CLINICAL USE OF GAIT ANALYSIS

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Pain deformity, and paralysis may all create difficulties in walking sufficient for the patient to seek medical care. Traditionally the clinical characteristics of physical impairment have been the only means available to physicians and therapists for predicting the functional gains from therapeutic intervention. The wide variety in results, however, indicates there is not a direct relationship between physical impairment and functional loss. A basic reason for this discrepancy is the varying significance of different types of impairment combined with the ability of patients to substitute. Thus the therapeutic world would profit from an objective means of measuring disabled function. Predictions and confirmation of therapeutic effectiveness would be more specifically determined. Gait analysis can do this for limb impairments leading to difficulties in walking.

Rancho Los Amigos Hospital has a large county rehabilitation program. For a research program to survive in this environment, clinical effectiveness had to be demonstrated early. This led to a selection of techniques that could handle large numbers of patients in an effective manner

Four techniques have been emphasized: footswitches, dynamic electromyography, energy cost measurements, and electrogoniometry. Each offers its own type of clinically useful information.

Footswitches provide a simple and direct means of defining a person's basic stride characteristics. While applicable to all patient groups with walking disability these measurements are particularly useful in those with degenerative joint disease. Their physical deterrents are pain and lack of mobility.

METHOD

These data are obtained with contact closing insole footswitches placed in each shoe to identify the swing and stance time, rate of travel, and foot support pattern. As the patient traverses a 10 meter course, the middle 6 meter walk is defined electronically. The electronic data are stored on analog tape for subsequent computer or visual interpretation of a printed record. Video tape also documents both the patient's gross performance and the electronic data.

Location of the switches within the insoles combined with electronic coding displays the normal sequence of foot support as an easily recognized staircase. The steps serially represent heel only support, lateral foot flat (heel and fifth metatarsal), total flat foot (heel, first and fifth metatarsal) and heel off (first and fifth metatarsal). The period of toe contact is a widening of the horizontal bar. No switch activity represents swing. Deviations from this pattern readily identify the patient's variation from normal performance. In addition by relating the swing and stance pattern of the two limbs and the time taken to cover the measured walkway one can calculate seven different stride characteristics. Of these, two have been selected as being clinically the most significant; these are velocity and single limb support time.

Velocity represents the distance a patient can cover per unit of time. It is the product of stride length and cadence. In 90 percent of the patients with hip pathology all three factors tend to change in the same direction thus one can consider velocity representative of all three. Stride length is slightly more reliable as some patients hasten their cadence to accommodate a shortened stride length. Velocity, however, offers the convenience of being readily measurable in any environment where there is a long hall and a stop watch available. These data are used to make several types of clinical decisions. One example is the determination of surgical candidacy in doubtful cases. This woman complained of hip pain after walking five blocks. She had some x-ray changes but appeared to walk well. When tested in the laboratory her initial records were normal, but after walking half a mile around our outside track all three gait values dropped significantly. Her surgeons used these data to confirm her complaints of functional loss, but felt it was insufficient to justify the risk of total joint replacement at that time. One year later (when the surgical program was better established) retesting reaffirmed the patient's endurance disability and surgery was performed with good functional gain.

Single limb support is a more sensitive measure of the patient's limb disability than velocity. It also correlates well with the clinical assessment of walking impairment (by the Harris criteria r=.76, for velocity r=.66). Single limb support time is that portion of the total stance period during which the other limb is in midair (contralateral swing). During this interval the stance limb is obligated to support the entire body weight and at the same time accept the momentum of the forward traveling trunk. In contrast, the total stance time may represent a large period of double support with both feet on the ground and almost all the weight on the sound limb, hence it is not clinically significant.

The difference in information provided by the velocity and single support time measurements is readily demonstrated by a study that compared the influences of walking aids. It was found that none of the aids, canes, crutches, or walkers change the patient's velocity either pre or postoperatively. Yet these devices significantly altered single limb support duration. Preoperatively canes increased the patient's single limb support 10 percent, with crutches the gain was 30 percent, and 120 percent by walkers.

