



WORKSHOP

Functional Analysis The Key To The Next Revolution in The Treatment and Prevention of Hip and Knee Arthritis *(Organized by Canadian Orthopaedic Research Society)*

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How to interpret Biomechanical/Functional Analysis of the Lower Extremity?

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INTRODUCTION: Orthopedic surgeons rely on patient-reported outcome measures (PROMs) to evaluate whether one treatment is better than another. PROMs can be classified as either “general” (e.g., SF-36) or “disease” (e.g., WOMAC) specific, and these measures are often combined by the surgeons’ clinical assessment, which often includes patient’s imaging for alignment and joint function¹. Scientific literature reports inconsistencies between PROMs and clinical-based outcomes. Although PROMs are easy to administer, their qualitative design and common ceiling effects severely limit its validity². Biomechanical/functional analysis, which includes the motion, forces, and muscle activity can provide both the researcher and clinician with objective evidence into joints functional performance before and after a surgery by including the joint motion, the forces causing these motions and the muscles that are being activated³. Objective measurements are necessary to assess the effectiveness of patient’s functional performance. The purpose of this presentation is to describe various biomechanical analysis procedures and their outcomes to help the orthopedic surgeons to make an informed clinical decision.

METHODS: One of the most common methods of data analysis in biomechanics consists of measuring gait parameters such as walking speed, stride length and cadence among others. This method provides gait performance but limited information about the joint biomechanics. A more advanced motion analysis of gait consists of measuring several relevant discrete kinematics and kinetics variables, such as peak and range of motion of joint angles, moment and power and sometimes peak values and total muscle activity together with a statistical hypothesis test to measure differences between groups. This more advanced data analysis cannot capture the complexity of these relationships. More complex data analyses for gait would use time-waveform analysis, which compares kinematics and kinetics variables across the entire waveform of the motion cycle. Examples of time-waveform analysis would be principal component analysis (PCA) and statistical parametric mapping (SPM). PCA is an algebraic algorithm that aims at reducing all of the variables of interest into a set of new variables or “components” that sufficiently captures the observed total variation of the original variables⁴. SPM provides topological analysis of smooth continuum changes⁵. It compares the entire time-waveform for biomechanical variables between two groups. The benefit of SPM is that statistical differences are presented directly in the original sampling space-time so their spatiotemporal biomechanical context is immediately apparent and removes the assumptions regarding the spatiotemporal foci of signals⁵.

RESULTS: As example, we report a study that compared a cohort of individuals ranging from 23 to 81 years of age and compared inter-limb variability for gait parameters and hip kinematics using discrete analysis and SPM. Participants were divided based on their age into four groups⁶. Table 1 provides an overview of the results for the spatiotemporal variables. Swing times, and consequently gait times, were significantly different greater in Groups 3 & 4 compared with Groups 1 & 2. Walking speed generally decreased with an increase in age. However, when comparing the oldest group (Group 4) for differences in peak hip flexion between left and right limbs, the discrete analysis did not identify a significant difference between the two limbs ($p > 0.05$). SPM analysis identified a significant difference between the two limbs for the first 15% of the stance phase (Figure 1).

DISCUSSION: Orthopedic surgeons want to make their clinical care on evidence-based medicine. Their clinical decisions need to be based on quantitative and objective findings considering individual patient needs and circumstances^{7,8}. Certain spatiotemporal and discrete biomechanical parameters may be relevant to both clinicians and researchers, such as the improvement of walking speed and hip ROM after hip replacement. However, these indicators have their limitations, as it does not take into account the entire gait cycle. For the gait parameters, we have significant differences among the groups but we cannot identify which joints are affecting the gait parameters. If we want to look at multiple biomechanical variables over the entire gait cycle. PCA and SPM analyses can be used to extract the significance in the dataset. Although PCA can help to reduce the large number of variables into a few principal components, the clinical significance is not always straightforward. On the other hand, SPM takes the discrete analysis one step further as it analyzes the entire gait cycle for a single variable and compare between conditions. With our dataset, the discrete analysis did not identify any difference between the two limbs; however, SPM did identify a significant difference for the first 15% of the gait cycle. This information is more meaningful as it indicates that differences arise during the transition from double-limb support to single-limb support. The gait parameters showed significant differences in stance time between the dominant and non-dominant limb but we could not identify which of the lower-limb joints affected the stance time. The comparison for statistical significance over the entire gait cycle can allow more detailed features of the compared variables. However, the statistical significance may or may not be clinically significance.

SIGNIFICANCE/CLINICAL RELEVANCE: Surgeons should aim to go beyond PROMs and start incorporating biomechanical findings into their clinical practice. Understanding the biomechanical changes that occur post-surgery would help evaluate if the surgery was successful. Although a difference of few degrees in hip ROM may be statistically significant, this may not be clinically significant. Therefore, Further investigations are still necessary to better understand the relationships between statistical and clinical differences.

