ARTICLE

Linking Biomechanics to Mobility and Disability in People With Knee Osteoarthritis

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MALY, M.R. Linking biomechanics to mobility and disability in people with knee osteoarthritis. *Exerc. Sport Sci. Rev.*, Vol. 37, No. 1, pp. 36–42, 2009. *Knee osteoarthritis is the leading cause of chronic disability among community-dwelling adults. The factors resulting in this disability extend beyond pathology. Therefore, understanding disability requires assessment of both pathology and the day-to-day consequences of knee osteoarthritis. This review develops a novel osteoarthritis construct, ''careful mobility,'' by linking qualitative and quantitative methods to study both patient experience and biomechanics.* **Key Words:** activities of daily living, arthritis, gait, qualitative, rehabilitation, self-efficacy

INTRODUCTION

Knee osteoarthritis (OA) is a joint disorder with a complex and heterogeneous etiology, involving both biochemical and biomechanical events. Despite heterogeneity in pathology, knee OA produces similar alterations in articular anatomy (*e.g.*, cartilage degradation) and function (*e.g.*, mobility limitations and disability). Excessive or abnormal joint loading is an important factor in knee OA pathology. Abnormal loading is theorized to damage articular tissues at a rate faster than the body can repair. As a result, substantial effort has been invested in exploring the biomechanical mechanisms involved in the progression of knee joint degeneration.

Biomechanics provides insight into knee OA mechanical pathology. Malalignment, weakness, and altered muscle activation patterns are a few biomechanical factors implicated in knee OA progression. Moreover, the peak knee adduction moment has been identified as a proxy for the joint load endured by the medial compartment. During walking, the net ground reaction force passes medial to the center of the knee in the frontal plane, resulting in an external adduction moment that rotates the tibia into adduction upon the femur. Bone distribution, cartilage thickness, and direct contact studies validate that the peak knee adduction moment is a reasonable estimate of the maximum medial load. Based on this work, research has evaluated interventions including surgery, bracing, foot orthoses, and gait retraining using the peak knee adduction moment. This measure may be useful in predicting outcomes of these interventions (*i.e.*, is the surgery successful or not?), but improvement in the knee loading environment does not necessarily translate into improved mobility or reduced disability.

What remains unclear is whether biomechanical quantifications such as the knee adduction moment can provide meaningful information about the sources of mobility limitations and disability experienced by people with knee OA. *Mobility limitations* refer to the declines in performance of physical tasks that are required to interact with the environment, such as walking. *Disability* refers to difficulties in fulfilling social roles, including family and occupational responsibilities. The relationships between biomechanical measures and mobility limitations or disability are often weak and uninformative. The limited predictive power of biomechanical data to explain these experiences is not surprising because mobility and disability are multidimensional constructs influenced by many factors including pathology, psychology, and the environment. Integrating biomechanics into studies of patient experience has potential to yield insights into factors facilitating mobility limitations and disability. A mixed quantitative/qualitative approach can study the role of biomechanics on these outcomes from the perspective of the patient.

This article first summarizes the evidence supporting a critical role for biomechanics in knee OA pathology, and second, introduces one approach to incorporating biomechanics into studies of patient experience. This juxtaposition revealed a new construct of *careful mobility* in knee OA, supported by both qualitative and quantitative evidence.

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Thus, a mixed methods approach can extend the impact of biomechanics beyond pathology, to mobility and disability.

BIOMECHANICS AND KNEE OA PATHOLOGY

Convincing evidence supports a role for biomechanics in knee OA progression, and some work even implicates biomechanical factors in the initiation of this disease process. Together, these studies confirm that mechanics are important to knee OA pathology.

Biomechanics and Disease Initiation

Studies of malalignment, weakness, and gait have revealed interesting, but sometimes equivocal, findings regarding knee OA initiation. Varus alignment has been implicated in biasing dynamic loading toward the medial compartment, thereby increasing the risk for knee OA development. However, studies to date do not provide consistent evidence to support this notion. A 6.6-year follow-up on the Rotterdam cohort (n = 1501), aged 66.4 ± 6.7 years at baseline, showed that varus was associated with a twofold increased risk for knee OA development; in the presence of obesity, this risk increased to fivefold (4). On the other hand, baseline knee alignment did not distinguish incident knee OA cases (n = 110) from those who did not develop the disease (n = 356) over 9 yrs in the Framingham cohort (8). The discrepancy between these studies suggests that malalignment may indicate disease severity rather than increase risk for incident disease, but future work is necessary to clarify the role of alignment in knee OA initiation.

