Gait Analysis and the Assessment of Total Knee Replacement

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Contents

Keywords
Dynamic EMG • Gait analysis • Kinematic assessment • Total knee replacement

Introduction

Over the last two decades the advances in biomechanical assessment of gait have been considerable. New insight into normal gait in terms of kinematics, forces around joints and muscular pattern have been widely reported, highlighting the complexity of walking. On the other hand more and more reliable instrumental devices and procedures have been available for quantitative measurements and today "gait analysis" is a well-established discipline worldwide both in clinical gait analysis services and clinical research laboratories [1]. Gait analysis is defined as the systematic study of human walking and its application can be divided into two main categories, clinical gait analysis and scientific gait analysis. While clinical gait analysis has the aim of helping individual patients directly, scientific gait analysis aims to improve our understanding of gait, either as an end in itself, or in order to improve medical diagnosis or treatment in the future [2].

It is in the latter field that gait analysis has made a large contribution to the assessment of total knee replacement (TKR) while there is still considerable controversy concerning the use of motion analysis as a tool for clinical decision-making [3, 4]. The instrumentation for three-dimensional (3D) analysis of human gait today

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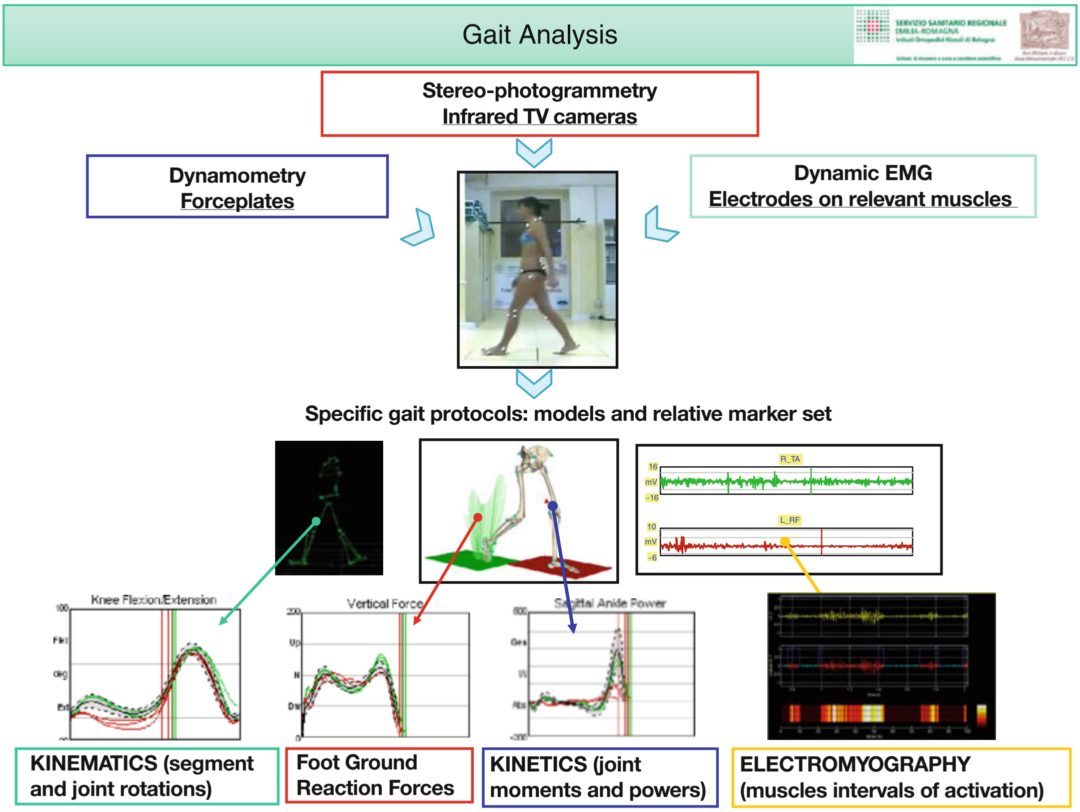

Fig. 1 Sketch of facilities of a modern gait analysis laboratory

provides much more than simple time-distance parameters, having reached a sophisticated level of complexity and accuracy useful for functional assessment in patients with TKR [5].

However, a recent review [3] on gait analysis of patients following TKR concluded that “whilst the findings of this research may have important implications for the understanding of the outcomes of TKR, the methodology of existing research appears to be diverse and many results inconsistent.”

The objective of this chapter will be to illustrate and to discuss the state of the art of gait analysis instruments and methodologies and findings in the functional assessment of TKR.

Gait Analysis

A typical modern gait analysis laboratory usually includes instruments able to measure specific variables of gait (Fig. 1). These are measures of motion (angular and segment rotation in the three planes of the space, time-distance parameters of gait), measures of forces acting at joints during walking as detected by forceplates in terms of ground reaction forces, and measures of muscular activity around joints in terms of timing of activation as detected by dynamic electromyography. Combining kinematic measures (joint position) and kinetic measures (vector representing ground reaction forces at different joints) it is possible to obtain biomechanical quantities as moments, powers about any joint.

Kinematic Assessment

Motion analysis through opto-electronic systems provides measurements of the position of various body segments as a function of time. Different emerging techniques can be used for this purpose (inertial devices), although the automatic motion measurement by using opto-electronic systems actually represents the state-of-the-art and the reference technology [6, 7].