REFERENCES: [1] Suk et al. 2010. *Orthop Clin N Am*. 41:139-143; [2] Wampa et al. 2010. *Acta Orthopaedica*. 81(6): 703-707; [3] Lamontagne et al. 2009. *Orthop Clin N Am*. 40: 397-405; [4] Chau. 2001. *Gait & Posture*. 13: 49-66; [5] Pataky. 2012. *Comput Methods Biomech Biomed Engin*. 15(3): 295-301. [6] Kowalski et al. 2018. *ORS Annual Meeting*. [7] Viveiros et al. 2007. *J Long Term Eff Med Implants*. 17 (1): 87-9; [8] Wright, James G., et al. "Introducing levels of evidence to the journal." (2003). *JBJS* 85 (1) 1-3.

IMAGES AND TABLES:

Table 1

Spatiotemporal variable results from analysis of variance.

	Group 1 (23-34 y/o)	Group 2 (35-49 y/o)	Group 3 (50-64 y/o)	Group 4 (65-81 y/o)
Speed (m/s)	1.49 ± 0.16	1.44 ± 0.16*	1.34 ± 0.15**†	1.35 ± 0.12**†
Dominant Stride Length (m)	1.43 ± 0.14‡	1.40 ± 0.18‡	1.40 ± 0.17‡	1.48 ± 0.24
Non-dominant Stride Length (m)	1.65 ± 0.18‡	1.61 ± 0.11‡	1.62 ± 0.17‡	1.60 ± 0.20
Dominant Stance Time (s)	0.43 ± 0.05‡	0.44 ± 0.05‡	0.43 ± 0.06‡	0.45 ± 0.08
Non-dominant Stance Time (s)	0.50 ± 0.05‡	0.50 ± 0.06‡	0.51 ± 0.06‡	0.51 ± 0.08
Dominant Swing Time (s)	0.53 ± 0.06‡	0.52 ± 0.06‡	0.59 ± 0.08‡	0.64 ± 0.12**†
Non-dominant Swing Time (s)	0.61 ± 0.06‡	0.61 ± 0.06‡	0.67 ± 0.09‡	0.67 ± 0.09
Dominant Gait Time (s)	0.96 ± 0.11‡	0.96 ± 0.11‡	1.02 ± 0.14‡	1.09 ± 0.20
Non-dominant Gait Time (s)	1.11 ± 0.10‡	1.11 ± 0.11‡	1.17 ± 0.14‡	1.18 ± 0.16

*Represents a significant ($p < 0.05$) difference from Group 1

†Represents a significant ($p < 0.05$) difference from Group 2

‡Represents a significant ($p < 0.05$) difference between dominant and non-dominant limbs

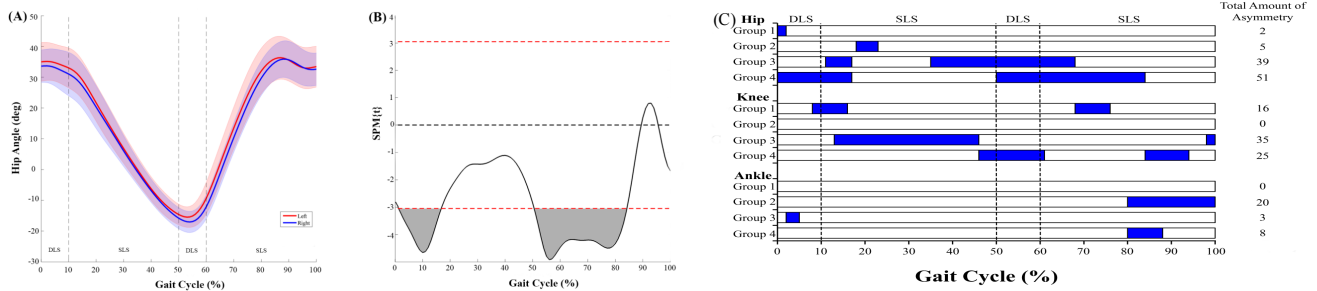


Figure 1: (A) Group 4 mean hip sagittal joint angles for the left and right limb during an entire gait cycle. Positive angles represent flexion and negative values represent an extension. (B) Paired-sample SPM t-test results comparing left versus right limbs for sagittal hip angles in Group 4 for an entire gait cycle. SPM {t} values reached the critical threshold (dashed line) for significance on two occasions and are represented by the shaded area. (C) Summary of paired-sample SPM t-test results comparing the joint angles between the left versus right limbs for an entire gait cycle. Shaded areas represent the critical threshold of the SPM {t} values at the percentage of the gait cycle. DLS represents double limb support; SLS represents single limb support.

Gait Analysis after Total Knee Replacement: Implant Design or Kinematic Reconstruction: Which is More Important?

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Introduction: Restoring the functional capacity of the knee joint is a primary objective of TKA. While research has supported that some improvements in joint-level mechanics during walking are achieved on a population average after surgery [1,2], it is unclear if functional improvement is optimized on an individual level, and what level of improvement is achieved by individuals after arthroplasty surgery relative to defined targets. This research aims to comprehensively capture the key features of joint-level functional deficits post-TKA surgery on a population and individual level, relative to targets of healthy adult knee function and that of a population with moderate levels of knee osteoarthritis (OA). Differences in joint-level functional improvement from TKA based on cruciate ligament retaining (CR) versus posterior stabilized (PS) implant design are explored. The relationships between pre-operative knee joint function during gait and minimal clinically important difference (MCID) improvement in self-reported function and pain outcome (WOMAC) were also explored.