More evidence supports the role of weakness as a cause of knee OA. Quadriceps weakness is commonly reported in patients with knee OA and may be a risk factor for knee OA development, particularly among women. Thirteen women who developed knee OA over 31 months demonstrated lower knee muscle strength and greater obesity compared with 165 other women (25). In a rabbit model, quadriceps weakness produced by injections of botulinum Type A was a risk factor for osteoarthritic knee changes (10). The gross morphology and histology of the knee articular cartilage suggested that even 4 wk of weakness resulted in degeneration.

Although it is often taken for granted that abnormal gait dynamics incite the cascade of biochemical events that result in OA (2), evidence to support this hypothesis in humans is only recently emerging (1,11). The role of gait biomechanics in incident knee OA has been described in only nine people in two studies. Abnormally high adduction moments at baseline (range of 8%–39% higher than the mean), during a variety of lower-extremity activities, predicted incident knee pain in 7 of 80 subjects (1). More recently, a 5- to 11-year follow-up study identified the role of the adduction moment in radiographic knee OA development (11). Twenty-eight healthy asymptomatic older adults with no evidence of radiographic OA at baseline participated. Although 15 of 28 subjects developed radiographic OA, only two developed both symptomatic and radiographic OA in this period. The person with the highest baseline adduction moment developed medial OA; whereas the person with the lowest baseline adduction moment developed lateral disease (11). Although these studies support that gait dynamics have an important role in knee OA development, both are retrospective. At baseline, the cohorts, aged 75.2 ± 6.2 (1) and 64.4 ± 8.5 years (11), were older than the typical age of knee OA onset. A longer follow-up period may be necessary to accommodate the radiographic criteria for diagnosis in a greater number of study participants. Finally, both studies suffer from small samples. Despite these limitations, these investigations are critical to furthering our understanding of the pathomechanics involved in knee OA initiation and provide an impetus to support future prospective longitudinal studies.

Biomechanics and Disease Progression

The profile of factors for incident knee OA is not necessarily the same as the profile of factors for knee OA progression. Compared with disease initiation, a greater portion of biomechanics research is dedicated to progression, which is most often characterized by radiographic measures.

Radiographic progression

Radiographic knee joint degeneration has been linked to both malalignment and abnormal gait mechanics. In a longitudinal study, the hip-knee-ankle angle (mechanical axis) was a potent predictor of radiographic knee OA progression (24). Over only 18 months, varus alignment was associated with a fourfold increase in the risk of medial knee OA progression in 237 subjects. Progression was captured over this relatively short time frame because of a precise positioning of each subject, aided by fluoroscopy, for long-leg, semiflexed, weight-bearing radiographs (24). The knee adduction moment also has been implicated in radiographic knee OA progression. In 106 subjects with existing medial knee OA, with each 1% weight·height increase in the adduction moment over 6 yrs (an increase of about 25%), the risk of progression was 6.46 times greater (18). Because the adduction moment and varus alignment are strongly related to one another, it is not surprising that both independently relate to radiographic knee OA progression. However, the weak relationship between radiographic disease and disability means that the role of these biomechanical variables in mobility limitations and disability remains poorly understood.

Clinical measures of progression

Some biomechanics research also investigates pain, self-report physical ability, and performance measures. Prodromos and colleagues (20) studied pain and self-reported physical ability, along with the knee adduction moment during level walking, in 21 subjects with OA varus knees before and 1 yr after high tibial osteotomy (20). Despite realignment, subjects with high adduction moments preoperatively continued to have high adduction moments postoperatively and reported poorer scores on pain and self-reported physical ability over 3 yrs (20). The role of pain on gait mechanics has been further explored. Nonsteroidal anti-inflammatories reduced pain and concurrently increased the peak adduction moment from 4.11 ± 1.20 to 4.57 ± 1.38 percent weight·height. Thus, pain may be a mechanism to decrease medial joint load (22); but since, the relationship between

pain and gait mechanics has not been consistently reported. In addition to self-reported outcomes, some biomechanics researchers consider mobility performance. Sharma and colleagues (23) examined the risk for poor scores on a timed chair-rise task in 257 adults with radiographic knee OA over 3 yrs. Strength and proprioceptive inaccuracy related to performance of a timed repeated chair-rise task (23).

