Biomechanics Instrumentation Design Laboratory II

3D gait lab analysis

Abstract

Gait analysis is very useful to understand movement of subjects to decide right treatment for patients. For biomedical engineers, gait analysis is used in broad ways to perform pathological motion surgeries to develop devices for patients. VICON, a three dimensional (3D) camera system is used to collect and observe gait patter of normal, crouched, and toe tipping walks. The crouched walk showed that the muscles are more inefficient and the toe tipping showed that muscles are firing more frequently with the highest moment and power among three cases. Hip and knee flexion/extension is very high, from the pelvis being tilted anterior to compensate for not being able to fully extend the knee. With moment and power results, toe and crouched walk spend much more power than normal walk. Because ankle power is not as good as normal walk, at second rocker, toe and crouched walk should use more leg muscles or arm muscles if supports are needed.

Introduction

In biomedical engineering field, gait analysis is very important to perform pathological motion surgeries, to develop devices for patients, to study human motions. The purpose of this lab is to understand 3D gait analysis with different situation. The objective of this lab is to be exposed to multi camera motion analysis system. Therefore, students can learn and compare to perform interpretation of normal and pathological gait data. The lab analyzed EMG data, joint rotation angles, and joint moments and powers. Surface EMG has a frequency spectrum of 10-1000 Hz with maximum amplitude of 5mV peak to peak. Indwelling electrodes have frequency of 20-2000 Hz and maximum amplitude of up to 10mV (Winters). When dealing with gait analysis an EMG is used to determine when muscles are on and off for this lab. The EMG signals are first rectified, then sent through a low pass filter, and finally integrated. The camera system that is used is VICON. There are 15 camera system positioned around the room in order to detect movement. The cameras recognize the markers on the body through infrared. There are two forms of calibration in order to make sure the cameras are detecting the right position. Static calibration used a frame calibration and dynamic calibration used a wand. The known distances are measured against what the computer is reading.

Method

The laboratory was performed at the gait lab of MCW (Medical College of Wisconsin) with VICON system which is 3D gait analysis multi camera motion analysis system and infrared markers. Before students arrived at MCW, cameras were calibrated already with bar and L shaped bar with fixed markers.

The student volunteer put shorts to put markers at calf, thigh, feet, ankles, hip, etc. The infrared markers were placed on the asis, sacrum, 2/3 up the leg center line between the greater trocanter and the knee center. These markers made the pelvic segment. The knee segment consisted of markers placed at the knee center, 2/3 up the leg center line between the knee center and lateral malleolus, and lateral malleolus. The ankle segment consisted of markers placed at the calcanus, and the base of the second metatarsal, and the lateral malleolus. All the segments are made of three markers. These markers were used in the computer program to collect data for pelvic tilt, pelvic obliquity, pelvic rotation, hip flexion.extension, hip ad/abduction, hip rotation, knee flexion/extension, knee varus/valgus, knee rotation, ankle dorsi/plantiflexion, foot progression, and ankle roation. EMG surface electrodes will be positioned over the muscles of interest (rectus femoris, hamstrings, anterior tibialis, and gastrocnemius) on both the right and left legs. Refelective markers placed on anatomical landmarks for kinematic data collection. The gait lab engineer will assist in positioning of the markers. The student volunteer did normal walk, bend knee walk, and bend knee with tip toe walk to compare the results. After collected data, data from the subject's right side will be collected for normal gait and crouched gait. The first step of processing is to identify the markers. Used the clinical gait analysis software to process the EMG, kinematic, and kinetic data. The gait lab engineer assisted in processing. Reviewed and interpreted all motion analysis data from the three different walks.

Results

Each gait has eight graphs for EMG analysis and 24 graphs for position analysis (joint rotation), power, and moments. The force plate at the gait lab also showed the resultant forces exerted as the subject walked across it.

For pelvic tilt, normal walk did not have any movement but crouched and toe walking showed very high angle movement during gait. For pelvic obliquity, normal walk showed very constant angle movement but toe and crouched walking showed high degree of changes. For pelvic rotation, normal walk showed very smooth curve, but toe and crouched walking showed very unstable curve and a lot of movement again.

For hip flexion/extension, normal walk showed u-shape curve with more extension. However, toe and crouched walk showed not clear u-shape curve and no extension movement at all. For hip ab/adduction, normal walk showed movement at second rocker but toe and crouched walk showed movement through gait. For hip rotation, normal walk mainly showed a sort of m-curve with shallow curves but toe and crouched walk show no pattern of movement. For knee flexion/extension, normal walk showed little extension at first rocker and a lot of flexion at third rocker but toe and crouched walk showed flexion of knee through gait. For knee ab/adduction, normal walk showed little movement at third rocker and very stable and smooth curve but toe and crouched walk showed unstabled movement through gait. For knee rotation, normal walk showed little m-curve again but toe and crouched walk show extremely higher rotation. For ankle dorsi/plantar, normal walk showed big movement at third rocker, but toe and crouched walk showed most of constant movement with no angle or very high angle. For foot progress angles, normal walk showed constant angle but toe walk showed constant but very high angle and crouched walk showed a lot of movement at first rocker and third rocker. For ankle rotation, normal walk shows little w-shape curve with more movement at third rocker, but toe and crouched walk showed more changed angles during gait and unbalanced movement between first and third rocker.

With moment and power results, toe and crouched walk spend much more power than normal walk. Because ankle power is not as good as normal walk, at second rocker, toe and crouched walk should use more leg muscles or arm muscles if supports are needed.