Methods: Three-dimensional instrumented gait analysis was performed on 73 individuals with end-stage knee OA scheduled to receive primary TKA surgery within the week, as well as demographically-matched cohorts of 72 asymptomatic individuals and 72 with moderate levels of knee OA (see [3] for methods). We examined the percentage of patients whose gait features were within one standard deviation of asymptomatic and moderate OA mean targets, and also the percentage of patients whose joint-level knee kinematics and kinetics during gait were closer (using a multivariate Mahalanobis statistical distance) to asymptomatic or moderate OA populations before and after surgery. Patients received one of four implant systems including the NexGen PS (n=34) (Zimmer), Triathlon PS (n = 14) (Stryker), Triathlon CR (n=11), and Medial Pivot CR system (n=14) (Wright Medical). Patients were grouped by global PS (n = 48) or CR design (n = 25), and changes in knee joint kinematics and kinetics during gait were compared between the CR and PS groups. A subgroup of 49 patients had pre and post-operative WOMAC scores captured before and at one (n=38) and two years (n=11) post-TKA. Correlations between pre-TKA gait features and WOMAC score changes were tested using Pearson's correlation coefficients.

Table 1: Percent of patients (n=72) with discrete parameter and waveform PC values within asymptomatic and moderate OA targets (+/- 1 standard deviation from group mean). Bold = decrease or no change in number of participants pre- to post-TKA.

Parameter	Asymptomatic Target			Moderate OA Target		
	PreTKA	PostTKA	Change	PreTKA	PostTKA	Change
Gait Speed (m/s)	7%	17%	10%	17%	42%	25%
Discrete Parameters						
Adduction Moment 1st Peak (Nm/kg)	44%	43%	-1%	44%	44%	0%
Adduction Moment 2nd Peak (Nm/kg)	21%	46%	25%	33%	46%	13%
Adduction Moment Mid-stance (Nm/kg)	17%	36%	19%	32%	49%	17%
Peak Flexion Angle Swing (°)	13%	28%	15%	28%	43%	15%
Peak Flexion Angle Stance (°)	13%	29%	16%	42%	47%	5%
Flexion Angle Range (°)	6%	18%	12%	22%	38%	16%
Peak Flexion Moment (Nm/kg)	31%	29%	-2%	44%	54%	10%
Peak Extension Moment Early-stance (Nm/kg)	24%	42%	18%	35%	42%	7%
Peak Extension Moment Late-stance (Nm/kg)	14%	19%	5%	32%	43%	11%
Peak Internal Rotation Moment (Nm/kg)	19%	29%	10%	26%	40%	14%
Waveform PCs						
Adduction Moment PC1	35%	67%	32%	57%	72%	15%
Adduction Moment PC2	15%	42%	27%	40%	57%	17%
Adduction Moment PC3	53%	72%	19%	63%	79%	16%
Flexion Angle PC1	24%	43%	19%	43%	65%	22%
Flexion Angle PC2	56%	71%	15%	56%	69%	13%
Flexion Angle PC3	51%	53%	2%	58%	68%	10%
Flexion Moment PC1	31%	33%	2%	53%	67%	14%
Flexion Moment PC2	13%	31%	18%	83%	82%	-1%
Rotation Moment PC1	36%	57%	21%	49%	81%	32%
Rotation Moment PC2	51%	43%	-8%	88%	81%	-7%

Results: Significant ($p < 0.05$) negative associations were found between pre-surgery knee kinematics and kinetics and their associated changes from the pre-to post-operative state (n =72 all groups). Of the knee joint kinematic and kinetic metrics during gait, the incidence of those falling within asymptomatic and moderate OA targets both before and after surgery are provided in Table 1. More gait features reached moderate OA targets before and after surgery, but the majority of patients did not reach either target for many of the gait features post-TKA. In general, sagittal plane kinematic and kinetic metrics saw less improvements toward targets post-surgery than frontal plane metrics. From the multivariate distance analysis, the majority of patients

Table 2: Based on Mahalanobis multivariate distances from centroids of the asymptomatic, moderate OA, and pre-TKA groups including all gait features, the change in classification from pre to post-TKA is presented. Improvement represented a change to a higher functional classification post-TKA, decline representing a change to lower classification, and no change representing the same function classification before and after TKA.

Change	N	Total (% of 72 Participants)
Improved from low to moderate function	24	31 (43%)
Improved from low to high function	4	
Improved from moderate to high function	3	
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Stayed low function	22	36 (50%)
Stayed moderate function	12	
Stayed high function	2	
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Declined from moderate to low function	3	5 (7%)
Declined from high to low function	0	
Declined from high to moderate function	2	

plane mechanics. This suggests that there is still room for improvements in surgical management and innovation to improve functional outcomes.