The number of studies reporting both gait mechanics and self-reported or performance-based outcomes continues to increase (9), demonstrating a growing interest in linking biomechanics to clinical outcomes. To add to this body of knowledge, substantial gains in clinical knee OA biomechanics can result from a holistic interpretation of biomechanical, self-reported, and performance-based measures of mobility and disability in people with knee OA.

EXTENDING BIOMECHANICS RESEARCH TO MOBILITY AND DISABILITY

Integrating biomechanics into clinical research shows great potential to better understand the sources of mobility limitations and disability experienced by people with knee OA. Models of disablement provide a framework for linking biomechanics and patient experience together. *Disablement* describes the process of functional consequences experienced by people with conditions such as knee OA (19). A model of disablement developed by the National Center for Medical Rehabilitation Research advocated nonlinear complex associations between domains including the person, disease, and environment to understand disability (Fig. 1) (19). Investigating all of these domains requires both quantitative and qualitative methods.

Quantitative research uses a linear deductive approach to isolating and analyzing variables and therefore is best suited to study pathology, impairment, and functional limitations. Qualitative research involves a circular, inductive, and systematic approach to explore complex combinations of variables within a natural context, to search for patterns and meaning. Thus, qualitative research can provide invaluable insight into domains pertaining to the person, disability, and societal limitation domains in knee OA. (More recently, the World Health Organization introduced the International Classification of Functioning, Disability and Health (ICF), which provides an excellent framework for research. The ICF contains two components. Part 1 deals with functioning and disability and includes the body (systems, structures), activities, and participation (capacity, performance). Part 2 of the ICF provides personal and environmental context to functioning and disability. More details about the ICF can be found at http://www.who.int/classifications/icf/en/.) Combining quantitative and qualitative methods can be used to understand the mechanisms underlying the development and progression of disability caused by knee OA. The following describes a series of qualitative and quantitative studies that provide evidence for a new construct, careful mobility, which may be useful to further understanding disability and mobility limitations that occur because of knee OA.

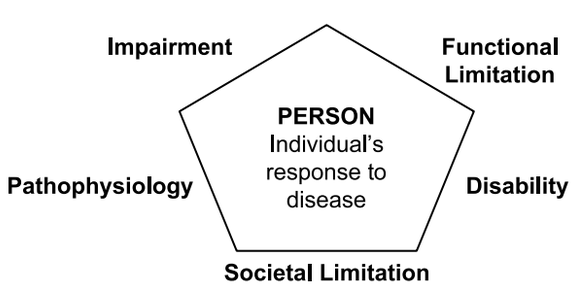

Figure 1. Schematic of the National Center for Medical Rehabilitation Research Model of Disablement as described in the *Research Plan for the National Center for Medical Rehabilitation Research* (19). *Pathophysiology* is the interruption or interference with normal physiological and developmental processes or structures. *Impairment* refers to loss or abnormality at the organ or organ system level. *Functional limitation* is a restriction or lack of ability to perform an action within the range consistent with the purpose of the organ or organ system. *Disability* is a limitation in performing tasks, activities, or roles to the levels expected within physical and social contexts. *Societal limitation* is a restriction attributable to social policy or barriers (structural, attitudinal) that limit fulfillment of roles or deny access to services and opportunities associated with full participation in society.

Patient Experience of Knee OA

A qualitative study was conducted to ensure that the fundamental experiences of disability caused by knee OA would be highlighted for clinicians and researchers (17). A phenomenological method was chosen to expose the familiar day-to-day experiences involved in living with knee OA. In a group of older adults with knee OA, serial face-to-face interviews were conducted. Participants described that 1) experiencing pain was central to daily living, 2) experiencing mobility limitations devalued self-worth, and 3) assessing their health involved comparisons to peers (17).

