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Gait Change After Local Anesthetic of Chronically Arthritic Knee

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ABSTRACT: Gait alterations of chronic knee arthritis before and after injection of local anesthesia was measured in the orthopedist's office area. A portable gait analyzer was used to evaluate gait characteristics before and after injection of local anesthesia in the chronically arthritic knee. Gait was analyzed during a 400-meter walk. Overall velocity and cadence increased 3.3% ($p = 0.016$) and 2.8% ($p = 0.005$). In-stance phase single and double support time (SLS and DLS) reduced 1.3% ($p = 0.003$) and 3.8% ($p = 0.028$). The ratio of SLS/DLS increased confirming a relatively increased duration in SLS as a percentage of the overall gait cycle. In swing phase the pulling power (initial swing), swing power (terminal swing) and ground impact increased 10.3% ($p < 0.001$), 6.8% ($p = 0.003$), and 4.2% ($p = 0.003$). Patients demonstrated fatigability at the end of walking measured as diminished velocity. Fatigability decreased after injection of the arthritic knee. The study demonstrates the specific gait phase changes afforded by injection of local anesthesia into the chronically arthritic knee. This study may serve as a benchmark for the measure of possible improvements afforded by different therapy for the patient suffering from chronic knee arthritis.

KEY WORDS: portable motion analyzer, gait lab, gait laboratory, kinesiology lab

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I. INTRODUCTION

Walking requires a complex sequence of limb motion to move the body forward while simultaneously maintaining stance stability. Gait can be viewed from three basic approaches.[1–3] One is the variation of reciprocal floor contact by the two feet. A second method uses time and distance qualities of the stride. The third approach identifies the functional significance of the events within the gait cycle and designates these intervals as functional phases of gait.

Motion is easier to observe than measure. Experts frequently disagree upon their observations. Gait analysis laboratories are used to record walking and other activity with a variety of methods. They are however expensive and frequently constrained to major health centers and not easily available to the general public. Gait recording currently requires a rather large space in an unnatural setting. Multiple observers and technicians are required to maintain the function of data collecting equipment. In spite of this costly set-up an oval track or a straight 10-meter walk is the limit of the possible walking record. Electronic devices including optical motion analysis systems, electrogoniometers, sonic digitizers, dynamic EMG, force plate vector recordings, and calorimetric measurements help elucidate factors of normal and pathological gait, but are beyond scope of longer distance measurement. They cannot be used effectively in free-living conditions. Realizing the problems, Churchill et al.[4] used a simple inexpensive video-based kinematic analysis for clinical disorders of gait and Hansen et al.[5] developed a simple method, using the relative positioning of the overall center of pressure and an ankle marker in the direction of forward progression for the determination of "heel-contact" and "toe-off" events. While these elegant methods diminished the overall expense of a formal gait lab, they could not function in a free-living setting.

Longer distance measurement of human gait in free-living conditions has been increasingly recognized. A variety of methods have been attempted to assess walking in free-living conditions, including accelerometers,[6] uni-axial gyroscopes,[7] accelerometers and rate gyroscopes,[8] rotary shaft encoders and inelastic tensioned strings,[9] microprocessor-based ambulatory activity monitoring systems,[10,11] drop foot stimulators,[12] ankle exercisers,[13] slip meters,[14] transmitters and electrical sensors,[15–17] and timer-logger-communicators.[18] These techniques, in general, are applicable in normal walking. However they can only measure a few gait parameters that may not provide enough useful information for the evaluation. In addition, because of the size of the data recorders and sensors, locations of sensors or monitoring devices, and number of motions measured, they have limitations when measuring pathological gait for longer durations because of the many problems such as detection of odd movements, difficulty of appropriate sensor positioning, connecting attachment, mechanical failure and patient compliance.[6]

The ideal device for assessment of walking in the free-living condition would be small, noninvasive, reliable, sensitive, low cost, and easy to operate and interpret. A portable motion analyzer (PMA, MiniSun LLC, Fresno, CA) was developed to evaluate human gait under free-living conditions. It measures and records angles and accelerations of feet, legs, and trunk, providing gait parameters. The patient comfortably wears the device in a free-living environment with unlimited motion. One technician was required for the performance of the recording.