The footswitch analysis of 150 patients showed that the functional gains from total hip joint replacement varied with the balance between pathology and surgery performed. All the patients with unilateral hip disease (105) and, therefore, a single joint replacement showed improvement unless there was a medical complication. They averaged a 24 percent improvement in velocity and 23 percent in single limb support time. Twenty-five percent showed less than representative gains and these were found to have unrecognized disease in the other hip. In the patients with bilateral joint disease the gains varied both with the degree of their impairment and whether one or both hips were replaced. All the patients with bilateral joint replacement experienced good improvement, at least a 50 percent in both velocity and single support time. If, however, only one of the two painful hips was replaced with a new joint, fewer patients improved their single limb support capability though modest gains in velocity were seen. A logical explanation for this difference is that the mobilities gained with the artificial joint improved stride length but the limited capability of the other hip continued to restrict walking endurance and vigor. Consequently the muscles could not strengthen enough to give good single limb support. These data convinced the surgeon that early bilateral hip replacement was clinically important. As a result we no longer see this semi-improved patient.

Stride characteristics also have helped us evaluate some aspects of surgical techniques. For instance, the most complete exposure of the hip joint is gained by a lateral approach that includes dividing the greater trochanter. The latter technique makes it possible to lift the abductor muscles out of the way. While heavy wires are used to reattach this bony segment, healing has been difficult to obtain since patients now have gotten up and walked in the immediate postoperative period. The question has been whether or not x-ray changes of incomplete union and broken wires were significant of functional loss. The stride characteristics demonstrated that both velocity and single limb support were good if no complications arose, whereas single limb support was poor if there were non-union of the greater trochanter or pain from the wires or calcifications. This information has encouraged surgeons to be more selective as to when they use this approach, reserving it only for those situations where the potential complications would be justified.

A common means of relieving a contracted adducted posture of the hip joint is to divide the abductor tendon. This has always been considered a very innocuous procedure because in the paralytic it commonly improves their ability to walk. However, measurement of the stride characteristics in the patient with total joint replacement demonstrated that both velocity and single limb support time averaged less than was found in those who did not have this procedure. Hence it is not totally inconsequential and will be done more selectively. The reason probably is that the patient substitutes for weak hip abductors with a lateral trunk lean. This pulls on the adductor area, which following its release, is less strong than previously.

Having demonstrated that measurements of patient's velocity and single limb support time have clinical value, a second project undertaken by our staff was make them measurable in any clinical environment with a hallway at least 35 feet in length. This effort focused on developing a portable footswitch system. Basically, it consists of a memory unit and calculator. The memory packet worn at the patient's waist stores the footswitch data generated as the patient walks. These data are then translated into velocity and right and left single stance times at the end of the run by the calculator. Lights set at the end of the measured walkway triggers a switch to active the system. This equipment is now being used routinely in our total joint and amputee clinics. It is gradually being made available to other centers.

Electrogoniometry is a convenient way to measure joint motion during walking. Its clinical value is readily demonstrated by the findings in patients with total knee replacement. In our laboratory we use a parallelogram type single axis goniometer to record the relative ranges and rates of flexion/extension occurring during walking. Customarily physicians judge the joint mobility by measuring the passive range of motion. Patients with severe knee degeneration usually walk with a relatively stiff knee. Improved motion is thus a significant gain from the total joint replacement. Surgeons, however, have been disappointed by the finding that following total joint replacement the average passive range is not significantly greater than it was pre-operatively (78° vs 82°) even though the patients appeared to walk better. By measuring the knee motion during walking it became evident that the range of motion used during swing was more than doubled over that employed pre-operatively (49° vs 22°). The difference in results is one of timing. During walking the knee must be flexed rapidly whereas the passive range of motion is obtained slowly. Swollen painful tissues will not change their length with sufficient speed to meet functional demands. In normal gait the knee reaches the needed 70° by flexing 300° per second whereas in pre-operative patients this rate was only 10° per second, forcing them to walk more slowly and with a relatively stiff knee.