Pain was a central feature of the knee OA experience. Pain indicated to participants that they should not trust their knee during challenging activities: "I didn't trust myself on the little humps of grass and loose pebbles…because it wouldn't take much to throw me now, my knees the way they are. I'm sure that I would trip very easily," (participant K2). For this reason, participants selected out of sport, occupational, and social activities (17).

Experiencing mobility limitations devalued self-worth — a significant finding considering that, clinically, knee OA is thought to be mundane: "I felt like parts of me were missing when I was in so much pain and unable to do things because of the pain. I was like a partial person, I was a half of myself," (participant K1) and "I'm less valuable physically… You may feel that maybe the words 'less valuable' [are] not correct, but for me, I feel that way," (participant K3) (17).

Finally, the participants assessed the severity of their condition by comparing themselves to their peers. "I think of my sister with losing a breast and how much she must be going through, and I complain about my knees?...There are so many worse things than I have…I can put up with a bit of pain and hurt," (participant K1). Notably, participants' health perceptions were not defined by how well they were able to complete tasks (17).

Mobility and Disability in Knee OA

A quantitative study was conducted to examine the role of biomechanics on mobility performance, self-reported

mobility, and self-reported disability in people with knee OA (Table 1). Mobility performance was assessed using the Six-Minute Walk, Timed Up and Go, and a stair-climbing task. Participants self-reported mobility on the Western Ontario McMaster Universities Osteoarthritis Index — Physical Functioning Subscale. Participants self-reported disability on the Short Form-36, which includes eight domains: physical and social functioning, role limitations due to emotional or physical problems, mental health, bodily pain, vitality, and general health.

In 54 adults with radiographic knee OA, mobility performance was strongly related to self-efficacy (12). *Self-efficacy* is a person's belief in their capacity to organize and execute actions required to achieve goals (3). It likely reflects, at least in part, the diminished trust in one's knee described qualitatively. Self-efficacy was assessed with the Arthritis Self-Efficacy Scale, which includes questions such as, "How certain are you that you can walk 100 feet on flat ground in 20 seconds?" Self-efficacy scores alone explained greater than 45% of the variance in mobility performance. Knee strength and obesity together added 10% to 15% to the model, suggesting that these factors were important to mobility, although to a lesser degree than self-efficacy (12).

TABLE 1. Models of mobility performance (Six-Minute Walk test), self-reported mobility (WOMAC-PF), and self-reported disability (Short Form-36) in 54 participants with radiographically confirmed medial knee osteoarthritis

Dependent Variable	Model	Adjusted R^2	Unstandardized β Coefficient ± SE	F Statistic
Six-minute walk, m	Functional Self-Efficacy Subscale, %	0.506	4.76 ± 0.92	54.2
	Quadriceps femoris muscle torque, Nm	0.555	1.16 ± 0.40	33.5
	Body mass index, $kg \cdot m^{-2}$	0.591	−5.55 ± 2.18	26.0
	Pain Self-Efficacy Subscale, %	0.620	1.26 ± 0.58	22.2
WOMAC-PF	Pain	0.688	2.96 ± 0.26	115.8
	Quadriceps femoris muscle torque, Nm	0.731	−2.49 ± 0.82	71.7
Short Form-36	Pain	0.376	−0.69 ± 0.13	32.4
	Hamstrings muscle torque, Nm	0.554	2.01 ± 0.58	33.3
	Centre for Epidemiological Studies Depression Scale	0.629	−4.74 ± 1.41	3.4

Quadriceps femoris and hamstring muscle torque were measured on a System 3 Biodex isokinetic dynamometer to represent knee muscle strength.

WOMAC-PF, Western Ontario and McMaster Universities Osteoarthritis Index–Physical Functioning Scale.

In contrast to mobility performance measures, the factors relating to self-reported measures of mobility did not include self-efficacy (14). When using a self-reported measure of mobility (Western Ontario McMaster Universities Osteoarthritis Index–Physical Function scale), the factors explaining these scores were specific to the knee: knee pain (69%) and quadriceps strength (4%). In the model of disability (Short Form-36), the importance of pain was diminished by nearly half (38%), resulting in a greater role for muscle strength (18%) and the addition of a psychological variable, depressive symptoms measured on the Center for Epidemiological Studies–Depression scale (7.5%). Thus, the disability model was multidimensional. Because the factors relating to performance-based mobility measures were different from the factors relating to self-reported measures, it seems that, like in many other populations, health perceptions of people with knee OA do not match their mobility performance. However, strength was important to mobility from both the patient's perspective and objective performance testing, suggesting that the mechanical environment around the knee has an impact on mobility regardless of the type of measure used.