We sought to examine and characterize gait changes associated with alleviation of pain in patients suffering with chronic knee arthritis. Our hypothesis was that there would be measurable improvement in gait parameters after injection of local anesthesia into the arthritic knee.

II. MATERIALS AND METHODS

II.A. Subjects

Twenty-six (11 males and 15 females) consecutive patients walking without an assistive device were evaluated for chronic knee pain and radiographic changes consistent with degenerative arthritis in a private orthopedic office and were the

subjects of this trial. Informed consent and IRB approval was attained. A modification of The Knee Society Score was used. Of a possible 100 points considering pain (45 points), function (35 points), range of motion (15 points), and stability (5 points). The mean score was 55.3 +/– 7.2 points (range, 44–69). The characteristics of the patients are shown in Table 1.

The injection consisted of 1% lidocaine, 5 mL (Astrazeneca Wilmington DE, USA), 0.25% bupivacaine, 5 mL (Abbott Laboratories, North Chicago, Il, USA), and 40 mg methylprednisolone, 1mL (Pharmacia, Kalamazoo, MI, USA). A 12-mL syringe was used with a 22-gauge needle applied through cleansed skin to deliver the injection into the suprapatellar pouch from a lateral suprapatellar approach. Lidocaine is known to have a rapid onset of action with a half-life of 2 hours. Marcaine and Depomedrol were mixed in the injection to afford the patient the possibility of longer-term benefit. All patients confirmed pain relief after the injection and before the second phase of the walk study.

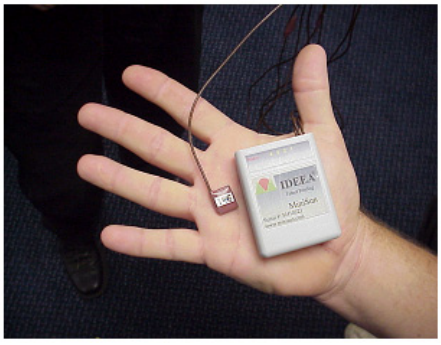
II.B. Device: Portable Motion Analyzer

The portable motion analyzer (PMA) was upgraded from the intelligent device for energy expenditure and activity (IDEEA, MiniSun, CA). The IDEEA device has been validated for the measurement of type, onset, duration, and intensity of daily physical activity with accuracy >98%.[19] In this study the 100-meter distance was measured with a metered tape device. Stopwatches were used to determine the exact time elapsed at 25 m, 50 m, 75 m, and 100 m of the 100-meter walk. The PMA consists of one recorder (58 g) and five 2-cm sensors each weighing 2 g. Figure 1A shows the recorder with one sensor held by one hand. A single AA battery powers the device. The sensors are placed on the chest at the manubrium, the frontal part of each mid-thigh, and under each foot at the interspace and 1 cm proximal to the forth and fifth metatarsal heads (see Fig. 1B, foot sensors not visible). The sensors are connected to the recorder by thin and flexible wires (1.8 mm outer diameter) worn at the waist belt of the patient. The sensors are fixed to body locations by hypoallergenic tape, and the PMA recorder connected to a personal computer by a communication cable. Figure 1B shows the position of the sensors on a subject. A Windows-based interface program controls the communication between PMA data collection device and a laptop or desktop computer (PC) processes the data for clinical evaluation. After entering the filename, weight, height, age, gender, an optional study ID, and short memo from the keyboard of the PC, the cable can be detached from the PMA, and the person can start data collection with minimal inhibition of normal activity in an outside environment. Parameters measured include single limb support time, double support time, pulling power, swing power, ground impact, velocity, cadence, step length, stride length, and fatigability.

Software is used to download, measure, and display the data from the unit and automatically interpreted on a personal computer. The raw data is displayed for the interested observer in Figures 2 and 3.

