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Review Article

Gait analysis methodology for the measurement of biomechanical parameters in total knee arthroplasties. A literature review

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ABSTRACT

Gait analysis using external skin markers provides scope for the study of kinematic and kinetic parameters shown on different total knee arthroplasties (TKA). Thus an appropriate methodology is of great importance for the collection and correlation of valid data. Calibration of equipment is of great importance before measurements, to assure accuracy. Force plates should be calibrated to 1080 Hz and optoelectronic cameras should use 120 Hz frequency, because of the nature of gait activity. Davis model which accurately defines the position of the markers is widely accepted and cited, for the gait analysis of TKA's. To ensure the reproducibility of the measurement, a static trial at the anatomical position must be captured. Following, all acquisitions of dynamic data must be checked for consistency in walking speed, and abnormal gait style because of fatigue or distraction. To establish the repeatability of the measurement, this procedure must be repeated at a pre-defined number of 3–5 gait cycles. Anthropometric measurements should be combined with three-dimensional marker data from the static trial to provide positions of the joint's center and define anatomical axes of total knee arthroplasty. Kinetic data should be normalized to bodyweight (BW) and percentage of BW and height depending on the study. External moments should also be calculated by using inverse dynamics and amplitude-normalized to body mass (Nm/kg). Gait analysis using external skin markers provides scope for the study of biomechanical parameters shown on different TKAs. Thus a standard gait analysis methodology when measuring TKA biomechanical parameters is necessary for the collection and correlation of accurate, adequate, valid and reproducible data. Further research should be done to clarify if the development of a specific kinematic model is appropriate for a more accurate definition of total knee implant joint center in measurements concerning 3D gait analysis.

1. Background

Both joint kinematics and joint kinetics are important input parameters for total knee arthroplasty wear testing according to International Organization for Standardization (ISO),(ISO 14243-3, ISO 14343-1).[1,2] Gait analysis measurements can sufficiently provide these data to scientists. Such parameters can also be correlated to in vitro data (input waveforms) in order to address wear and longevity as well as to provide an integrated aspect for the development of total knee implant designs. Especially in case of knee prosthesis, the behavior of the joint in transversal plane may represent a crucial factor, because the modern knee prosthesis are focused in stabilizing the knee and allow the most natural movements, such as rotation.[3,4] Thus the measurement of biomechanical parameters in all three planes is equally important to identify the actual behavior of the arthroplasty and contribute to a more precise design of the implant.

Knee implants development over the past decade has been greatly advanced in designs and the presence of polyethylene bearings has resulted in superior resistance to wear. The polyethylene bearing is one of the major factors involved in wear performance of the knee. More specifically the method of forming the bearing, the choice of polyethylene resin, the sterilization method of choice, any post-sterilization heat treatments and the shelf aging of the polyethylene bearing before implantation, can majorly affect wear performance. Obvious improvements have been made in the polyethylene bearings as a result of sterilization with the use of radiation in an inert environment or with non-irradiation sterilization methods. However, controversy remains over whether it is preferable to highly-crosslink polyethylene bearings

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in an effort to obtain maximum wear resistance or to use of non-crosslinked polyethylenes to maintain better mechanical properties such as tensile strength and fatigue resistance. Wear can be clinically assessed either from radiographic studies of ongoing patients or from laboratory simulations or through biomechanical assessment such as gait analysis. All of the above represent very demanding tasks and the more exacting the method the fewer number of patients or follow-up duration.

From a biomechanical point of view it would be interesting to study whether wear rate for walking combined with stair climbing would be more severe than for normal walking tests. In such a study, Cottrell et al [5] compared NexGen CR Augmentable (CR) to 5 NexGen Legacy PS (LPS: Zimmer, Warsaw). All specimens were 25 kGy gamma/N2 tibial inserts. Three wear tests were conducted: one using standard gait (ISO 14243-1) and two using a combination of gait plus stairs. The authors concluded that higher wear rates were present in standard gait compared to gait with added bouts of stair climbing. Therefore normal walking appeared to be the best estimate for a 'worst case' scenario. Thus our literature review examined studies that approached the biomechanics parameters of TKA's using gait analysis, that being the most important daily activity for humans.