Relationships between mobility performance, self-reported disability, and gait variables including the peak knee adduction moment were also studied. Kinematics related to both mobility performance and self-reported disability. The range of knee flexion and extension explained variance in mobility performance and self-reported disability, whereas knee kinetics including the adduction moment did not appear in the models (15). Although the knee adduction moment reflects pathology, this moment did not provide insight into mobility or disability. More work is necessary to explore other biomechanical factors, such as kinematics, that can inform researchers and clinicians about the sources of disability and mobility limitations in knee OA.

The Role of Self-Efficacy in Knee OA

Self-efficacy was a potent factor in mobility performance (12), and as such, the interactions between mechanics and self-efficacy in people with knee OA were studied. Self-efficacy is at the heart of Social Cognitive Theory, which posits that self-efficacy beliefs operate in concert with cognition, goal setting, outcome expectations, and perceived environmental influences in the regulation of human action (3). In Social Cognitive Theory, Bandura (3) contends that a person's performance is better predicted by their beliefs about their capabilities than by their actual capabilities. For example, among a group of runners, one runner's performance in a marathon will be better predicted by his or her beliefs about his or her ability to complete the race, which drive effort, than measures of cardiovascular and strength capacity. From such a perspective, mobility performance in people with knee OA should not relate well to biomechanical measures of capacity but instead relate to self-efficacy. This theory is supported by studies of elite athletic performance, poststroke recovery, and mobility performance in knee OA. Several researchers have shown that self-efficacy explains most of the variance in walking, stair-climbing, transferring, balance, and exercise performance in knee OA (5,6,12,21,23); whereas biomechanical measures of capability contribute relatively little (12).

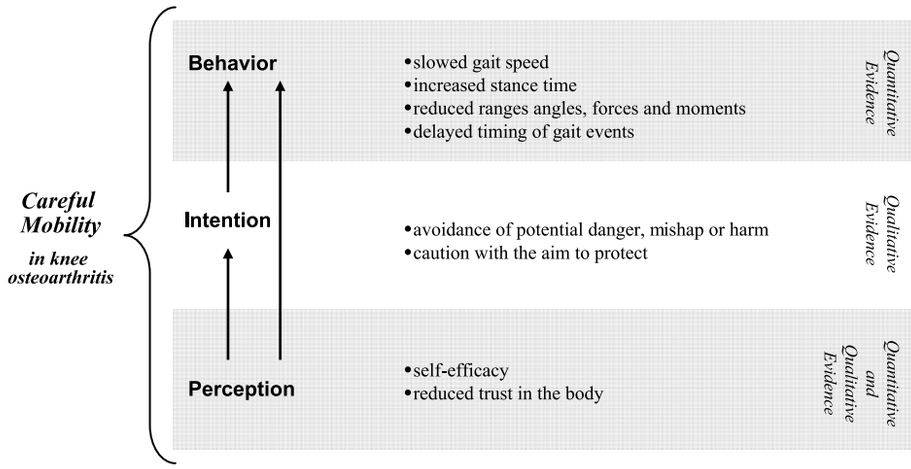

Figure 2. Mixing quantitative and qualitative methods revealed a new construct in knee osteoarthritis. *Careful mobility* refers to a person's perceptions, intentions, and behaviors that demonstrate either 1) an avoidance of potential danger, mishap, or harm; or 2) caution with the aim to protect during mobility tasks. *Quantitative and qualitative evidence* in 54 people with knee osteoarthritis (OA) demonstrates that people with knee OA demonstrate reduced self-efficacy and trust in their bodies as a result of their knee OA. *Qualitative evidence* links this reduction in trust to the intention to be careful in mobility tasks and links careful intention to mobility behavior. Finally, *quantitative evidence* demonstrates a careful gait strategy, which relates to self-efficacy.

Fundamentally, though, it is possible that mechanics interact with self-efficacy to influence mobility.