Many of the gait parameters changed on average from pre to post-TKA, consistent with previous work [1]. However, interestingly, there were no statistically significant differences in the extracted features of the knee joint kinematics, kinetics, or gait speed between the CR and PS groups either pre-or post-TKA, or in terms of the change pre to post (all $P > 0.05$) (Figure 2). Yoshiya et al. [2] showed differences in rollback kinematics between CR and PS implant designs, but with no other differences in gait kinematics.

Objective biomechanics analysis before and after surgery is rarely used to evaluate the added value of new implant designs. Our results show relative group-average equivalence between the CR and PS designs in terms of gait mechanics after surgery, and change in mechanics from pre to post to surgery. This does not mean that particular individuals may not benefit from one design over the other, but at this time, implant design is not coupled with patient selection to optimize functional outcome.

Overall, 39/49 and 38/49 patients met the MCID criteria (>23 and 19 in Pain and Function WOMAC domains) [4]. Change in both Pain and Physical Function domains from before to after surgery was only correlated with less stance-phase flexion angle range of motion. In regression analyses, younger age (OR=0.73, $p<0.01$), lower BMI (OR=0.66, $p<0.01$), less stance-phase flexion angle (OR=0.58, $p=0.02$), a prolonged stance and later occurring peak flexion angle (OR=0.96, $p=0.03$), contributed to greater odds of an MCID physical function response ($R^2=43\%$, linear model). Those who did not achieve MCID in WOMAC function showed a reduction in overall adduction angle magnitudes during gait ($p=0.004$) (Figure 1). Those who did achieve MCID in function showed improvement in flexion angle and moment, and adduction moment features during gait ($p<0.01$). These results demonstrate that those patients with more ‘severe’ gait biomechanics have the most to gain in terms of improvements in self-report clinical outcomes.

after surgery had gait biomechanics most similar to those diagnosed with moderate levels of knee osteoarthritis. Interestingly, 50% of patients remained within the same functional category from before to after surgery, and a 7% actually experienced a functional decline (Table 2). These results support that the pre-operative functional state during gait is a strong predictor of the post-operative functional state, suggesting the potential need for improved pre-habilitation strategies or surgical intervention before walking function is significantly deteriorated. These results also suggest that although functional gait improvements are achieved by most individuals after arthroplasty surgery, the majority of individuals achieve gait function most similar to those with moderate knee OA, and very few achieve levels similar to asymptomatic gait. Particular deficits were noted in sagittal

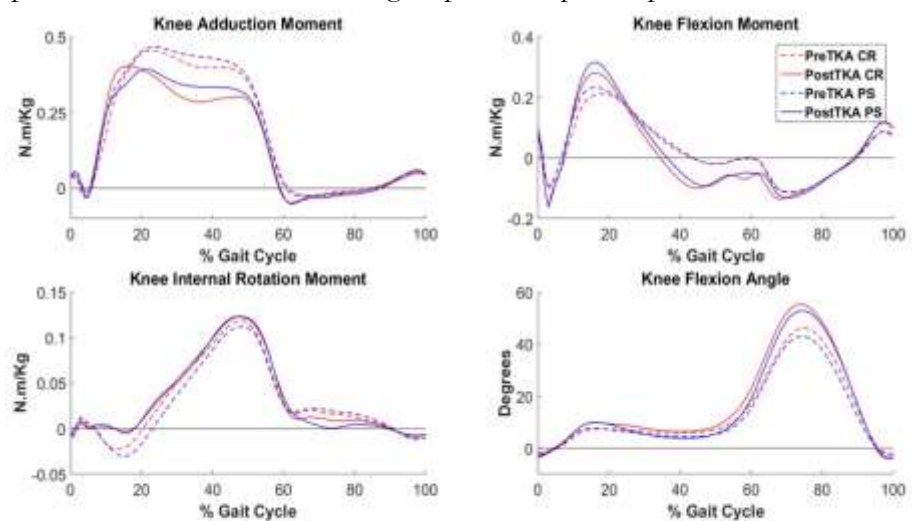


Figure 1. Average knee joint kinematic and kinetic waveforms during gait, pre-(dashed) and post-TKA (solid).

Conclusion: 3D gait analysis offers objective measurement of joint-level function for examining differences between implant designs and patient-to-patient variability in terms of their functional response to surgery. This research has shown that, despite improvements in aspects of gait function on a population average, there is much patient-to-patient variability. In general, standard of care TKA surgery improves aspects of frontal plane knee function during gait toward asymptomatic and moderate OA functional targets more than sagittal plane metrics. We have also shown that the function of the knee joint before surgery is a large predictor of improvement in function post-TKA, with those patients with worse function improving more post-surgery. Similarly, we've shown that those patients with poorer gait function pre-TKA are more likely to see larger clinical improvements in terms of self-reported pain and physical function. Despite this relationship, the associations between objectively measured function and self-report pain and function were not strong. Looking at categorizations of CR and PS systems, we showed no significant differences in joint-level biomechanical improvement from pre to post-TKA based on design.

