Gait Comparison of Bicruciate Retaining and Cruciate Sacrificing Knee Arthroplasties Using Machine Learning

Introduction:

Preservation of both cruciate ligaments is believed to result in superior kinematics and function compared to cruciate sacrificing knee arthroplasty. Gait analysis has the potential to provide an objective measure of performance, without the inherent subjectivity and ceiling effect associated with patient reported outcome measures (1). But whilst abnormal gait patterns following traditional knee arthroplasty are well documented, studies of bicruciate retaining arthroplasty remain limited(2).

We hypothesised that the gait characteristics of patients with bicruciate retaining knee arthroplasties [BRA] would closer approximate healthy controls than patients with a cruciate sacrificing arthroplasty [CSA]. A machine learning approach was chosen to analyse the large volume of spatiotemporal gait variables and ground reaction force data generated over a range of walking speeds.

Method:

276 participants (132 healthy controls, 115 bicruciate retaining [BRA] and 29 cruciate sacrificing knee arthroplasties [CSA]) prospectively underwent gait analysis on a treadmill instrumented with force plates according to an established protocol(3). All arthroplasty patients were a minimum of 6 months post-op. The control group was subdivided into control group 'A' (age < 55 years) and 'B' (age ≥ 55 years) [Figure 1]. All subjects were asked to walk at a comfortable speed for 6min in order to familiarize themselves with the treadmill (4) before data was recorded. Walking speed was then increased in increments of 0.5km/h until the patient's maximum walking speed was reached (defined as the point at which the patient felt unsafe or would need to run if the speed was further increased). Subjects were similarly asked to walk at 4km/h on a 5,10,15, and 20 degree incline if able to do so. Temporal and spatial gait parameters, together with ground reaction force data from the force-plates, were captured for 10s at each speed and incline, with a sampling frequency of 100Hz. All data was adjusted for body size using the methodology described by Hof (5).

A decision tree algorithm (6) programmed in Matlab software (Mathworks, MA) was used to analyze the gait variables. Firstly, all of the CSA and BRA patient gait data was used to train a classification tree for each speed [Figure 2]. The following variables were considered: speed (km/h), incline (^{0}), maximum force time (s), maximum force (N), 1st and 2nd peak time (s), 1st and 2nd peak force (N), mid-support time (s), mid-support force (N), peak ratio, active force time (s), active force (N), impulse (N*s), weight acceptance rate (N/s), push-off rate (N/s), contact time (s), gait cycle time (s), cadence (1/s), step time (s), double-support time (s), single limb stance time (s), base of support (cm), anteroposterior center of pressure average [Ax average] (cm), mediolateral center of pressure average [Az average] (cm), step length (cm), stride length (cm) and gender. Gait data from healthy controls was then tested by the decision tree at each speed to predict whether they most represented a CSA or BSA. The results from each speed were averaged to provide an overall class prediction i.e. the algorithm classifies any gait data as representative of someone with either a CSA or BRA.

Results

Normalized speed, step length and 1st peak force were the most commonly chosen features in the decision tree model to discern between the two arthroplasty groups [Figure 3].

95% of healthy controls were classified by the decision tree as a bicruciate retaining arthroplasty; this group consisted of 108 of the group 'A' controls , and all 17 group 'B' controls. 7 group 'A' controls were classified as a cruciate sacrificing arthroplasty.

Discussion

This study supports the theory that preservation of both cruciate ligaments during knee arthroplasty results in a more normal gait pattern; 95% of healthy controls were classified into this group using a decision tree algorithm trained to discriminate between CSA and BRA. In particular, speed, step length and first peak force were the most common discriminators between the two implant designs. Indeed, higher peak force in the CSA group is unsurprising when the proprioceptive role of the anterior cruciate ligament [ACL] is considered (6). Whilst the quadriceps avoidance gait commonly observed in CSA patients, and attributed to anteroposterior instability induced by ACL sacrifice (7), might account for the smaller step length and lower speed observed in this group. The study is limited by the lack of randomization between the operative groups, and the smaller number of controls older than 55, and CSA patients.

Significance

Preservation of both cruciate ligaments during knee arthroplasty results in gait characteristics closer to those associated with healthy controls. This finding is consistent with the theory that the proprioceptive and biomechanical role of the cruciate ligaments is vital in maintaining normal walking attributes. From a purely functional point of view the use of such implants should be favored.

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