Typically, a number of cameras, ranging from 4 to 12 are required for a three-dimensional (3D) analysis. The cameras are equipped with a light-emitting infrared crown illuminating a number of retro-reflective spherical markers placed in defined positions of the body of the subject under examination. The computer interfaces with cameras tracks the reflected position of each marker during gait, and provides motion data for various body segments by using biomechanical models according to different protocols.

Protocols of gait analysis are intended to make the kinematics and kinetics of the pelvis and lower limbs clinically interpretable [8–11]. A protocol defines a biomechanical model and the procedures for data collection, processing, analysis and reporting the results. Historically, probably because of the constraints implied in the pioneering technology, only few laboratories have developed their own protocol independently, according to specific clinical requirements [12]. In addition to the different marker-sets and collection procedures, there are many important differences between the current protocols also in the biomechanical model, which includes the measured variables, degrees of freedom assigned to the joints, anatomical and technical references, joint rotation conventions and terminology. In spite of these differences, gait analysis data are shared, exchanged and interpreted irrespectively of the protocol adopted. The original ‘Newington model’ [13, 14] is the pioneer and the most commonly used technique for gait data acquisition and reduction. It has been also the basis of many commercial software packages, the most recent being Plug-in Gait (PiG – Vicon Motion Systems, Oxford, UK). Later, a distinction between internal anatomical landmarks and external technical markers was introduced [15]. The ‘Calibration Anatomical System Technique’ (CAST) was followed by definitions of the references [16] and a standard application [17]. Following recently published recommendations, the Total 3D Gait protocol (T3Dg – Aurion s.r.l., Milan, Italy) was also proposed as a development of the Cast [18]. The precision and accuracy of gait analysis experiments are certainly influenced by the instrumentation used [19], but particularly by the interposition of soft tissues between markers and bones, which have unpredictable effects [20, 21]. The estimation of knee joint kinematics, for example during walking, using clusters made of skin markers, may be affected by inaccuracies which, for flexion-extension, adduction-abduction, and internal-external rotation, amount to roughly 10 %, 50 % and 100 % of the respective movement range angle. This calls for a special effort in improving both experimental protocols and relevant mathematical procedures [22]. In addition, there is natural intra-subject variability, particularly related to different walking speeds [23]. Furthermore, large differences have been observed among subjects, mainly concerning age, gender, body mass index, and probably ethnic characteristics. Intra- [24] and inter-examiner [25] gait data variability, resulting from inconsistent bony landmark identification and marker positioning, has also been underlined. Inter-laboratory variability has also been analysed, before and after relevant instructions provided to the examiners [12]. Marker placement among examiners was identified as the largest source of variability, although a 20 % decrease in variability was noted following implementation of the standardized protocol. All these studies were based on the ‘Newington model’ or its modifications, limiting the figures of variability to that single protocol. A quantification of inter-protocol variability is fundamental to separate the variability associated to the protocol in itself from that of all the other sources. Recently, a comparison was made of five worldwide representative protocols, i.e., T3Dg [21], PiG [13, 14], SAFLo [26], CAST [17], LAMB [27] by analysing kinematics and kinetics of the pelvis and lower limbs exactly over the same gait cycles [28]. A single comprehensive arrangement of markers was defined by merging the corresponding five marker-sets. All five protocols showed good intra-protocol repeatability. Joint flexion/extension showed good correlations and a small bias among protocols. Out-of-sagittal plane rotations revealed worse correlations, and in particular knee abduction/adduction had opposite trends. Joint moments compared well, despite the very different methods implemented. Closer correlations were observed between the protocols with similar biomechanical models, whereas little influence seems to be ascribed to the marker-set. Furthermore, an assessment study on the inter-trial, inter-session and inter-examiner variability of the T3Dgait anatomical-based protocol was also performed [29] taking into account the rotations in the three anatomical planes of the pelvis, hip, knee and ankle. For each rotation, the inter-examiner variability was larger than the inter-session, and the latter larger than the inter-trial. The ratio between inter-examiner and inter-trial variability was found to be smaller than that of the conventional protocol for each of the gait variables.

Kinetic Assessment

Forceplates are devices equipped with piezoelectric cells, able to quantify the reaction force to the force exerted on the ground and due to gravity and momentum of inertia while the subjects is walking (Ground Reaction Force – GRF) in its three components: (1) vertical force, (2) fore-aft shear and (3) medial-lateral shear.

Combining the GRF module with the position of the centre of rotation of the joints during walking it is possible to calculate the rotational potential of the forces acting on a joint that is the external joint moment in the three spatial planes, which influence the direction the joint tends to rotate in. The external joint moment is counteracted during gait by an internal joint moment that is the net result of all of the internal forces acting about the joint, and due to muscles, ligaments, joint friction and structural constraints.

The joint power is used to describe the product of a joint moment and the joint angular velocity. Joint power is generated (produced by concentric muscular contraction) when the moment and the angular velocity are in the same direction and absorbed (produced by an eccentric muscular contraction) when they are in opposite directions. The joint power is null when there is no force acting on the joint or when there is a balanced agonist–antagonist muscle isometric co-contraction around the joint, and the moment vector passes through the joint centre of rotation.

