3,\,16)} = 29.425$, $p = .016$) measurements. Upon analyzing the main effects of knee across all levels of time, non-surgical knee had significantly higher force values compared to surgical knee in pre ($F_{(1,\,18)} = 4.988, p = .038$), post ($F_{(1,\,18)} = 39.939$, $p < .001$), 2w ($F_{(1,\,18)} = 18.338$, $p < .001$) and one month ($F_{(1,\,18)} = 25.374$, $p < .001$) measurements (Fig. 2a).

Regarding knee flexion results, no effect of surgical type was noticed ($F_{(1,\,18)} = 0.058$, $p = .813$, $\eta_p^2 = 0.003$). Significant interaction of Time and Knee factors was found ($F_{(2.277,\,43.936)} = 4.661, p = .012, \eta_p^2 = 0.206$;

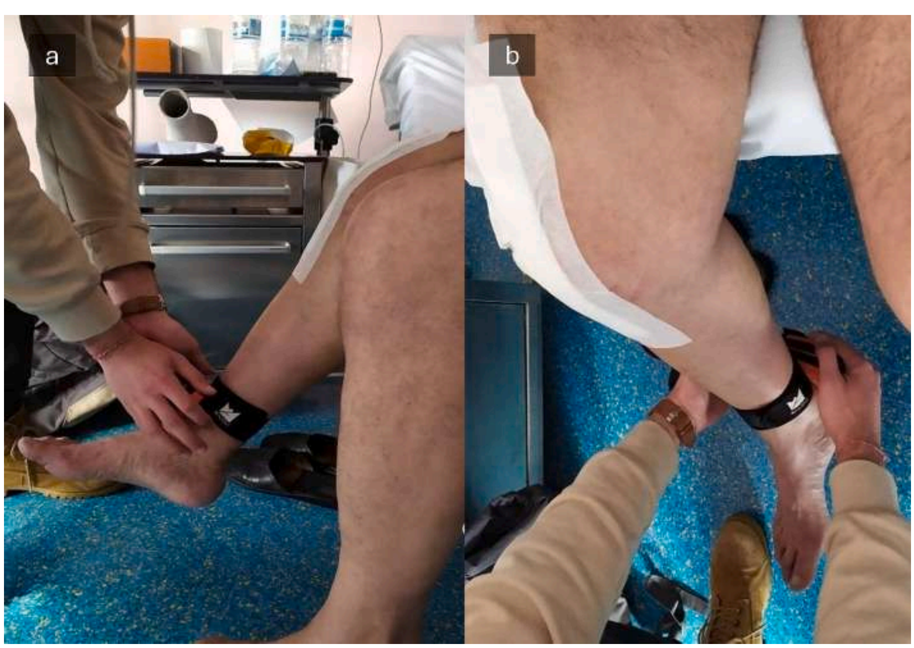

Fig. 1. — Depiction of knee extension (a) and flexion (b) force data acquisition.