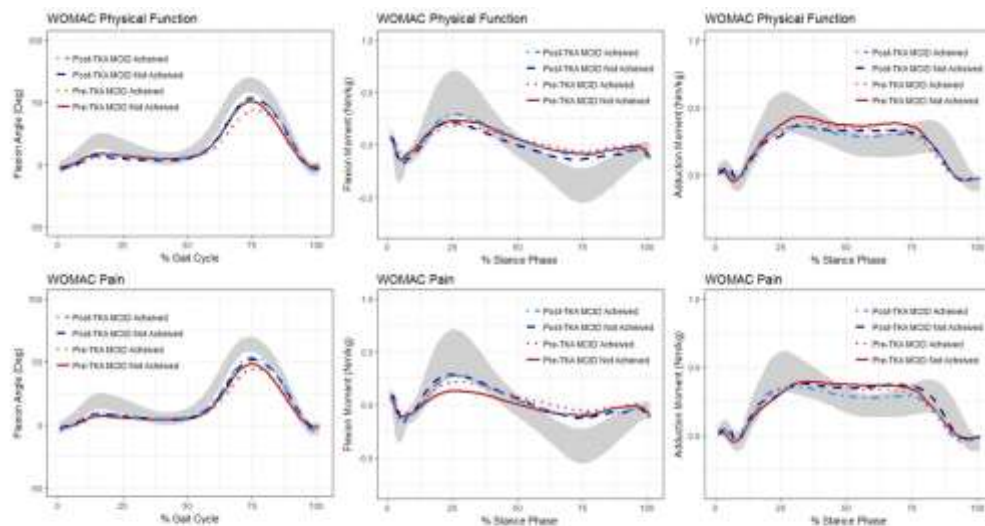


Figure 2. Mean pre and post-TKA a) flexion angle, b) flexion moment, and c) adduction moment waveforms of those who did (dash) and did not (solid) achieve an MCD response in the WOMAC Physical Function and Pain domains (n=49). The shaded regions represent one standard deviation around the mean waveforms from 209 asymptomatic individuals.

Patient factors and person-specific function pre-operatively are more dominant factors in functional outcome than design at this time. More research should address how to use this information to help inform surgical planning, decisions and design, and how to use objective gait analysis to understand patient-selection with new TKA innovations. The research presented fits within a larger program of examining how factors (implant design, obesity, female sex [3]) influence the functional response to surgery, and links between function, other aspects of outcome and surgical planning, including radiostereometric analysis for implant stability [5,6] and surgical navigation [7].

References:

1. Hatfield et al. 2011. The effect of total knee arthroplasty on knee joint kinematics and kinetics during gait. *J Arthroplasty*. 26(2):309-18.
2. Yoshida et al.. 2012. Do patients achieve normal gait patterns 3 years after total knee arthroplasty? *J Orthop Sports Phys Ther*. 42(12):1039-49.
3. Astephen Wilson et al., 2015. Knee joint biomechanics and neuromuscular control during gait before and after total knee arthroplasty are sex-specific. *J Athroplasty*. Jan 30(1):118-25.
4. Escobar A et al., 2007. Responsiveness and clinically important differences for the WOMAC and SF-36 after total knee replacement. *Osteoarthritis Cartilage* 2007. Mar, 15(3):273-80.
5. Astephen Wilson et al., 2010. Pre-operative gait patterns and BMI are associated with postoperative tibial component migration in total knee arthroplasty. *Acta Orthopaedica*. Aug, 81(4):478-86.
6. Wilson et al., 2012. Preoperative muscle activation patterns during walking affect tibial implant migration. *Clinical Biomechanics*. 27(9): 936-942.
7. Roda et al., 2012. The knee adduction moment during gait is associated with the adduction angle measured during computer-assisted total knee arthroplasty. *J Arthroplasty*. June, 27(6):1244-50.

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INTRODUCTION

Osteoarthritis is prevalent, disabling and costly to individuals and the healthcare system. Symptomatic hip OA affects 4.2% of people over 50, although radiographic OA changes affect almost 20% of that population¹. The natural history of osteoarthritis is that of progression with increasing pain and physical disability. Ultimately in many patients arthroplasty is used to relieve pain and improve function². Though effective in improving a patient's quality of life³, joint replacements will eventually fail, which necessitates further (revision) surgery that has a higher complication rate and a less predictable result⁴. Better strategies to delay or arrest the progression of osteoarthritis are needed, and these can only be devised with a clearer understanding of the etiology of the disease.

There is strong evidence that mechanical and structural changes at joints are major etiological factors in the development of osteoarthritis. It was originally assumed that 50% of hip osteoarthritis was idiopathic (not associated with any obvious deformity)⁵. More recent studies have suggested that 90% or more of hip osteoarthritis cases can be attributed to anatomical abnormalities^{6,7}. These structural deformities can be corrected with a range of operative strategies, including both pelvic and femoral osteotomies, in an effort to improve patient symptoms and delay osteoarthritis progression⁸. There is a strong need for more evidence in support of the mechanical effectiveness of prevention and treatment approaches that aim to change joint mechanics. The objective of this presentation is to review some contemporary imaging and modeling approaches for studying links between joint mechanics and osteoarthritis.