The analysis of joint moments is of particular relevance in gait analysis of TKR as it provides information about the restoration of a physiological loading pattern at knee joint, a good alignment of prosthetic component and the action produced by muscles crossing the joint.

Dynamic Electromyography

The purpose of dynamic electromyography (EMG) in clinical gait analysis is essentially to define the muscular activity that controls joint movement during gait. The characterization of muscular activity, however, is a very delicate process because there are many factors that come into play, and that make clinical interpretation difficult [30].

Commonly EMG is performed by surface electrodes (or fine wire probes for deeper muscles) and particular attention is paid to the problem of crosstalk, which is the presence of an improper signal deriving from a muscle close to the muscle where electrodes are placed for registration [31]. The study of the electromyographic signal for clinical gait analysis concerns the analysis of the envelope of the myo-electric signal historically used to estimate the intensity of activation and the measurement of muscle intervals of activation during the gait cycle [32]. The study of envelopes in a clinical context is often normalized to the maximum voluntary contraction (MVC), or scaled to the maximal walking signal [33], to have an estimate of the muscle force exerted during the dynamic contraction. However, the amplitude of the myoelectric signal recorded during dynamic contractions depends on several physiological, anatomical, and technical conditions; therefore, the correlation between the instant value of the envelope and the force exerted is rather questionable [31]. Information about the shape of the envelope, its amplitude, position and sharpness of the peaks of myoelectric activity, and its frequency content is nevertheless useful for studying muscular function under normal and pathological conditions. The study of intervals of muscular activation has been widely used for clinical purposes and has proven to be a useful tool in many Orthopaedic and neurological pathologies. Recently, sophisticated and reliable methods have been introduced in detect the duration of muscular intervals within the gait cycle. They are able to adapt to different signal-to-noise ratios and reach an adequate level of sensitivity and specificity [34, 35].

Gait Analysis in TKR

Review of the Literature

An electronic search for articles in PubMed. using a combination of terms "Total Knee replacement" and "Gait analysis", provided, at the time of writing this chapter, more than 150 papers, the oldest one published in 1980.

Based on the availability of instrumental gait analysis systems to measure functional performance of total knee replacement in vivo, an increasing interest has developed around problems related to TKR implants: comparison of different designs, functional outcome after surgery, kinematic pattern during gait, pattern of joint loading in the sagittal and coronal plane, behaviour of muscles around the knee, biomechanical performance during different motor tasks (stair/step climbing, chair rising). On the other hand walking is the best model to measure the effects of the mechanical environment of the knee joint in vivo, as it is the most common and repetitive dynamic human task [36].

Early studies showed that, even in the most clinically successful cases, many patients treated by total knee replacement could not achieve normal joint function over time. In most cases gait remained slower than normal, and the treated knee had limited flexion both during the stance and the swing phase. Different patterns of external flexion-extension joint moments have been described. The abnormal characteristics of flexion-extension moments found during gait were thought to be associated to abnormal phasing of quadriceps and hamstrings [37, 38]. Dorr et al. [38] found a continued "stiff knee" during stance associated with increased knee flexion moment, and greater request for quadriceps and biceps activity in the cruciate-sacrificed TKR with respect to the posterior cruciate-retained knee. This gait pattern was attributed to the avoidance of shear forces at the knee, or a habit developed before surgery. Wilson et al. [39] found a decreased knee range of motion in posterior-stabilized prostheses, and two groups of flexion and extension knee moment, with increased quadriceps and hamstrings muscle activity, but no isokinetic strength deficits. Nevertheless, altered muscle function was not considered responsible for decreased knee range of motion during gait, in the presence of functional passive range of motion. Andriacchi et al. [37] found a gait pattern which tended to extend the knee throughout the stance phase thus avoiding the quadriceps demand. The extension pattern at the knee, very similar to that of patients with anterior cruciate ligament injuries, was called "quadriceps avoidance gait" and attributed to proprioception impairment and the disruption of the mechanical advantage mechanism during knee flexion with consequent functional adaptation as a response to factors such as instability or weakness [40].

Recently, a systematic review on common themes in the methods of research in gait analysis of TKR patients was published [3]. Eleven studies were included, as they responded to definite selection criteria. First of all the results of the review provided information about the wide variability of studies in terms of subject characteristics, prosthetic design, and methodology of gait analysis, which undermine the relevance of research findings in the clinical field. The common results of the studies reviewed were a reduced total range of motion in the treated knee due mainly to reduced knee flexion during the swing phase of gait and reduced knee flexion during load response phase. A stiff knee attitude which may serve to protect the quadriceps as a feature of total knee replacement gait, pre- and post-surgery was also recently confirmed also by Mendeville et al. [41].

As far as joint moments are concerned, a lack of a joint moment biphasic pattern in the sagittal plane is present in 64–80 % of TKR versus 80 % of controls.

In the coronal plane adduction moment abnormalities are well documented [42], and considered a key variable in understanding the mechanical loading environment of patients with medial compartment knee OA. Only two studies comparing the adduction moment between TKR patients and controls were included in the review [3]. They reported conflicting results, whereas in Saari et al. [43] no differences were found compared with controls. In Benedetti et al. [44], the adduction moment was reduced in patients with a PCL-retaining design. Finally, only a few studies collected EMG data. Abnormal activity of muscles around the knee was described in terms of prolonged quadriceps activation and co-contraction with hamstrings [3].