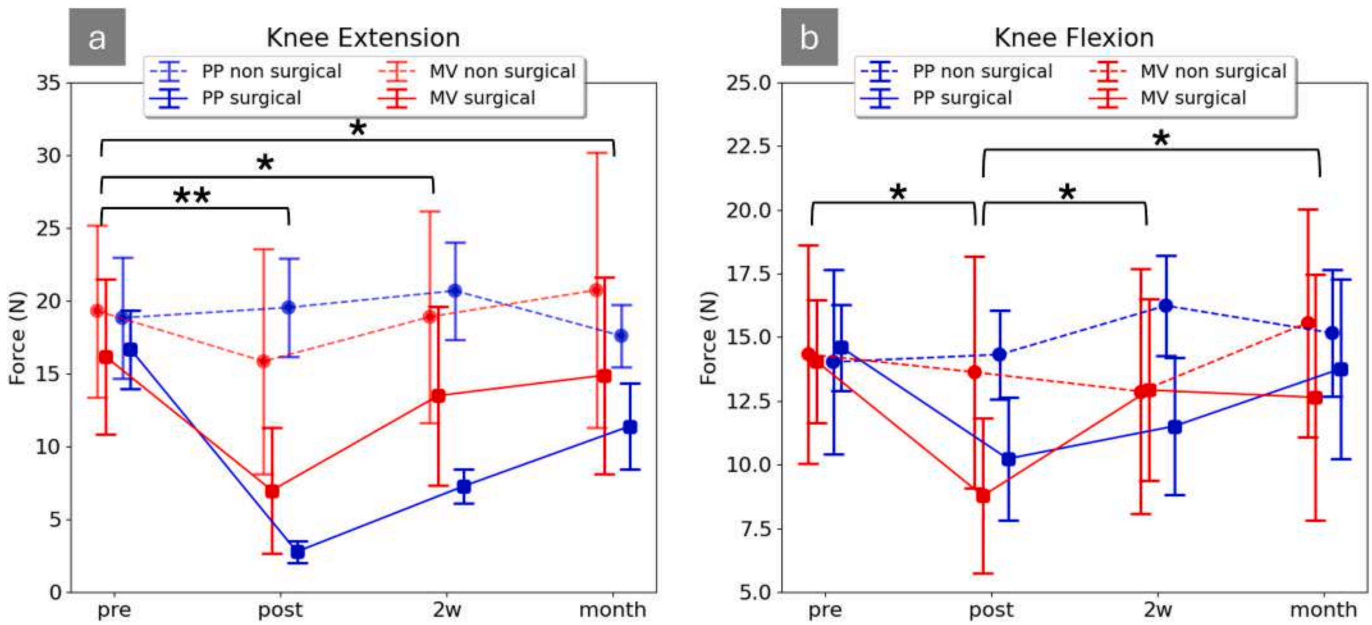

Fig. 2. — Knee extension (a) and flexion (b) force (N) across all four measurements for both groups and both knees. Boxes and circles represent the group mean and error bars the group standard deviation. Significant differences between time points for the surgical knee are represented with *. Significant differences between time points for the surgical and non-surgical knee are represented with **.

Fig. 2b). Post surgery force was significantly lower compared to pre- ($F_{(3, 16)} = 16.122$, $p < .001$), 2w ($F_{(3, 16)} = 16.122$, $p < .001$) and month ($F_{(3, 16)} = 16.122$, $p = .001$) measurements for the surgical knee, while non-significant differences between time measurements were noticed for the non-surgical knee (Fig. 2b). The non-surgical knee had significantly higher force values compared to the surgical knee in post ($F_{(1, 18)} = 25.261$, $p < .001$) and one month ($F_{(1, 18)} = 6.381$, $p = .021$) surgery measurements.

Regarding weight distribution, no significant effect was noticed between surgical types ($F_{(1, 18)} = 2.190$, $p = .156$, $\eta_p^2 = 0.108$; Fig. 3). A significant effect of Time factor was found ($F_{(3, 54)} = 26.933$, $p < .001$, $\eta_p^2 = 0.599$) in weight distribution. Significantly lower values of loading at the surgical knee were found in post-surgery ($F_{(3, 16)} = 37.577$, $p < .001$) and 2w ($F_{(3, 16)} = 37.577$, $p = .005$) compared to the pre measurement (Fig. 3). However, no differences were noticed between pre and month measurements (Fig. 3).

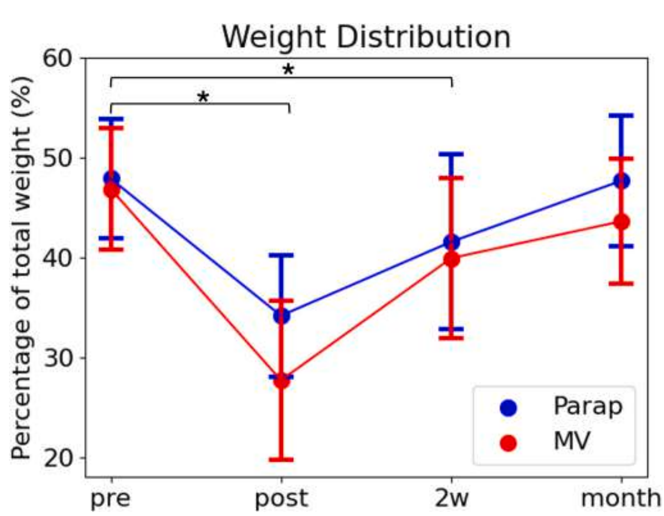

Fig. 3. — Weight distribution across all four measurements expressed as the percentage of the total body weight loaded in the surgical knee. Circles represent the group mean and error bars the group standard deviation. Significant differences between time points are represented with *.