ENERGY COST

The amputee population probably best presents the clinical gains that can be accomplished with this technique. One limitation, however, is the fact that a person must reach a steady aerobic state in order to make the measurements valid. This requires the patient to walk approximately three minutes to reach his measurable condition and then continue another two minutes for adequate gas samples to be obtained. The patient's physiological tolerance of this effort is identified by simultaneously recording their heart rate and respiratory rate. At the same time, work is indicated by recording the patient's velocity using a heel switch. To have the patients walk in their customary manner, a sixty meter concrete track is used with all the data being telemetered into the laboratory.

Gas is collected in a light plastic bag and analyzed at the end of the test. The amount of energy consumed is indicated by the amount of oxygen extracted from the air. This extent of oxygen consumption may be related to three base lines: time, distance walked, and maximum energy production capability. Energy cost per minute expressed as milliters per kilogram body weight per minute is the most common measure. This is an index of the person's immediate physiological experience. All the amputees except the youngest and huskiest, i.e. traumatic below-knee patients have a minute oxygen consumption slightly less than normal. They averaged 12 vs 13 ml/kg/min while the traumatic BK used 15 ml/kg/min. This latter value, however, did not represent excessive use but good physical conditioning. They were able to expend this much energy (and hence walk faster) while using only the normal 35 percent of their aerobic capacity (i.e. the maximum minute oxygen exchange possible). All the other patient groups stayed within the normal limit except the diabetic above knee amputees who required 63 percent of their aerobic capacity in contrast to the normal 43 percent for their aged group.

Heart rate confirmed this indicated level of stress. It was close to the normal 104 for all the patients except the same diabetic group with the above knee amputations. Age proved to be the significant differential with the diabetic patients averaging 60 years and the traumatic amputee groups only 30 years. This difference in age was reflected in the patient's velocity. Hence both age and amputation were functional determinants.

Correlation of energy cost per minute and gait velocity gives the energy cost per meter traveled. This is a very significant functional measure because the object in limb management is to allow the person to travel the distances necessary for self-care, vocational, or advocational pursuits. Both the two traumatic groups (AK and BK) and the two elderly diabetic populations who had retained their knee joint (BK and Syme) had an average penalty of approximately 50 percent above the normal requirements. However, the diabetic above knee patient showed a much greater deficit. Theirs was more than double that of the normal requirement (220 percent). These data very clearly identify why gait training has been universally successful with most patients, yet so ineffective for the elderly (diabetic or vascular) patients with above knee amputations. Their failure to become ambulatory commonly has been blamed on lack of motivation. It is now well documented by the energy cost studies that the degree of exertion necessary for these persons to accomplish an effective gait is almost physiologically intolerable. The clinical response to these data has been a more intense drive by our surgeons to preserve the knee, even to accept slower healing rates because the social outcome is so different. A second clinical response has been more realistic planning for those elderly patients who must have an above knee amputation. Their preference to walk with crutches rather than prostheses is now accepted by the clinical staff. For comparable energy cost values both the traumatic and diabetic above knee amputees walk faster with crutches (and no prosthesis) than when wearing their prosthesis. Such is not true in those patients who have retained their knee. In addition, heart rate in all patients depending on their arms for walking was high regardless of their limb capabilities. This rate, however, did not exceed that which elderly, above-knee patients experienced in the attempt to walk with a prosthesis. Thus with no increase in energy they could experience a faster gait and therefore be more effective. The rationale of this finding is supported by other energy cost studies which show that upper limb function is 30 percent less efficient than lower limb function.

Another question investigated by energy cost measurement was the significance of carpeted surfaces in comparison to concrete. In patients minute energy cost was increased 25 percent while their velocity was decreased 30 percent by the carpet. Comparable values were obtained for normal persons using a wheelchair. As a result, the oxygen uptake per meter increased 37 percent for normals and 56 percent for patients. This indicates that in areas where disabled patients walk or push wheelchairs carpet should be avoided so that the patient can function most easily.