Actually, the conclusion of the review by MacClelland was that the literature on gait analysis in TKR lacks consistency, as results can be biased by several variables not considered in the design of the studies. The speed of progression, selection of patients with bilateral prosthesis, severe contralateral knee arthritis, other co-morbidities, TKR design (implant geometry, LCP-retaining/sacrificing, mobile bearing, cam, curvature of radio, patellar resurfacing), different age, gender, height and weight are all features that potentially influence findings [3].

Also in the case of kinetic knee pattern in the sagittal plane, the explanation of such abnormalities, recurrent both in flexion and extension moment, can only be hypothesized. The lack of ACL, the role of residual PCL (proprioception, joint kinematics, stability for ligamentous-bone force transmission), extensor apparatus strength (lever arm-roll-back; patellar tracking), the pivoting and screw home mechanism, the roll back mechanism during flexion, reduced proprioception, pre-operative arthritic “stiff-knee pattern” due to pain or altered biomechanics (joint instability, axial deviation), abnormal muscle function (weakness of extensor apparatus), surgical skills in soft tissue balancing, and component positioning during surgery were all considered as possible causes. Besides these clinical variables, technical gait analysis issues must also be considered to explain different gait analysis findings [3, 45], particularly with respect to joint moment calculation [46].

McClelland et al. [3] concluded that the clinical relevance of this finding was obscure, as there are no studies demonstrating that the reduced swing flexion might impair function in ADL, or has a relationship with implant wear (Fig. 2). However, recently a relationship between adduction moments obtained by gait analysis was found to be determinant in the failure of total knee arthroplasty due to excessive wear and loosening because of asymmetrical loading on the tibial component [36]. These authors also showed that higher levels of prosthesis migration were associated to a gait pattern with more constant extension moment during stance. The stiff knee pattern, where the knee flexion during the loading response phase is lacking might have a detrimental effect on the mechanical stability of the implant due to repetitive greater impact loading (Fig. 3). A similar relationship was previously found by Hildings et al. [47, 48], but they found a positive correlation between aseptic loosening and higher knee flexion moment. Also in this case differences might be attributable to the analysis technique [46].

The IOR Experience

The first studies on gait analysis and TKR at the Rizzoli Institute(IOR) were aimed at developing a methodological approach to assess gait in TKR objectively to find a correlation between joint biomechanics and the action of muscles that act on the limb segment involved during movement. A review of the literature revealed in fact that muscle function during gait had not been studied sufficiently in the past directly by dynamic electromyography [38, 39, 49].

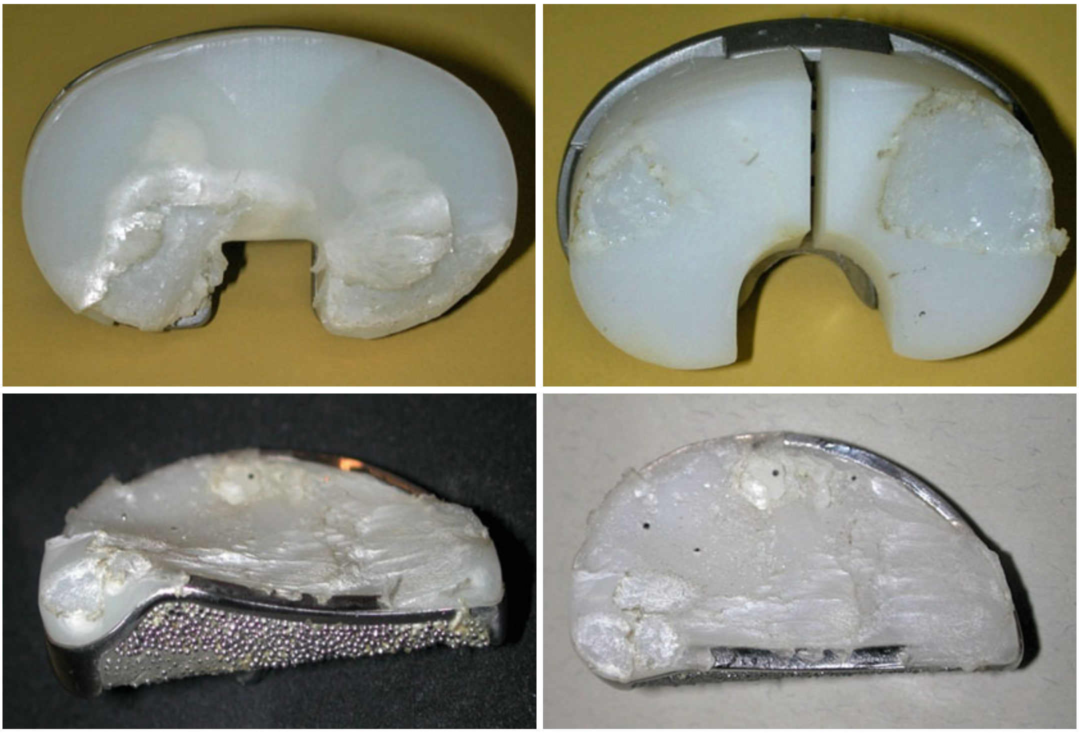

Fig. 2 Example of wear of the prosthesis insert

A reliable assessment of muscle function during gait was achieved thanks to the collaboration with bio-engineers from the Turin Polytechnic who made a statistical detection algorithm to obtain muscle on–off timing [34].