The total CoP of the PP group showcased significantly higher travel distance compared to the MV group at the 2w measurement ($Z = -2.268$, $p = .023$, $|r| = 0.507$) (Fig. 4c). Significant effect of time was noticed in the travel distance of the non-surgical knee ($\chi^2(3) = 17.400$, $p = .001$, $w = 0.580$) for the PP group (Fig. 4a). Post-hoc test indicated that travel distance was significantly lower in the pre measurement compared to 2w ($p = .002$) and month ($p = .006$). No effect of time was noticed for the MV group. The travel distance of the non-surgical knee limb was significantly higher for the PP group in the post ($t = 3.259$, $p = .004$, $d = 1.456$), 2 weeks ($Z = -2.570$, $p = .009$, $|r| = 0.574$) and one month measurement ($t = 2.653$, $p = .016$, $d = 1.185$) (Fig. 4a) compared to MV group. Travel distance was also higher for the non-surgical knee limb compared to surgical knee limb at post ($Z = -1.988$, $p = .047$, $|r| = 0.444$), 2 weeks ($Z = -2.701$, $p = .007$, $|r| = 0.603$) and one-month ($Z = -2.497$, $p = .013$, $|r| = 0.558$) measurements only for the PP group. No effect of knee was noticed for the MV group. Also, no effect of group or time was noticed for the surgical knee (Fig. 4b).

4. Discussion

The main findings of this study were, first that MV and the PP surgery approach for TKA caused similar decline in knee strength during the first post-surgery month. Second, weight distribution changed in favor of the non-operated leg, irrespective of the surgery approach. Finally, amongst the two approaches, the PP approach resulted in a lower CoP travel distance during postural balance tests, and, hence, greater postural control deterioration.

Surgical knee extension force was significantly lower 5 days, 2 weeks, and 1-month post-surgery compared to pre-surgery, independent of surgery approach (Fig. 2a). Surgical knee flexion force was significantly lower post-surgery compared to all other measurements, independent of surgery approach (Fig. 2b). The reduction in knee strength could be explained by the fact that just 5 days after the surgery, patients are afraid to use their knee, they are in pain, under medication, and their surgical knee is swollen. This impacts not only the force capacity of the knee extensors but also the strength which is exerted by the knee flexors even though the surgical procedure does not involve the knee flexor musculature. These results are not in agreement with previous literature

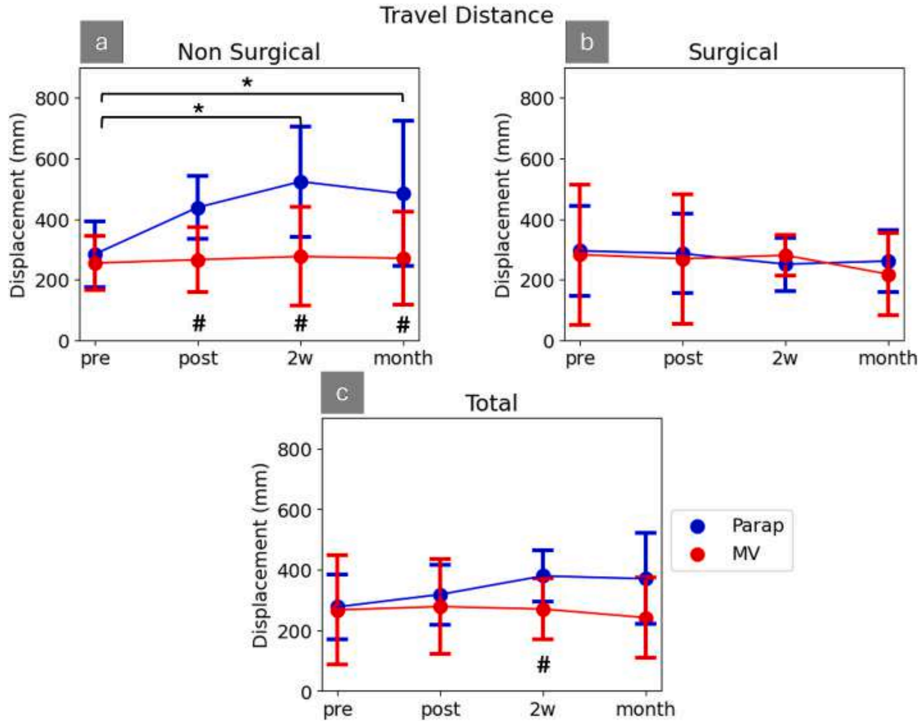

Fig. 4. — CoP total travel distance for non surgical (a), surgical(b) and both lower limbs (c). Circles represent the group median and error bars represent the group interquartile range. Significant differences, or the PP group, between time points are represented with *. Significant differences between MV and PP are represented with #.

findings (Bäthis et al., 2005; Dalury and Jiranek, 1999; Nestor et al., 2010; Nutton et al., 2014) which reported higher knee extension strength levels of the MV knee compared to the PP knee 3- and 6-weeks post-surgery (Bäthis et al., 2005; Dalury and Jiranek, 1999; Nestor et al., 2010; Nutton et al., 2014). However, the present study reports results at 5 days, 2 weeks and 1-month post-surgery. It is possible that during this (acute) phase, the overall functional status of the knee is highly diminished in both techniques, resulting in severe damage, due to their highly invasive nature (Niki et al., 2009). Based on these results, rehabilitation protocols could aim to restore knee extensor and flexor strength during the first month post-surgery (Dávila Castrodad et al., 2019).