The Social Cognitive Theory proposes four sources of self-efficacy: past performance or mastery, vicarious experience, persuasion, and negative physiological feedback (3). Influential factors on self-efficacy include outcome expectations and affect (3). Notably, capacity measures such as strength are theorized not to be sources of, or influences on, self-efficacy. Analysis of correlates in a group with knee OA provided some support for this theory. Self-efficacy was related to negative physiological feedback (stiffness and pain) (13). Age and depression were related to self-efficacy, suggesting that outcome expectations and affect influence self-efficacy (13). A statistical test of mediation (where self-efficacy represents a mechanism whereby an independent factor can influence mobility) showed that self-efficacy fully mediated the effect of stiffness, pain, and age on mobility performance.

TABLE 2. Gait variables that were distinct to a group of 54 adults with radiographic knee osteoarthritis compared with a group of 55 healthy older adults separated into those that relate to knee anatomical axis in standing and those that relate to the Arthritis Self-Efficacy scores for physical functioning

Anatomical Axis of Knee Joint	Arthritis Self-Efficacy for Physical Functioning Subscale
Peak knee adduction angle	Peak knee extension angle
Peak knee abduction angle	Range knee flexion-extension angle
Average stance knee adduction-abduction angle	Average stance knee flexion-extension angle
Peak hip anterior force	Peak knee posterior force
Peak hip medial force	Peak knee distal force
Average stance hip medial-lateral force	Range knee proximal-distal force
	Range knee flexion-extension moment
	Range hip anterior-posterior force

Thus, a person likely perceives impairments and their age to determine the level of effort and resources they will invest in mobility performance (16).

The role of muscle strength, though, was more controversial. Strength was only partially mediated by self-efficacy, suggesting that strength related to self-efficacy in some manner (16). Strength may reflect past successful performance. However, strength may play a more direct role on mobility performance. Weakness may facilitate the knee degradation by failing to control loading. Indeed, aberrations in motor control of knee muscles relate to poorer walking and stair-climbing (7). Despite Social Cognitive Theory, some evidence suggests that a capacity variable has a role in mobility performance. A clearer understanding of the determinants of mobility is necessary to explain the apparent disconnection between theory and evidence.

Integrating these results regarding self-efficacy with the qualitative findings led to a new construct (or idea containing several conceptual elements) of careful mobility. Biomechanical study was then added to search for empirical evidence of careful mobility in knee OA.

CAREFUL MOBILITY: A NEW CONSTRUCT FOR KNEE OA RESEARCH

I propose that *careful mobility* refers to a person's perceptions, intentions, and behaviors that demonstrate either 1) an avoidance of potential danger, mishap, or harm; or 2) caution with the aim to protect during mobility tasks (Fig. 2). Careful behaviors include both volitional efforts and unconscious adaptations that reduce risk during mobility activities. Qualitative and quantitative evidence shows that people with knee OA demonstrate a careful gait strategy that is distinct from healthy older adults. This gait strategy occurs beyond simply reduced gait speed.

The perception of reduced capacity was captured quantitatively by self-efficacy. Qualitative evidence clarified that

the perception of reduced capacity translated into an intention to engage in mobility tasks with caution (17). Either participants avoided activities that aggravated their knees, "I don't do much. I sit down. It doesn't hurt a bit when I'm sitting or lying in bed" (participant K2); or participants engaged in physical activity with increased vigilance because of their reduced confidence in their body (self-efficacy) due to knee OA, "With the knee, the way it's been explained to me, it could come back at any time. So it's always kind of there, looming in the distance, as in, 'I can come back and hurt you…if you aren't very careful, if you don't watch what you're doing…I could just all of the sudden be hurting you again, and then you won't be able to walk again. You won't be able to do what you want to do again.' It's kind of there in the back of your mind that you have to be careful," (participant L17).

This reduced confidence, or poor self-efficacy, resulted in a careful mobility strategy. Indeed, carefulness was identified in the most fundamental aspects of mobility through gait analysis.