Toe walking is the most difficult to walk among three cases. For normal walk, the force in the z axis had a double bump such as a M-shaped. The resultant vector was created by summing the Fz and the shear forces seen by the force plate. However, toe walking showed almost square shaped curve with high amplitude due a lot of moment, shear force, unstable power transmitted mechanism through muscles and joints, etc. EMG signals support muscle involvement during gait with toe tipping and crouched walking. EMG signals show much higher voltage during toe and crouched walk.

****Appendix A. Joint rotation angles of normal, crouched, and toe tipping walk.**
****Appendix B. Joint rotation moments and powers of normal, crouched, and toe tipping walk.**
****Appendix C. Muscle activities by EMG of normal, crouched, and toe tipping walk.**

Discussion

1. The markers were placed on the subject based on observation and feeling for the muscles. The markers which were placed 2/3 up the leg center line between muscles have the most room for error in them. This can give errors because there was no exact muscle showing where the markers needed to be placed. In addition, it is difficult to show the ankle rotation with only 3 markers especially in transverse plane. The computer program used the data obtained from where the markers should be written down to make sure the exact calculation is performed through computer. The force plate is another potential for error. In order to make sure the forces exerted are correct, only one foot can be placed on each force plate. The subject should also make sure that the gait was not affected when tried to hit the force plate making it either a smaller or larger gait. Because the subject can control the gait due to nervousness, adjusting distance, etc. it included potential human errors.

2. There only needed two cameras placed perpendicular of each other in order to track a marker. The more cameras make the marker placement more accurate and have less likely that markers drop out from the view or calculation. Reasons of markers drop out are that obstructions in the view of the camera, rotations of the marker, and the cameras not being able to distinguish where in space the maker is.

3. The gait is detected by the force plates in the lab. However, it is possible to detect gait by video camera system and physically observing when heel strike and toe off occurs. In the lab, students could determine first, second, and third rocker with 3-D model that was constructed through computer program. Also on the path, foot switches such as force transducers can be positioned so when feet are contacted to transducer then gait can be identified with on and off of transducer.

4. The EMG data shows when the muscles used during gait are turned on and off. The EMG data is obtained through hooking up a cable-telemetry system which is placed on the subject's back. The advantages are the subject is more freely able to move throughout the room without markers drop out due to cables. Also, electrodes can collect data of individual muscles and compare left or right muscles. This gives more motion and data analysis. However, if patients are children who do not have capability to carry at their back then sometimes their parent carries EMG box along with patients. Students can alternate this method with telemetry EMG system to get rid of many wires but still it will be a big box that patients need to carry at somewhere such as back, waist, chest, etc. However, this also can increase error of data such as moment, posture of walking, etc. Therefore, the new design of EMG must be small, light, and good signal transmission capacity.

5. For hip flexion/extension, normal walk showed u-shape curve with more extension. However, toe and crouched walk showed not clear u-shape curve and no extension movement at all. For hip ab/adduction, normal walk showed movement at second rocker but toe and crouched walk showed movement through gait. For hip rotation, normal walk mainly showed a sort of m-curve with shallow curves but toe and crouched walk show no pattern of movement. For knee flexion/extension, normal walk showed little extension at first rocker and a lot of flexion at third rocker but toe and crouched walk showed flexion of knee through gait. For knee ab/adduction, normal walk showed little movement at third rocker and very stable and smooth curve but toe and crouched walk showed unstabled movement through gait. For knee rotation, normal walk showed little m-curve again but toe and crouched walk show extremely higher rotation. For ankle dorsi/plantar, normal walk showed big movement at third rocker, but toe and crouched walk showed most of constant movement with no angle or very high angle. This cause the hip and knee moments to be high. For foot progress angles, normal walk showed constant angle but toe walk showed constant but very high angle and crouched walk showed a lot of movement at first rocker and third rocker. For ankle rotation, normal walk shows little w-shape curve with more movement at third rocker, but toe and crouched walk showed more changed angles during gait and unbalanced movement between first and third rocker.
The EMG patterns follow the gait data. The normal data used less energy and therefore the muscles were not firing as much as toe and crouched walk. During crouched and toe tipping gait, the anterior tibialis and gastrocnemius were constantly firing. The rectus femoris and hamstrings are also firing a lot more than normal gait. This showed how inefficient is toe and crouched gait.
Pathological motion can be corrected by surgery at knees, ankles, and hip. Usually, surgeons extend tendons or hamstrings to reduce moment and power of joints during gait.

Conclusion

This lab was successful because students understood 3D gait analysis including the basic fundamental theories with multi camera motion analysis system. This lab is very useful to biomedical engineers to analyze gait of patients to increase muscle efficiencies and decrease power and moment of the muscles. The VICON and the system accurately show the power and moments produced in the muscles during the gait. The 15 camera system helped to decide positions are accurate and there are not many markers drop out during gait analysis. The differences between normal walk and toe or crouched walk were high moment and power at ankles and knees. There is also high rotation at hip due to high knee moment during toe or crouched walk. Definitely, crouched walk is more stable and more efficient than toe tipping walk due to less usage of leg muscles. The toe and crouched walk EMG shows that muscles are firing continuously which is different from the normal gait. There is no full swing phase during the toe and crouched walk. Limitation of lab was marker drop out. During the experiment, students had to assign markers with pointers repeatedly during analyzing with computer program because cameras lost markers due to be covered up with clothes, wires, and other obstructs. This even explains that data could have errors with patients who use canes, supports, equipments, etc. which are easy to cover up the reflective markers. To improve results for next lab, students can measure heart rate with different gait positions to compare muscle activities besides EMG.

Reference

[1] Harris, Gerald, "BIEN 192, class notes", Marquette University, Spring 2006

[2] Winters, D. A. *Biomechanics and Motor Control of Human Movement Second Edition.* New York 1990.