In fact, the first study on patients up to 2 years after TKR [50] showed that a stiff-legged pattern during stance was present, consistently with an extensor moment and a nearly null power at the knee and a co-contraction pattern of activation of quadriceps and hamstrings. Thus, we hypothesized that there might be a problem with quadriceps strength and an appropriate, intensive rehabilitation training after TKR might improve and resolve this pattern.

The second study [44] was hence aimed at exploring changes in gait in a group of nine patients with a posterior cruciate-sparing total knee replacement design with up to 2 years' follow-up after TKR. The patients underwent a rehabilitation program aimed at restoring the strength in knee muscles, proprioception and gait-reappraisal, for 2 weeks after surgery, at 6 months, at 12 months and at 2 years post op. Gait analysis was performed at each follow-up to highlight any residual muscular EMG function abnormalities and their relationship with knee biomechanics. Despite rehabilitation to improve the quadriceps strength, proprioception and gait performance, 6–24 months after surgery gait abnormalities continued to be present in patients with excellent clinical scores (Fig. 4). A prolonged muscular co-contraction was described, associated to "stiff knee pattern" during stance. As confirmed also by other authors at that time [51] and later [52], rehabilitation of quadriceps strength and endurance was not thought to influence the gait outcome after TKR.

Other hypotheses were based on pre-surgical gait pattern (habit and proprioceptive hypothesis) and different prosthetic designs.

Due to the large number of patients treated at the Rizzoli Institute with different implant models, a careful quantitative analysis of the functional performance of the patients with respect to different TKR designs was carried out [53].

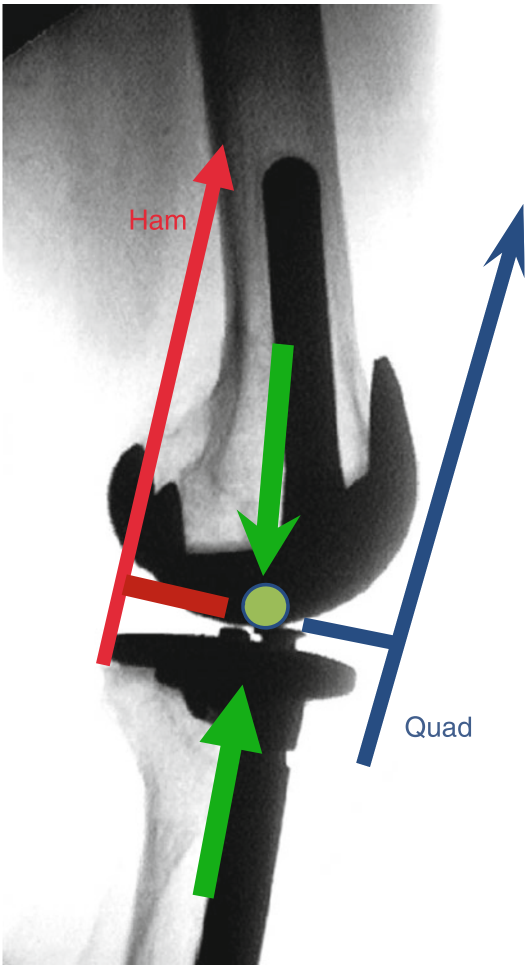

Fig. 3 The stiff knee pattern with hamstrings and quadriceps co-contraction imposes an increased longitudinal force on the joint

Six groups of patients treated by TKR were studied at a minimum follow up of 1 year. A stair-climbing task was chosen for this experimental research, as it is functionally highly demanding and therefore hopefully a more revealing task. The designs of the implants were MBK, IBII, Optetrack CR, Optetrack PS, Interax ISA and Nexgen Legacy. Several knee kinematic and kinetic abnormalities were found, despite the excellent clinical outcome of the patients. While the alterations of time-distance parameters were common to all the designs, prostheses with PCL retention and fixed bearings gave the best active range of motion during gait. Furthermore, PS designs showed the least deviation from controls in quadriceps activation timing (Fig. 5). Mobile-bearing prostheses showed the reduced external adduction moment, probably related to the external rotation pattern allowed by this design.