TABLE 1. Subject Characteristics

Number of Subjects	**26 (11 males, 15 females)**
Age (years)	63.8 ± 10.8 (Mean ± SD, 43.0 – 84.0)
Body weight (kg)	85.5 ± 15.9 (Mean ± SD, 65.3 – 130.5)
Height (cm)	167.4 ± 10.7 (Mean ± SD, 149.0 – 185.0)
BMI (kg/m^2)	30.8 ± 4.8 (Mean ± SD, 23.3 – 42.1)
Modified Knee Society Score (max. possible 100 pts.)	55.3 ± 7.2 (Mean ± SD, 44.0 – 69.0)



A B

FIGURE 1. (**A**) The photo of PMA recording device with one senor held by one hand. (**B**) Positions of sensors: a subject wearing the PMA recorder.

II.C. Study Protocol

After informed consent and device application patients walked 50 meters outside to our straight level 100-meter outdoor track and were asked to walk 100 meters twice (going forward and coming back) at self-selected speeds. A 10-s break was taken between each 100-meter walk. The first 100-meters allowed the patient to become familiar with the terrain, road conditions, and environment.[20–22] The second 100-meters was used for gait analysis. The patients then returned to the office for injection, a 10-min rest, confirmation of pain relief, and a second phase of the walk started, with the same protocol as the first. The total walk distance studied was 400 meters for each patient.

II.D. Statistical Analysis

Basic descriptive statistics by gender, age, weight, height and body mass index (BMI) and knee scores are presented in Table 1. Only the second

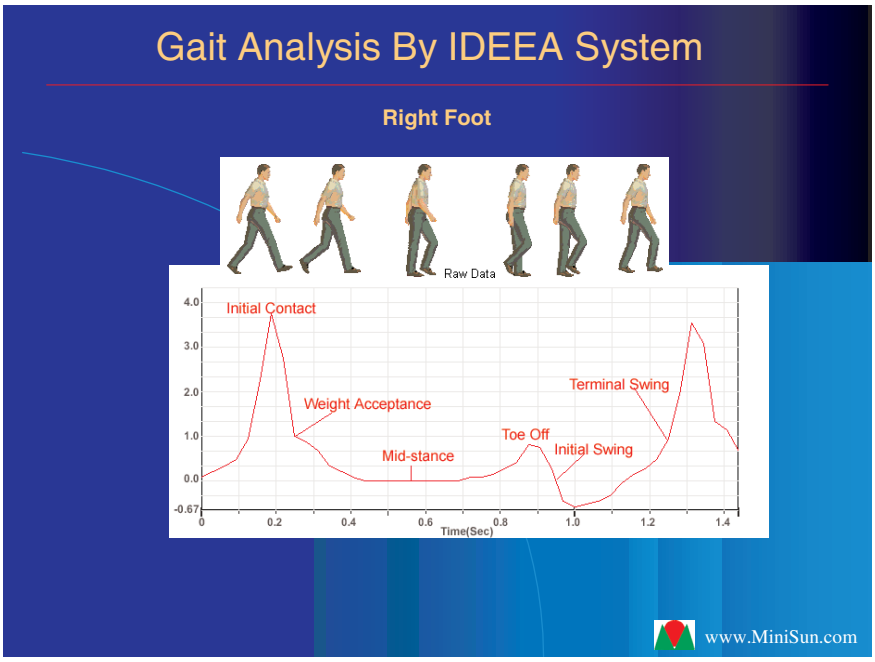


FIGURE 2. Gait cycle measured by the sensors from right foot.