METHODS

A number of biomechanical studies have been done that aimed to confirm hypotheses about the role of mechanical and structural changes at joints on osteoarthritis initiation and progression and to predict the effects of treatments that aim to correct these mechanical and structural changes⁹. All current approaches (*ex vivo*, models, movement analysis) have limitations that affect how well we can characterize links between mechanics and osteoarthritis.

Ex vivo studies are of limited utility because of the difficulty of simulating *in vivo* load/movement combinations *ex vivo*. Models have been used to predict joint mechanics given certain inputs. Current model predictions are limited because a) models require simplifications of joint anatomy, mechanical properties and movement; b) model validation is difficult and often perfunctory and c) most model studies have been done on very small populations.

Experimental measurements of activities using motion analysis provide substantial experimental data but do not provide direct measurements of some of the most relevant parameters.

Recent work incorporating patient-specific models and/or external measurements of mechanics have potential to provide the most accurate predictions of joint mechanics parameters that are related to osteoarthritis. Subject-specific models driven by gait analysis have been applied in the hip and knee¹⁰. Recent developments in MR¹¹ (Figure), CT, and biplanar radiography/fluoroscopy¹² all have potential for more direct measurements of quantities of interest.

CONCLUSIONS

Emerging modelling and imaging approaches have potential to improve osteoarthritis prevention.

REFERENCES

1. Kim C, Linsenmeyer KD, Vlad SC, et al. Prevalence of radiographic and symptomatic hip osteoarthritis in an urban United States community: the Framingham osteoarthritis study. *Arthritis Rheumatol (Hoboken, N.J)*. 2014;66(11):3013-3017. doi:10.1002/art.38795.
2. Manek NJ, Lane NE. Osteoarthritis: current concepts in diagnosis and management. *Am Fam Physician*. 2000;61(6):1795-1804. 10750883.
3. Ethgen O, Bruyere O, Richy F, Dardennes C, Reginster JY. Health-related quality of life in total hip and total knee arthroplasty. A qualitative and systematic review of the literature. *J Bone Jt Surg Am*. 2004;86-A(5):963-974. 15118039.
4. Haydon CM, Mehin R, Burnett S, et al. Revision total hip arthroplasty with use of a cemented femoral component. Results at a mean of ten years. *J Bone Jt Surg Am*. 2004;86-A(6):1179-1185. 15173290.
5. LLOYD-ROBERTS GC. Osteoarthritis of the hip; a study of the clinical pathology. *J Bone Jt Surg Br*. 1955;37-B(1):8-47. 14353950.
6. Tanzer M, Noiseux N. Osseous abnormalities and early osteoarthritis: the role of hip impingement. *Clin Orthop Relat Res*. 2004;(429):170-177. 15577483.
7. Harris WH. Etiology of osteoarthritis of the hip. *Clin Orthop*. 1986;(213):20-33. 3780093.
8. Millis MB, Kim YJ. Rationale of osteotomy and related procedures for hip preservation: a review. *Clin Orthop Relat Res*. 2002;(405):108-121. 12461362.
9. D'Entremont AG, Buchan LL, Wilson DR. *Biomechanical Considerations in Arthritis of the Hip*; 2015. doi:10.1007/978-3-319-19905-4_4.
10. Ng KCG, Mantovani G, Lamontagne M, Labrosse MR, Beaulé PE. Increased Hip Stresses Resulting From a Cam Deformity and Decreased Femoral Neck-Shaft Angle During Level Walking. *Clin Orthop Relat Res*. 2017;475(4):998-1008. doi:10.1007/s11999-016-5038-2.
11. Buchan LL, Zhang H, Konan S, Heaslip I, Ratzlaff CR, Wilson DR. Open-MRI measures of cam intrusion for hips in an anterior impingement position relate to acetabular contact force. *J Orthop Res*. 2016;34(2). doi:10.1002/jor.22999.
12. Kapron AL, Aoki SK, Peters CL, Anderson AE. In-vivo hip arthrokinematics during supine clinical exams: Application to the study of femoroacetabular impingement. *J Biomech*. 2015;48(11):2879-2886. doi:10.1016/j.jbiomech.2015.04.022.