DYNAMIC ELECTROMYOGRAPHY

The objective definition of muscle action during walking in patients with hemiplegic, cerebral palsy, and head trauma has been a particularly rewarding clinical contribution. Muscle action with these pathologies is a mixture of voluntary control, stretch reactions, and primitive patterning. As a result, performance cannot accurately be predicted by static testing despite many years of effort to do so. For example, the "prone rectus test" was designed to differentiate excess tightness (contracture or spasticity) in the rectus from that in the hip flexors. It depends on the anatomical fact that the rectus femoris muscle crosses both the hip and knee where as the other relate to the knee. For the test the patient is prone with limb extended. If the hip flexes as the examine passively flexes the knee, it is assumed that there is tightness of the rectus muscle and this muscle should be surgically released to improve the patient's gait. Dynamic EMG has demonstrated that the major hip flexor also may equally react to this test and thus the desired differentiation will not result. Similar ambiguity has been demonstrated in the majority of the other stretch tests.

To overcome this limitation our laboratory has been using wire (50 μ) electrodes inserted in the significant muscles to identify thier activity during walking. The phases of gait are determined with the insole footswitches differentiating swing and stance. Telemetry transmits the signal to the recording equipment where permanent storage is by both video and an tape. A printed record provides the immediate source for visual qualitati analysis.

Management of the cerebral palsied child's flexible varsus (internall twisted) hindfoot demonstrates the value of EMG over customary clinical testing. When a foot twists in during walking but is manually correctable when standing, it is due to excessive or inappropriate muscle activity. Surgical correction focuses on the two primary foot inverters: the tibial anterior which is normally active during swing to pick-up the foot and the tibialis posterior which contributes to foot stability during stance. Thr variations in normal muscle function has been identified by dynamic electr myography in the cerebral palsy child. One type is the tibialis posterior changing its phase from stance to swing so that it functions at the same time as tibialis anterior. This makes available a muscle that can be move anterior to pull up the lateral side of the foot at the same time the tibialis anterior is raising the medial side. The results postoperative has been good correction with a balanced foot. Postoperative EMG studies have confirmed that the muscles continue their same pattern of action. Clinical type two consists of persistent tibialis posterior activity in all phases of gait. The surgical management of this problem has been to release the tendon so that the muscle no longer can create an adverse pull In this way the other muscles are allowed to function in an uninhibited no fashion. The third situation is to have the tibialis anterior display continuous activity throughout both phases of gait. The foot is balanced by splitting this muscle's tendon and putting half of it laterally so that the continuous activity is now balanced with equal pull on both the medial and lateral side of the foot. All three of these procedures are common throughout the country but rather than being selected on a muscle activity basis, operations have a geographical distribution depending on which one procedure has been most effective in the senior surgeon's hand. Through dynamic electromyography, we have been able to match the surgical choice to the individual patient's muscle pattern and therefore have consistently good results in all patients rather than having to accept many undesirable outcomes. The same type of analysis has been done for the reverse deformity of valgus foot or the internal rotated hip.

Thus in summary, several examples of the way gait analysis have been used to make surgical decisions have been discussed. Preliminary experience confirms that these same analytical techniques also provide objective means for determining the relative effectiveness of different orthosis or physical therapy techniques.

Both instrumentation and testing techniques still require considerable development. Reliability, patient convenience, universality of measurement, and proper results are the goals. Some functions still do not yield to ready measurement. Equipment is bulky: it has the unreliability of prototypes, and requires considerable staff involvement for operation. Data analysis remains time consuming, either because of staff involvement or the lack of routine on-line (or immediate) computer processing. The research aura must be transformed into the production demands of routine patient care if clinical staffs are to profit from the assistance objective gait analysis can provide.