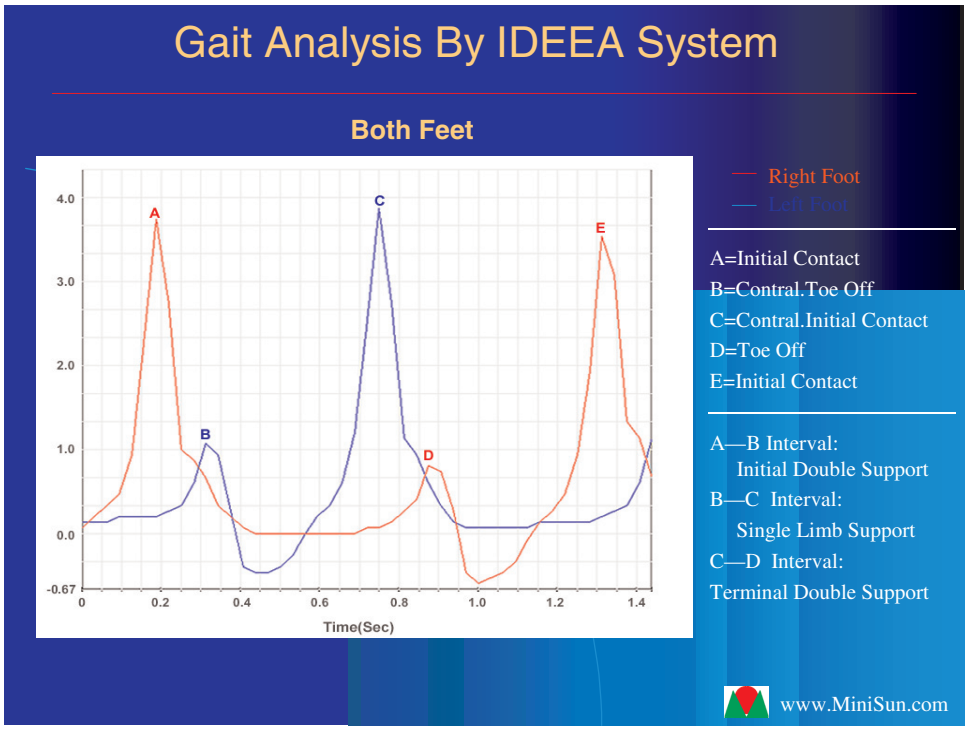


FIGURE 3. Gait cycle measured by the sensors from both feet.

100-meter walk before and after injection was used for gait analysis to allow the patients an opportunity to familiarize themselves with the walking surface. Before the calculation of gait variables, the first three steps and last three steps were discarded. In analysis, an average of 240 steps was used for each patient. Gait parameters included single support time, double support time, pulling power, swing power, ground impact, velocity, cadence, step length, stride length, and fatigability. The pulling power was defined as the maximum forward acceleration of the foot during the initial swing phase, the swing power is defined as the maximum deceleration during the mid and terminal swing phases, and the ground impact is defined as the maximum deceleration in the vertical direction during the weight acceptance. Fatigability was defined as the (mean velocity of gait for last 20 steps per mean of overall gait velocity)*100%. Paired *t* test was performed to determine if there is improvement of these variables after the injection significantly different from zero. Significant level was defined as the values of $p < 0.05$ with one tail.

III. RESULTS

The results (mean values, standard deviations and the differences of pre and post injection) are illustrated in Tables 2 and 3. Note the parameters such as velocity, pulling power, and swing power are measured for the leg during swing phase.

Overall step length and stride length did not change significantly after the injection. However average velocity and cadence increased 3.3% ($p = 0.016$) and 2.8% ($p = 0.005$). During stance phase the average single support and double support time decreased 1.3% ($p = 0.003$) and 3.8% ($p = 0.028$). The ratio of average single support time over average double support time increased 2.5% ($p = 0.038$). During swing phase, after the injection into the pathological knee, the average pulling power, swing power, and ground impact increased 10.3% ($p < 0.001$), 6.8% ($p = 0.006$) and 4.2% ($p = 0.006$) (Figs. 4, 5, and 6).

Fatigability testing revealed that the terminal velocity diminution was 2.7% preinjection ($p = 0.002$) and 1.3% postinjection ($p = 0.042$) respectively. The average terminal cadence diminished 3.3% preinjection ($p < 0.001$) and 1.8% postinjection ($p = 0.089$, not significant); the average pulling power diminished 6.3% preinjection ($p < 0.001$) and 4.5% postinjection ($p = 0.010$).