Gait analysis using external skin markers provides scope for the study of kinematic and kinetic parameters shown on different total knee prostheses. Patients after TKA show altered gait mechanics that developed prior to, or soon after surgery.[6] Patients with TKA walk slower, have less knee flexion excursion during stance, demonstrate lower peak knee flexion during swing phase and altered sagittal plane knee moments compared to controls (Fig. 1).[7,8]

Previous studies examined level walking patterns in TKA patients.[9–12] Two recent reviews concluded in agreement that TKA patients walk with a characteristic pattern that differs than that of asymptomatic healthy controls.[13,14] When walking at a self-selected speed, TKA patients walk with decreased speed, have shorter stride length, and decreased single support. Kinematic abnormalities are characterized by decreased flexion in both stance and swing. A dynamic and proper knee flexion in weight acceptance (early stance) and before lift-off (late stance) is important to propel smoothly the entire body in the changes of balance between stance and swing phases.[11]

Gait analysis after total knee arthroplasty has been assessed in two systematic reviews over the past few years.[15,16] These have shown consistently reduced total range of motion in the knee, and reduced range of flexion during stance. There are also indications of knee kinetics alteration, with only one out of three TKA patients in the studies exhibiting a biphasic pattern of sagittal plane moments. More recently, similar results have been reported for reduced knee angle during stance phase, but detailed musculoskeletal modelling has shown that the forces and extension moments developed by the quadriceps are reduced in early stance in TKA.[17] All systematic reviews assessed the findings of the studies without focusing on the gait analysis methodology followed for the data capture.

When an accurate and adequate methodology is followed to minimize as much as possible all sources of errors referred in bibliography, gait analysis procedure can sufficiently calculate the kinematic and kinetic parameters of TKA's. Thus the purpose of this literature review is to provide an in depth evaluation of the gait analysis methodology followed by researchers for the study of the biomechanical behavior of TKAs.

2. Literature review-Body

In our literature review we tried to identify the basic principles of gait analysis methodology followed by researchers for the assessment of TKAs.

A literature review search database of Pubmed, Medline, EMBASE, AMED and CINAL was conducted using the following relevant keywords and phrases that describe relevant studies: Gait analysis, Total knee arthroplasty, Total knee replacement, Kinetic analysis, Kinematic analysis, Force plates, Optoelectronic cameras, Motion analysis, Gait analysis methodology, TKA biomechanics.

All research teams used clinical evaluation tools prior to data collection. Radiological examination is one of the most common methods used. Wilson and colleagues [18] used radiostereometric analysis (RSA) and double clinical examination of the subjects to ensure accuracy according to Valstar directions.[19] The importance of radiological examination [20,21,22] lies on the fact that it can accurately evaluate the alignment of the knee and the femoral and tibial component positions.

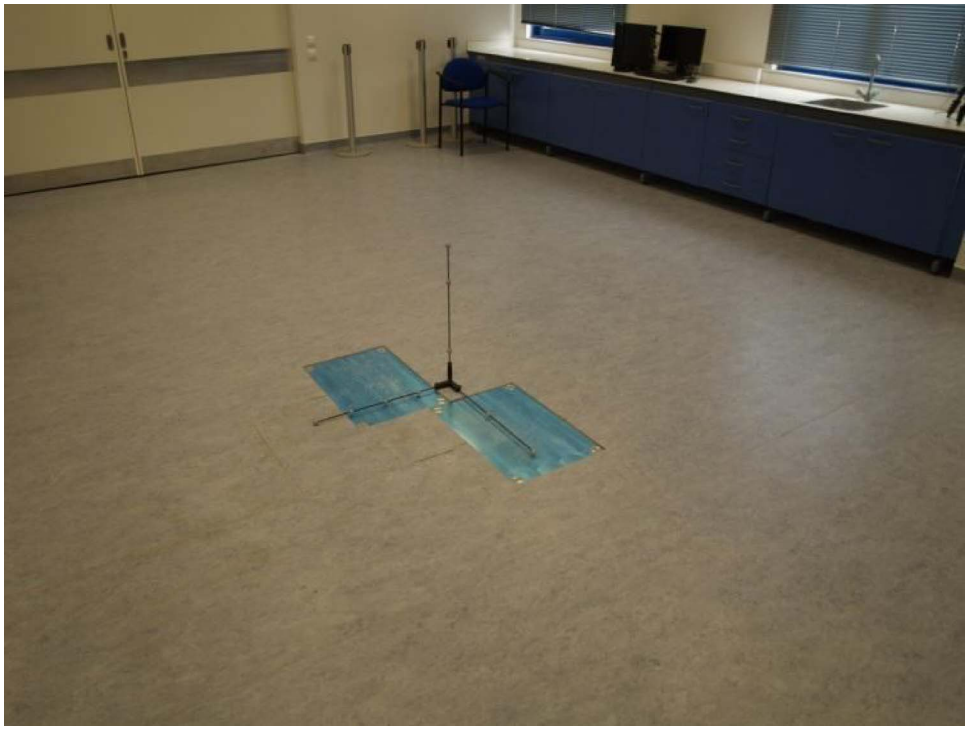

Fig. 1. Kistler force plates calibration.