The advent of new TKR designs, particularly mobile- bearing designs, prompted a further study to understand possible differences between mobile (MBK) and (fixed-bearing IBII) total knee prosthesis [54]. MBK total knee arthroplasty design shows a different kinematic pattern with respect to that of IBII. Abnormal peak knee flexion moment and abnormal EMG patterns while ascending and descending stairs, when the knee is approaching full extension, and a decreased knee adduction moment during stair climbing were the main compensatory mechanisms adopted to optimise the central position of the prosthesis in MBK patients. Antero-posterior constraint structures (ligamentous or mechanical) were supposed to be important to maintain more physiological knee kinematics. This pattern was interpreted, in fact, as a consequence of a possible antero-posterior translation of the mobile bearing. In many patients with mobile-bearing design, the presence of a “paradoxical pattern” of anterior femur translation during knee flexion was revealed by fluoroscopy [55]. These findings suggest that physiological knee kinematics can rarely be obtained in vivo without the intact control mechanism of the anterior and posterior cruciate ligaments. The presence of muscle co-contraction around a “stiff knee” during stance might be the result of abnormal prosthetic biomechanics in terms of functional adaptation of the patient to a sense of instability. During stair ascending, when the knee approaches near extension, the component of the muscle forces (quadriceps and hamstrings) parallel to the tibial plateau tends to pull the tibia forwards [56]. In the intact knee the ACL resists this force. This force, pulling the tibia forwards, might cause posterior displacement of the femur. As the body moves forward, the ground reaction force moves closer to the knee joint centre and the knee starts to extend. Due to the knee laxity, which may cause the knee to buckle, as such the proprioceptive response is to activate the quadriceps muscle group for stabilisation. This pattern is supported by the EMG finding: the rectus femoris muscle has a prolonged activity toward the terminal stance phase.

In the late 1990s fluoroscopic studies gave a strong impetus to investigating implant biomechanics in vivo, demonstrating unpredictable intrinsic knee kinematics both in fixed and mobile insert implants [55, 57–62]. In a study of 213 knees in 173 patients, Banks and Hodge [70] found the same pattern of internal/external rotation: in 75 % PS TKR the presence of a medial centre of rotation, indicating posterior femoral translation with flexion; in 63 % CR Fixed bearing TKR a lateral centre of rotation; and in 86 % MB TKR a lateral centre of rotation, indicating anterior femoral translation with flexion.

Based on the new findings of fluoroscopic studies – "Unfortunately, clinical and biomechanical studies (i.e., gait analysis) to date have provided little information on detailed intra-articular motion of knee arthroplasties that might be useful in refining designs and surgical techniques to reduce wear" [63] – a study using combined three-dimensional fluoroscopic (FA) and gait analysis (GA) techniques was carried out [64] on 11 knees with PCL-retaining mobile bearing prosthesis (Interax ISA, Stryker/ Howmedica/ Ostetonics) and 10 knees with a posterior stabilised fixed bearing prosthesis (Optetrak PS, Exactech) during stair ascent. While the post/cam mechanism in the PS group

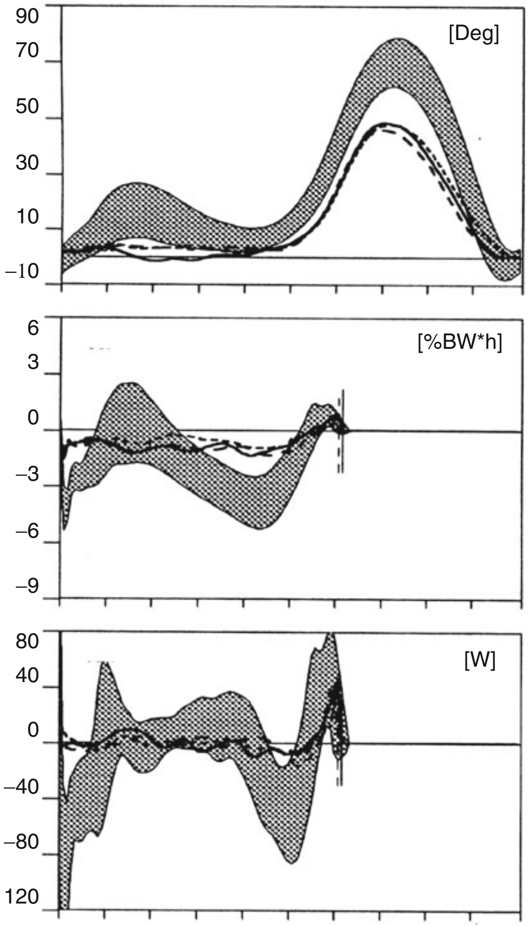

Fig. 4 (continued)