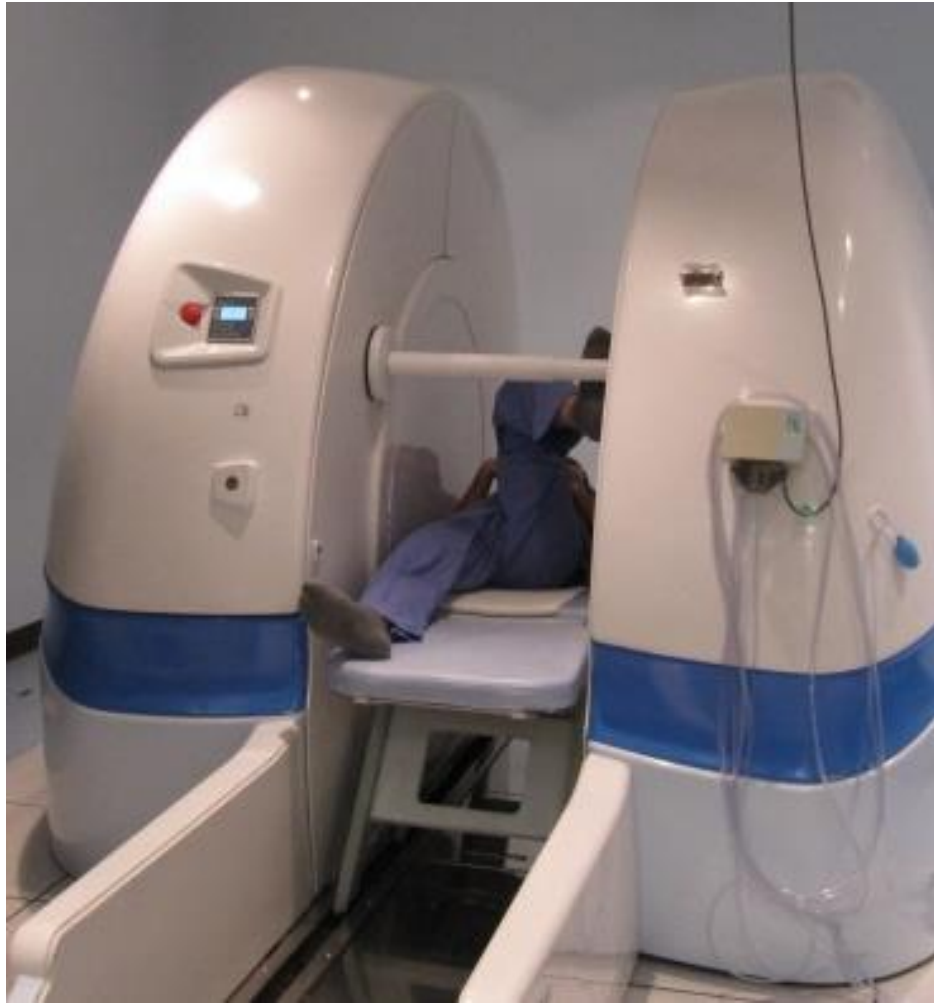


Figure. Illustration of imaging in a biomechanically relevant posture for hip osteoarthritis using an upright open MR scanner.

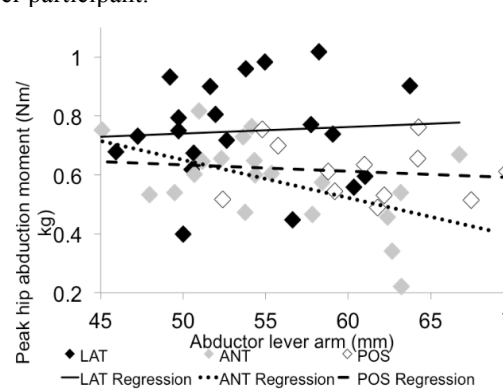
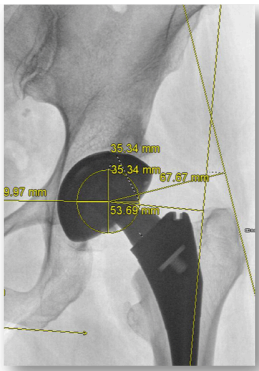
Gait Analysis after Total Hip Replacement: What is the influence of surgical approach and Implant Design?

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Because the treatment effect is so significant after total hip replacement it has overshadowed our aptitude to study the various levels of function achievable. Concomitantly, as patients' expectations have increased over the last two decades in regards to hip function after joint replacement, there has been a renewed interest in gaining a better understanding on how surgical approach, rehabilitation protocol as well as implant design can affect the clinical outcome after total hip replacement (THA). From a patient's perspective being able to walk without a limp is certainly an important goal for them to achieve after total hip replacement. One important determinant of gait is the hip abduction moment as the abductors play a key role in stabilizing the pelvis in the frontal plane, particularly in phases of transition, such as the single leg stance in walking or stair climbing. From the surgeon's perspective, although our capacity to restore normal limb function is important to us, minimizing the risk of instability both in the short term as well as during various levels of activity is primordial and has been a strong focus of implant development i.e. large femoral heads and dual mobility implants. To illustrate these important concepts within the context of gait analysis, we will present two studies conducted at our center, one looking at influence of surgical approach and biomechanical reconstruction; and the second, is a prospective RCT comparing a dual mobility implant to a standard total hip replacement.

Study 1:

We analyzed fifty-two patients underwent motion analysis approximately 10 months after hip replacement. A motion capture system and force plates collected data for five walking trials per participant.



