The role of gait analysis in the management of the knee

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Abstract

Gait analysis has been used as an investigative tool for locomotion disorders since the early 20th century when it was done using time-lapsed photography. Since the advent of video and advances in strain gauge technology and fast data-handling devices coupled with computers, many of the movements and forces acting on and around the knee can now be measured with a high degree of accuracy. The magnitude and position of the force in 3-dimensional space can be accurately determined relative to the anatomy of the knee, consequently the clinician can assess and evaluate the forces and movements of the structures around and within the knee. This information can help the clinician predict and monitor post-surgery changes to the anatomy of the knee, and the forces and movements on these structures.

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1. Introduction

The measurement of movement and force during walking has been undertaken for many years. The defined phases of walking are split into two, the stance phase and the swing phase and since the 1950s, the events of when forces related to limb position and the associated muscle activity has been rigorously investigated in “Gait analysis” laboratories [1]. The first use of gait analysis in the direct clinical management of lower limb problems was directed at children in Los Angeles led by Dr. Jacqueline Perry at Rancho los Amigos Hospital. Using film cameras and a crude force plate embedded in the floor, the characteristics of children with orthopaedic problems of the lower limb was established and used to monitor the effects of surgery and splintage on gait [2]. Visual assessments of movement, step length and step time were found to be an unreliable clinical skill when compared with quantitative measurements using video cameras detecting light reflective markers attached to subjects limbs [3]. The development of sophisticated electronic-based force plates, which were able to isolate the values of the forces and the moments in three dimensions, enabled the generation of the resultant force vector relative to the stance phase limb. Combined with solid-state video systems and skin mounted markers detected by the video camera, the position of the force vector at any point in the gait cycle relative to the joint centre enables the bioengineer to calculate the forces and moments about any joint in all planes with a high degree of accuracy.
accuracy. The down side is that these facilities are extremely costly, need a large dedicated laboratory area for the investigation to be undertaken, and the use of scientists trained in the interpretation of the data. The current analyses that have been of value to the clinical management of knee problems have included screening of patients who would benefit from an upper tibial osteotomy for the varus deformed knee, the adjustment of orthoses for children with cerebral palsy to minimise joint loading and the monitoring of the forces on knee replacements. Force analysis combined with EMG analysis may also aid the surgeon in the transfer of tendons to restore function of the lower limb about the knee.

A description of the apparatus used and examples of gait analysis used in the management of problems of the knee is described, and the potential of developments of gait analysis in the future.

2. Spatiotemporal measurements

Many of the parameters such as cadence (steps/min), step length and walking velocity can be easily measured with simple apparatus such as a black mat with a scale and timer and foot imprint powder such as talc. Fig. 1 shows such an arrangement in which these parameters can be easily and quickly measured in a clinical environment. The restrictions of this arrangement are that if one has to allow acceleration before, and stopping at the end of the measured length of 10 m, a run up and stopping area is needed making the overall length up to 15 m which entails its use in a corridor or large laboratory. The data can be used to assess the temporal parameters before and after a surgical procedure on the knee [4,5] but lacks biomechanical data since force and movement information is not produced.

Spatial and joint information can be obtained to provide movement data of the lower limb by either attaching sensors with trailing leads to a data collection device as developed using a polarized light goniometer (Fig. 2), electro-mechanical goniometers attached to the thigh [6] and calf or more recently using reflective markers stuck to anatomical points around the ankle, knee and hip which are detected by sensitive video cameras. The advantage of the last two systems is that the movement in more than one plane can be measured. The disadvantage of the first two systems is that the signals from the angle sensors require trailing wiring, the electro-mechanical goniometers

![Fig. 1. Footprint patterns using talc on a scaled black rubber mat (top) and the plan view of the 10-m long mat with photoelectric trigger switches at both ends.](image)
are also cumbersome to wear for disabled patients and may not give representative data as a consequence. Foot-switches can accurately determine heel strike during gait and negates the use of expensive multiple force plates along a walkway to ascertain when the heel applies force to the ground at heel strike. Again, the perturbing effect of instrumented insoles and trailing wiring can have an effect on the gait patterns detected. Changes in movement patterns can reveal improvements in the range of motion of the knee after surgical procedures on the knee in the sagittal plane before and certain intervals after reconstructive knee surgery (Fig. 3).

EMG electrodes placed at strategic points over the main muscle groups involved in movement of the knee and the measurement of heart rate can add more information about the muscle work expenditure during gait in neurological disease in children[7], and in total knee replacement patients [8,9].

3. Force visualization

With improvements in strain gauge technology and force measurement methods, the introduction of force plates used in the weighing industries enabled Bioengineers to use force data in appropriate biomechanical models of the knee to estimate the forces on any structures in or around the knee [10]. By detecting the ground reaction force in the three planes and utilizing a model of the forces around the knee, the dynamic forces through or on any structure can be estimated [11]. One needs to relate the force to the knee joint centre to also
estimate the joint moment, which is the multiple of the force and the displacement of the force from the joint centre. This is achieved during gait analysis by superimposing the force vector (a representation of the direction and magnitude of the force) on the visual image of the subject in a particular plane [10,12]. The force vectors are synchronised with the visual image on the video display screen and the joint centre and its relationship to this force vector can be calculated by software in the image storage medium. The force vectors and how they are visualized in relation to the videoed image, in the sagittal and coronal planes are shown in Fig. 4, and by computing the displacements and vector values, the flexion–extension and abduction–adduction moments can be calculated (Fig. 5). The penalty is that these analyses are more complex as they require consideration of the inertial effects of many limb segments.

The adduction moments about the knee have a major influence on the distribution of the force on the tibial plateau especially the medial plateau, and has a magnitude comparable to the moment that flexes and extends

Fig. 4. The superimposed force vectors in the frontal plane (top), and a sequence of lateral views of the force vector relative to the knee joint.
the knee during gait [13]. It is thought that this may give rise to the degeneration of the medial plateau in genu varum and medial compartment osteoarthritis which appears to be much more common than lateral plateau degeneration. Patients who display a high adduction moment have a higher success rate of pain relief following upper tibial valgus osteotomy because of a decrease in the force on the medial plateau is more likely in these patients [14]. In other words patients with painful medial gonarthrosis who undergo a force vector simulation gait analysis and display a high adduction moment is a good predictor of a successful outcome following a valgus osteotomy. However, patients with a preoperative high peak adduction moment at the knee that changed after 3 years or more to a varus situation because an inadequate correction was performed was associated with a poor clinical result [15]. Certainly there is a relationship between static alignment and adduction moments determined from gait analysis [16] and may account for the failure due to excessive wear and loosening of knee arthroplasties because of asymmetrical loading on the tibial component.

4. Discussion

Clinical use of gait analysis to define pathological changes to the knee has come a long way from simple temporal measurements conducted with a stopwatch and range of motion measured statically using mechanical goniometers. The instrumentation has reached such a sophisticated level of complexity and accuracy that the pivot point on the tibial plateau can be determined for stair climbing to within 1° and 0.5 mm for movement in the sagittal plane in patients with a total knee replacement [17]. However, the equipment to achieve this degree of accuracy, which is necessary to define the loading patterns on knee prostheses precisely, are currently confined to large research laboratories. Simple spatiotemporal data do provide a reliable source of functional data in a hospital clinic setting. The force vector system can aid the management of the cerebral palsy child when designing and adjusting ankle-foot and knee orthoses, as well as provide objective information on the moments about the knee in the sagittal and coronal planes.

References


Further reading