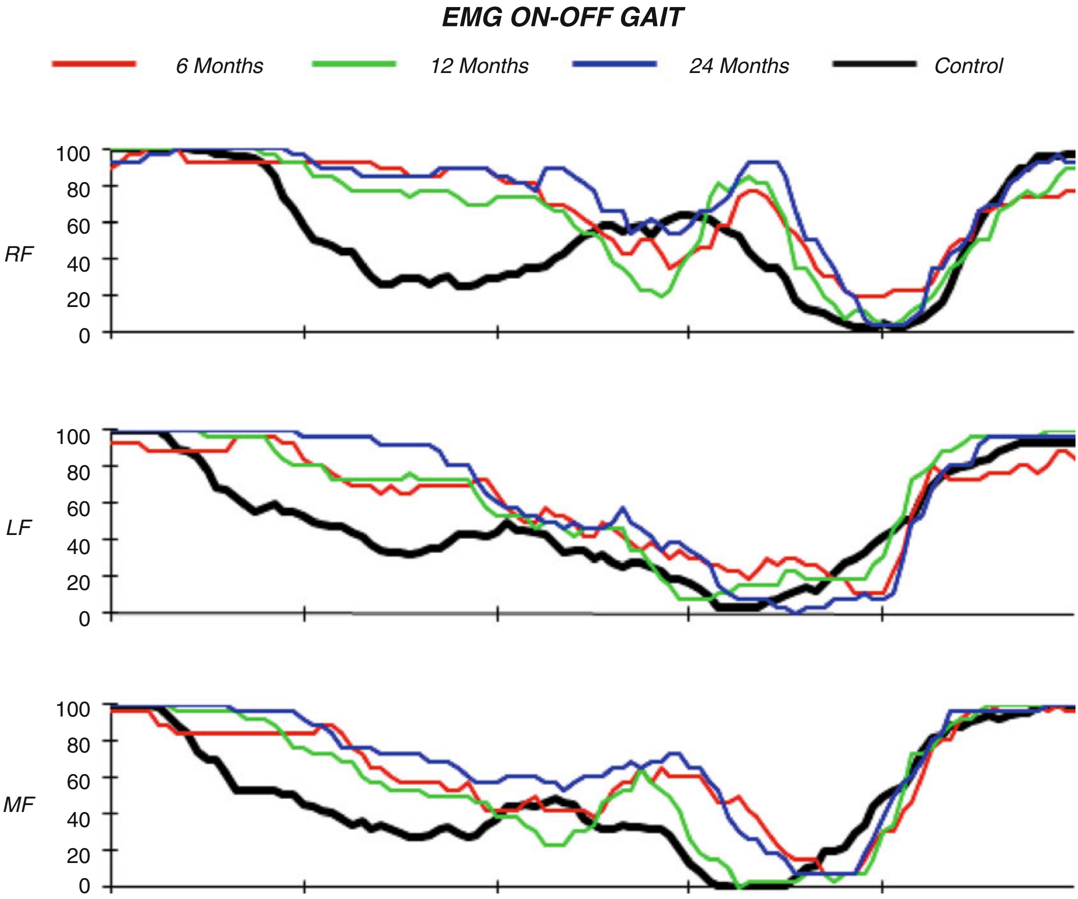

Fig. 4 Stiff knee pattern (*left*: knee sagittal kinematics, knee external flexion-extension moment, knee power sagittal plane) in a patients after 12 months from TKR implant, *right*: EMG activity of quadriceps and hamstrings at 6, 12, 24 months follow up. On–off muscle timing percentage of gait cycle. (The pattern of muscular activity is presented as percentage of number of patients for each muscle at different stages of the follow-up compared to control data)

showed a more normal femoral rollback attributable to greater conformity of the articular surfaces and control from the post/cam mechanism, the MB group had paradoxical posterior translation of the condyles during extension. The mobile bearing knees also had a non-physiological lateral-based centre of axial rotation. Significant relationships were found between FA and GA between knee flexion at foot strike from GA and mid condylar contact point position from FA and between maximum adduction moment and pivot point location only for the PS group.

Intrinsic kinematics of TKR is continuously revised to replicate normal knee motion and new conception TKR designs are being proposed. As most recent studies have highlighted that preserving both cruciate ligaments in knee arthroplasty appears to maintain some basic features of normal knee kinematics [65, 66], a study was recently performed to explore the in vivo kinematics and kinetics of a guided motion bicruciate substituting TKR [67]. Guided motion kinematics implies that a physiological kinematics pattern is reproduced. After TKA, external