Based on the postural control findings (Fig. 4), it seems that patients that undergo TKA through the PP technique use their non affected leg more to control posture during upright stance. Postural control is heavily dependent on the proprioceptive input from lower limb muscles and joints including knees (MacKinnon, 2018). Although somatosensory input is better in replaced knees compared to OA knees (Barrett et al., 1991), the ability to maintain balance is deteriorated in the post-operative period (Chan and Pang, 2015; Levinger et al., 2011). MV patients presented no significant increases in travel distance post-operation or over the course of one month. PP patients on the other hand, presented significantly larger total travel distance two weeks and one month after TKA compared to pre-surgery measurement (Fig. 4c) Minimal invasive techniques do not affect tissues and proprioceptive organs the way Parapatellar approach does. In MV approach the surgeon creates an incision and "moves" the muscle fibers of the vastus medialis without severely damaging the muscle (Scott et al., 2018). This technique probably minimizes the damage of muscle spindles which influence proprioception and, hence, postural control (Proske and Gandevia, 2012). On the other hand, in the traditional parapatellar approach, the surgeon is instructed to create an incision in the tendon using the surgical lancet and therefore, completely damaging the tendon tissue probably along with the Golgi organs that are also important for human proprioception (Proske and Gandevia, 2012; Scott et al., 2018). As a result, reduced sensory information on the operated knee may have forced the patients to overuse their non-affected knee to control posture.

The differences in postural control after TKA between surgical techniques agree with the literature (Pethes et al., 2015). Pethes and colleagues used postural perturbations in patients 12 weeks after TKA (Pethes et al., 2015). They found that the minimal invasive technique group showcased faster adaptation to perturbation compared to traditional techniques, possibly implying lower risk of falling. To our knowledge there is no longitudinal evidence of falls after TKA using different surgical techniques. Our findings combined with these of Pethes and colleagues (2015) indicate that, compared to minimal invasive approaches, the traditional PP approach is more detrimental to postural control both in terms of larger postural sway in the early stages of rehabilitation and of adaptability 3 months after TKA. These results are also in line with previous studies which reported that 12 weeks post-surgery, MV patients had close-to-normal gait compared to healthy controls while Parapatellar patients did not (Kiss et al., 2012; Lee et al., 2023).

Overall, the results indicate that the surgical technique influences the post-surgery biomechanical characteristics of movement. Our protocol was designed to be easily applied outside the laboratory, in the hospital rooms. This protocol includes two novel innovations. Firstly, data were collected 5 days after the operation because of the portability of instruments and secondly, the pair of force plates allowed the recording of CoP separately for the two lower limbs.

The results of the present study should be interpreted taking into consideration some limitations. The sample size was small; a larger number of participants could further bolster or disprove our findings. In addition, no functional, perturbation or gait tests were performed. Instead, our approach focused on easily executed tests such as 30s upright stance to evaluate posture as soon as possible after the operation. The study did not involve longitudinal measurements, and this restricts the applicability of the results in the first post operative month. Nevertheless, this approach was deliberately adopted since evidence of the short-term effect of surgery is scarce in the literature and this was the main focus of this study.

The present study is the first to identify postural deficits as a function of surgical technique in the early stages of rehabilitation and showed that PP approach affects posture more compared to the minimal invasive approach of MV. Although postural sway during upright stance is not directly linked to falls, it is possible that early-stage postural control could predict the dynamic balance and adaptability of the patient in the later stages. Therefore, the predisposition of individuals to become fallers may be quantified early on and steer rehabilitation interventions towards fall prevention training. Nevertheless, such speculation requires further experimentation.

5. Conclusions

The MV and the PP approaches for TKA caused a vast decline in knee flexion and extension strength during the first post-surgery month. In this time period, MV approach did not affect CoP travel distance, while the PP group showed a greater CoP travel distance after surgery. Therapists could plan the rehabilitation process during the first post-surgery, by taking into account the type of surgery approach which is followed for TKA.

CRediT authorship contribution statement

Thomas Nikodelis: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Stylianos Grigoriadis:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation. **Dimitris Metaxiotis:** Writing – review & editing, Resources, Methodology, Data curation, Conceptualization. **Vasileios Mylonas:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation. **Eleftherios Kellis:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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