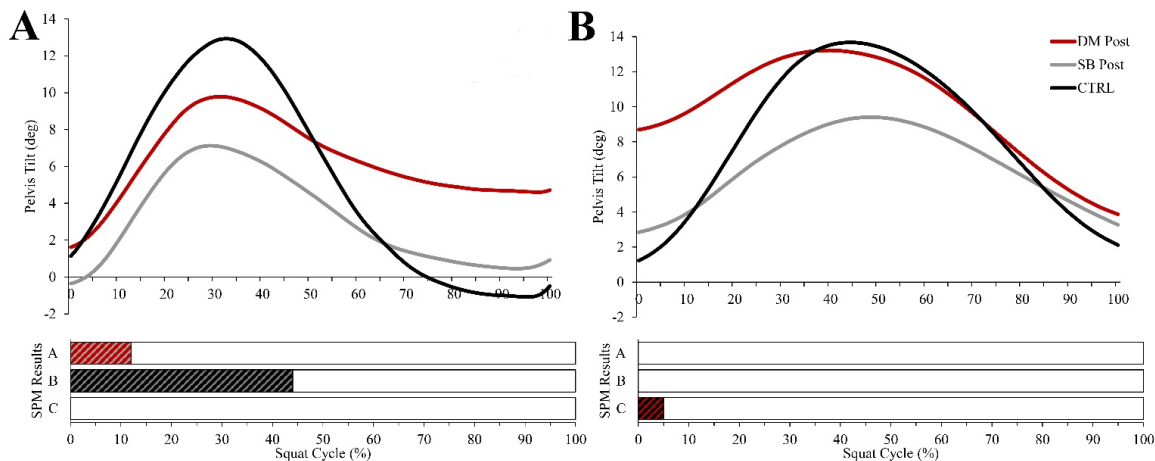
A hierarchical regression analysis was performed on each of these variables in the following order: (1) age, (2) sex, (3) abductor lever arm and (4) surgical approach (anterior, lateral or posterior approach).

Age was the most influential factor, especially in the sagittal plane. As hypothesized, peak hip abduction moment was influenced by the abductor lever arm and by surgical approach.

This study underlines the important effects of demographic factors such as age and sex, and that surgical approach and abductor lever arm also influence biomechanical variables during gait, to a lesser degree. Results suggest that an excessive increase in abductor lever arm can negatively affect the abduction moment of force in patients after total hip replacement and that the more intact the abductors remain during the surgical approach the greater that effect.

Study 2:

Twenty-four THA patients were randomly assigned to either a Dual Mobility (DM) or Standard Bearing (SB) implant and matched to 12 healthy controls. They underwent 3D squat motion analysis prior and nine months after surgery. Sagittal and frontal plane angles of the pelvis and hip were analyzed using statistical parametric mapping. Paired analyses compared pre- and post-surgery squat depth. Peak sagittal pelvis angle of DM were closer to normal compared to SB. Both implant groups had similar hip angle patterns and magnitude but significantly lower than the controls. SB reached a much large hip abduction compared to the other groups. Both surgical groups had significantly worst squat depth than the controls. Neither THA implant groups were able to return pelvis and hip kinematics to the level of controls.



Mean of sagittal pelvis angles during squatting task: (A) descent phase, (B) ascent phase. Sagittal Pelvic Motion results are displayed below the figure and indicate significant ($p < 0.05$) differences between (A) Dual Mobility(DM) post vs Standard Bearing (SB) post; (B) SB post vs CTRL; and (C) DM post vs CTRL

STANDARD FIXED CUP



VERSAFITCUP DM



The deficit of DM implants at the pelvis may be due to higher coefficient of friction at the interface causing greater co-contraction of the hip flexors and extensors. SB design causes a larger hip abduction in order to reach their maximum squat depth.

Conclusion:

It is clear that normal hip mechanics are not fully restored after THA despite using muscle sparing approaches and that innovative implant designs have a limited capacity to reproduce normal joint mechanics. Future research in muscle adaptation pre and post THA may provide the key to further improve patient function with rehabilitation program focusing more on this aspect to maximize joint ROM and strength.

References:

- 1) Lower limb biomechanics during gait do not return to normal following total hip arthroplasty. Beaulieu ML, Lamontagne M, Beaulé PE. *Gait Posture*. 2010 Jun;32(2):269-73
- 2) Comparison of joint mechanics of both lower limbs of THA patients with healthy participants during stair ascent and descent. Lamontagne M, Beaulieu ML, Beaulé PE. *J Orthop Res*. 2011 Mar;29(3):305-11.
- 3) Lower-limb joint mechanics after total hip arthroplasty during sitting and standing tasks. Lamontagne M, Beaulieu ML, Varin D, Beaulé PE. *J Orthop Res*. 2012 Oct;30(10):1611-7.
- 4) Does the anterior approach for THA provide closer-to-normal lower-limb motion? Varin D, Lamontagne M, Beaulé PE. *J Arthroplasty*. 2013 Sep;28(8):1401-7.
- 5) Orthopaedic Research Society William H. Harris Award; "How do Reconstruction Parameters and Surgical Approaches in Total Hip Arthroplasty Affect Hip Biomechanics During Gait". Varin D, Lamontagne M, Beaulé PE,
- 5) Does the Dual-Mobility Hip Prosthesis Produce Better Joint Kinematics During Extreme Hip Flexion Task? Catelli DS, Kowalski E, Beaulé PE, Lamontagne M. *J Arthroplasty*. 2017 Oct;32(10):3206-3212.