IV. DISCUSSION

Microelectronics and accelerometers have been used here to describe in statistically significant terms the manner in which arthritic knee pain may affect various phases of gait and have clinical significance. Many systems provide classic gait analysis in terms of velocity, cadence, step length, stride length, single and double limb support time. The PMA provided this data as well as swing characteristics. Variables such as pulling power, swing power, and ground impact are expressed in terms of acceleration and deceleration. The swing characteristics are isolated and identified as specific changes associated with musculoskeletal functions and their relations with functional capacity such as velocity, cadence, and endurance. The PMA device measures instantaneous power of motion. Pulling power documents the rate of initiating swing. Knee flexion for toe clearance is the primary determinant of this event. Swing power reflects ease of limb advancement and terminal knee extension. Deceleration caused by ground impact identifies the vigor of the event. Evaluation of the effects of intra-articular anesthesia on gait and walking performance in patients suffering from chronic arthritic knees may seem clinically unrecognizable or trivial. However, as microelectronics, computers, and intelligent sensors increasingly affect our everyday lives, new terms of measurements such as gigabytes, nanometers, milliseconds, and accelerations will inevitably become part of our lexicon and affect how we diagnose and treat our patients.

Validation of this technique has been demonstrated in other fields of medical research, particularly, for physical activity and energy expenditure studies.[19] In this particular study, measurements of the PMA such as the distance and velocity were validated against the traditional distance and velo-

TABLE 2. Overall Average of Gait Variables (Mean ± SD)

	Before injection			After injection		
Gait variables	**Pathological leg**	**Healthy leg**	**Both legs average**	**Pathological leg**	**Healthy leg**	**Both legs average**
Single support time (SST) (ms)	424.1 ± 31.8	430.4 ± 37.0	427.3 ± 32.1	419.8 ± 30.9	423.7 ± 34.0	421.8 ± 30.5
Double support time (DST) (ms)	145.6 ± 34.19	152.5 ± 32.6	149.0 ± 32.2	140.4 ± 27.8	147.9 ± 32.0	143.3 ± 28.17
SST/DST (100%)	298.6 ± 56.7	314.4 ± 71.2	307.5 ± 59.1	308.0 ± 53.0	323.2 ± 61.3	315.3 ± 54.9
Step length (m)	0.64 ± 0.12	0.62 ± 0.93	0.63 ± 0.10	0.65 ± 0.10	0.62 ± 0.09	0.63 ± 0.09
Stride length (m)	1.26 ± 0.21	1.26 ± 0.22	1.26 ± 0.20	1.27 ± 0.18	1.26 ± 0.19	1.27 ± 0.18
Cadence (steps/min)	102.6 ± 10.8	107.1 ± 10.85	104.9 ± 10.3	105.5 ± 10.61	109.7 ± 9.8	107.6 ± 9.6
Velocity (m/min)	65.65 ± 14.29	65.53 ± 14.57	65.60 ± 14.39	67.79 ± 12.71	67.45 ± 13.82	67.84 ± 12.94
Pulling power (G)	0.697 ± 0.295	0.657 ± 0.252	0.676 ± 0.257	0.769 ± 0.342	0.726 ± 0.386	0.747 ± 0.328
Swing power (G)	0.908 ± 0.389	0.933 ± 0.325	0.922 ± 0.324	0.970 ± 0.378	0.985 ± 0.312	0.975 ± 0.314
Ground impact (G)	1.276 ± 0.387	1.332 ± 0.409	1.305 ± 0.383	1.329 ± 0.369	1.369 ± 0.386	1.349 ± 0.355

Note: The parameters such as velocity and pulling power are measured for the swing leg. Unit of G: 9.8 m/s^2.