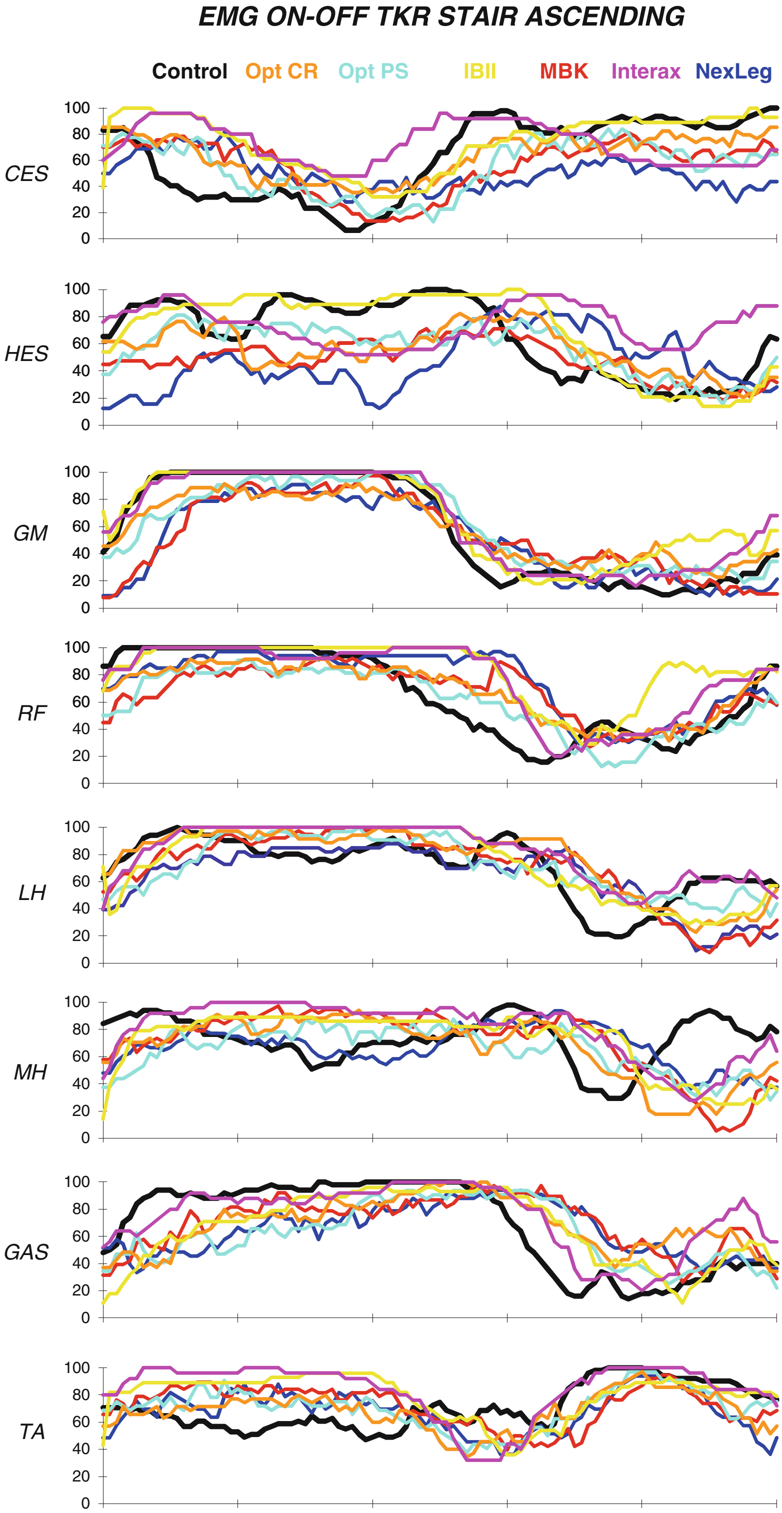

Fig. 5 EMG intervals of activation (percentage of patients) of lower limb muscles during stair ascending in patients with different TKR designs: Optetrack CR, Optetrack PS, IBII, MBK, Interax, NexLeg. *HES* ipsilateral erector spinae, *CES* contralateral erector spinae, *GM* gluteus medius, *RF* rectus femoris, *MHAM* medial hamstrings, *LHAM* lateral hamstrings, *GAS* gastrocnemius, *TA* tibialis anterior

rotation of the femur during knee flexion is related to the mechanics of the cam/post interaction and geometry of the medial and lateral tibiofemoral surfaces. Several features have been incorporated into the implant tested in this study to reproduce normal knee kinematics. An anterior cam is present to limit anterior translation of the tibia during knee flexion (up to 20° of flexion) and replicates ACL function. Results suggested that the guided motion BCS design, which features an asymmetric spine-cam mechanism and an anatomically shaped tibial insert to enhance roll-back and screw-home during flexion, restores relatively normal patterns of knee joint motion. Recovery of normal muscle activity of extensor and flexor muscle groups at the knee probably accounted for the restoration of more physiological knee mechanics even in the absence of the cruciate ligaments.

Conclusions

The main aim of TKR is relief of disabling pain although patients' expectations often depend on their age, diagnosis, and lifestyle. The true ability of a knee arthroplasty to restore normal, healthy function is however still debated. Noble et al. [68] stated that only approximately 40 % of the functional deficit present after a total knee arthroplasty seems to be attributable to the normal physiological effects of aging, other possibilities include biomechanical deficiencies of contemporary designs, alteration of the remaining soft tissues (scar, changes due to OA), absence of the native cruciate ligaments and a possible reduction in muscular tone and lower limb strength.

Studies on functional deficits following TKA measured in patients versus controls highlighted greater difficulties in running, kneeling, standing for extended periods of time, and walking long distances [68].

Basically, mechanical factors are involved in the limited functional outcome as well as in the implant failure, although biological factors such as the implant integration with capsulo-ligamentous and musculo-skeletal apparatus during activity, the age of patients and their functional status should not be underestimated [69]. As even younger and more demanding patients are undergoing TKR, good function restoration is increasingly relevant after replacement. Clinical outcome scales are commonly used for these patients, but they measure the overall function of the knee and are unable to enter in the detail of walking impairment due to knee dysfunction [7]. In particular, it has been proposed that gait analysis is valuable in TKR patients through its ability to monitor forces at the knee [5].

Future work should be devoted to modern designs such as ACL/PCL preserving TKR by studying the role of the cruciate ligaments in knee implant function. UCA can be considered also an excellent conceptual model to understand the impact of ACL removal in the abnormalities found in TKR. Knee joint biomechanics after TKR can be more fully investigated by combining motion analysis technologies with synchronized videofluoroscopy or functional MRI. From a methodological point of view, gait analysis needs improvement in protocols for knee rotation definition in vivo to measure the expected implant biomechanical performance with more precision. Finally new wearable devices are promising to assess knee joint biomechanics in the real life context, during daily living activities, and particularly the more demanding ones (kneeling, squatting). Therefore, since evidence in the literature supports the fact that gait analysis is an indispensable tool in the field of total knee replacement by providing information otherwise not detectable, further research is needed to obtain its best application in TKR patients.

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