Careful behavior in people with knee OA was identified using kinematic and kinetic gait analysis in 54 people with medial knee OA and 55 radiographically healthy asymptomatic older adults. The peaks, timing of these peaks, ranges, and averages from gait waveforms were identified. Gait speed was used as a covariate in a multivariate analysis of covariance between the groups because, in general, angles, forces, and moments share a positive relationship with gait speed. Twenty-five variables were distinct in those with knee OA compared with the healthy older adults, over and above differences in gait speed. The knee adduction moment did not distinguish between these groups once gait speed was used as a covariate. Instead, the 25 variables that did discriminate between the groups reflected two independent constructs: 1) malalignment characteristic of medial knee OA and 2) *carefulness* as a strategy for gait (Table 2).

Varus alignment related to 6 of the 25 distinctive OA gait characteristics, suggesting that gait analysis can detect malalignment caused by knee OA. The peak and average knee abduction-adduction angles (r = 0.55–0.75) angles related to the standing anatomical axis. The peak (r = 0.58) and average stance phase (r = 0.75) force pushing the femoral head medially into the acetabulum and the peak forces pushing the femoral head anteriorly (r = 0.45) were also related to the lower extremity anatomical axis. The finding that static malalignment related strongly to "dynamic alignment" is not unique; however, it is important to note that the OA sample demonstrated minimal malalignment in standing, at -0.8 ± 4.5 degrees (slightly valgus) but much greater average malalignment during gait 6.3 ± 6.3 degrees, suggesting that a dynamic weight-bearing task might offer a more sensitive measure. Based on a resolution of the forces, it is not surprising that greater varus alignment of the lower extremity would result in greater medially directed force acting at the hip.

The second construct identified within the distinctive knee OA characteristics was *carefulness*. Slower gait speed and increased percent stance time in the OA group compared with controls provide some evidence of careful gait. Slowed timing of five major events during stride and 11 of the OA-distinctive gait variables, including reduced ranges in knee angles (about the frontal and longitudinal axes), knee and hip forces (anterior-posterior and proximal-distal directions), and knee moments (about the frontal axis) were classified as evidence of a careful gait strategy. The multivariate analysis of covariance showed that these decreases in ranges and slowed timings occurred over and above declines in gait speed within the OA group. To support this interpretation, the relationships between the gait parameters exemplifying carefulness with self-efficacy were explored. Self-efficacy related with eight of these range of motion, force, and moment variables (r = 0.35–0.58). This approach involved an interpretation of a broad range of gait parameters. Hence, in addition to studies of disease pathomechanics, researchers may want to also consider that some gait variables, such as those associated with carefulness here, will reflect a person's strategy to optimize mobility with their given resources.

The construct of careful gait is a unique and valuable contribution to the knee OA literature. It demonstrates the use of a multimethod approach: the qualitative findings led to the conceptualization of careful mobility, which was later explored using quantitative methods. The participants articulated their goal to be careful during mobility tasks, and this qualitative data provided the impetus for a detailed investigation of mobility behavior using gait analysis. Volitional attempts at careful mobility can translate into *safe* motor programs requiring no conscious effort. Identifying significant relationships between discrete gait variables, which could represent either voluntary efforts or involuntary adaptations reflecting carefulness, with perceptions such as self-efficacy, is rare. Nonetheless, future work is necessary to provide further support for careful mobility in knee OA and explore the voluntary and involuntary contributions to this approach to mobility. Investigations clarifying the relationship between intention and behavior and the role of muscle activation patterns are the next steps in examining the careful mobility strategy in people with knee OA.

CONCLUSIONS

The knee OA biomechanics literature has emphasized the pathology involved in disease initiation and progression. Studies of outcomes meaningful to people with knee OA, such as disability and mobility, have been emerging recently. Understanding mobility and disability requires a multimethod approach. Mixing methods in knee OA has revealed several novel findings. First, mobility limitations and pain have a profound effect on daily living and self-worth in people with knee OA. Second, both qualitative and quantitative methods demonstrated that self-report and performance measures reflect different aspects of mobility. Finally, a new construct emerged: careful mobility refers to a person's perceptions, intentions, and behaviors that demonstrate either 1) an avoidance of potential danger, mishap, or harm; or 2) caution with the aim to protect. Qualitative findings identified the intentions and perceptions of carefulness as a mobility strategy; whereas quantitative results related these perceptions to definitive motor output variables representing behavior. These findings demonstrate the

clinical use of gait analysis in the study of disability and mobility limitations caused by knee OA.

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