TABLE 3. Change in Gait Parameters After Injection. A Small But Persistent Improvement Is Seen for Most Patients

	Pulling power			Swing power			Ground impact		
Patient no.	Pathological leg	Healthy leg	Both legs	Pathological leg	Healthy leg	Both legs	Pathological leg	Healthy leg	Both legs
1	0.02	0.04	0.03	–0.012	0.003	–0.004	0.065	–0.03	0.02
2	0.13	0.01	0.07	0.26	0.369	0.254	0.164	0.226	0.196
3	0.34	0.25	0.29	0.22	0.26	0.24	0	0.17	0.09
4	0.06	0.13	0.09	–0.038	0.007	–0.016	–0.004	–0.016	–0.01
5	0	–0.01	–0.01	–0.13	–0.06	–0.09	–0.25	–0.16	–0.2
6	0.04	–0.05	–0.01	0.17	0.106	0.138	0.1	0.036	0.06
7	0.06	0.04	0.05	0.19	0.06	0.12	0.09	0.08	0.08
8	0.12	0.02	0.07	–0.01	–0.1	–0.06	0.12	0.03	0.08
9	0.06	0.02	0.04	0.016	0.077	0.047	0.06	0.09	0.07
10	0.06	0.09	0.08	0.038	0.011	0.024	–0.023	–0.03	–0.02
11	0	–0.06	–0.03	0.002	–0.055	–0.024	–0.06	–0.143	–0.098
12	0.01	0.09	0.05	0.242	0.176	0.207	0.12	–0.03	0.05
13	0.09	0	0.04	0.156	0.114	0.124	0.151	0.22	0.18
14	–0.04	–0.04	–0.04	–0.084	–0.027	–0.056	0.01	0.03	0.02
15	0.29	0.09	0.17	0.11	0.19	0.15	0.04	0.12	0.07
16	0.16	0.03	0.1	0.02	–0.003	0	0.03	0.03	0.03
17	–0.03	–0.06	–0.04	–0.04	–0.14	–0.09	0.03	–0.2	–0.09
18	0.05	0.07	0.06	0.102	0.202	0.152	0.19	0.33	0.26
19	0.09	0.04	0.07	–0.05	–0.05	–0.05	0.03	0.01	0.02
20	0.1	0.09	0.09	0.16	0.138	0.149	0.18	0.194	0.19
21	0.03	–0.05	–0.01	0.12	–0.01	0.05	0.07	–0.09	–0.01
22	0	0.02	0.01	0.004	–0.04	–0.019	0.03	–0.01	0
23	0.02	1.09	0.56	0.057	0.016	0.037	–0.01	0	–0.01
24	0.06	0.02	0.04	0.069	0.086	0.078	0.08	0.05	0.06
25	0.06	0.06	0.06	0.09	0.08	0.08	0.13	0.15	0.15
26	0.13	–0.11	0.02	–0.06	–0.07	–0.06	0.02	–0.1	–0.04

city measures using tape measure and stopwatch. Results indicated the discrepancy of 3% or less between the two methods. Validation with force plate measurements is to be carried out in the future.

Our results show that the percentages of improvements following pain relief were small yet consistent (Table 3). Results obtained per subject were highly significant statistically. The standard deviation of variables for the group as a whole was fairly large and overlapping due to the heterogeneity of the patients (Tables 1 and 2). This seeming insignificance is also due to the high precision and reproducibility of the PMA, as well as analysis of multiple gait cycles over the 100-meter distance.

After injection, the cadence and velocity increased because of improved knee tolerance for more rapid motion and greater loading impact. Stride length and step length did not change because the ankle and hip, not the knee, are the major determinants of these variables. Total stance time was reduced; that is, both the single and double limb support time decreased following injection. However, the ratio of single limb support time

divided by the double limb support time increased, reflecting that single leg support time actually increased as a percentage of the gait cycle, as would be expected by eliminating the nocuous stimulus of an arthritic joint. This is consistent with the traditional understanding that patients with a painful lower limb will decrease their overall velocity and affected single limb support time. Before injection, subjects' whole gait cycles were inhibited by the pathology of one knee because the normal contralateral swing leg stressed the painful knee by its imposed moments.

With the benefit of the PMA accelerometers the swing phase of gait and ground impact deceleration were also measured. After injection, the power of swing was significantly increased. Indeed, there was increase in average pulling power and swing power for both legs. This increase in swing power was notable in both legs despite the injection being applied to only the painful knee. As the pathological limb gains functional improvement in various phases of gait, the sound limb concurrently must change to meet the demands imposed by increased velocity, momentum, and muscle action. This change could also be caused by a reduction in substitution. Ground impact, which indicates rate of weight acceptance of the arthritic knee, was more rapid after injection. This confirms the expectations that the painful knee accepts weight in a slower fashion than a pain-free knee. How-

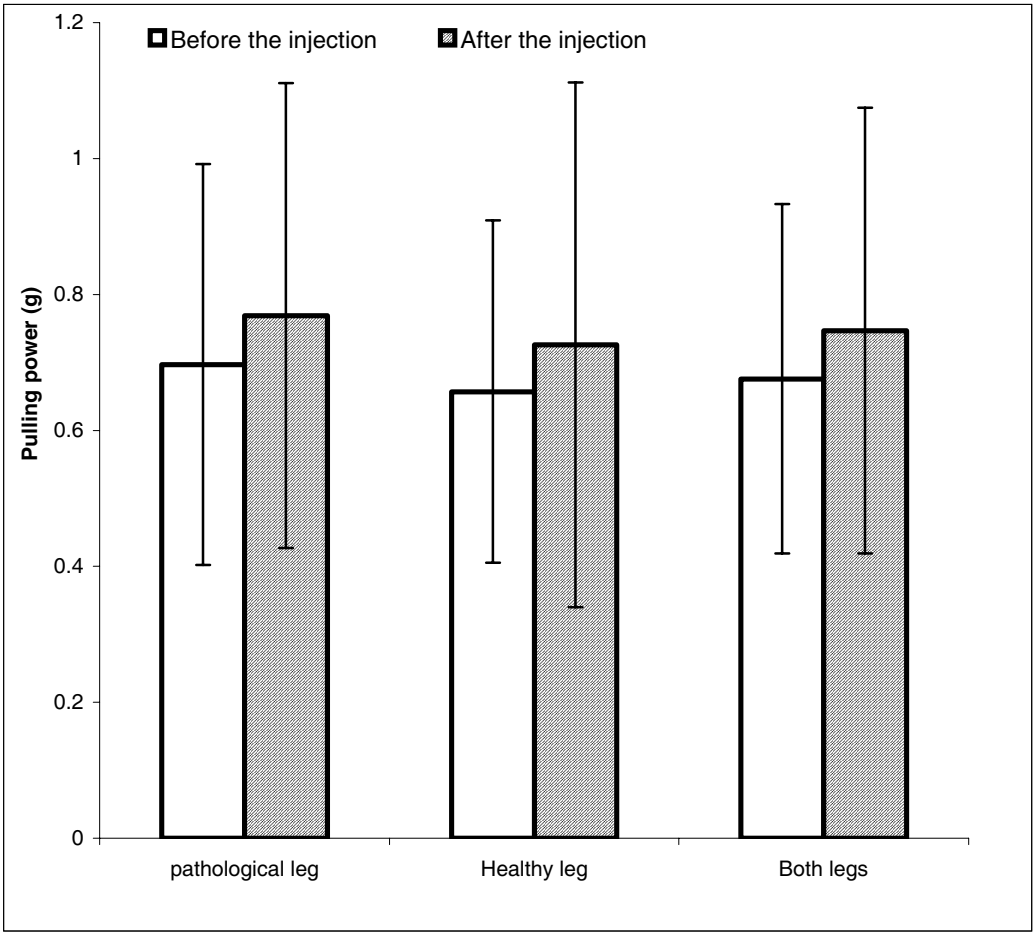


FIGURE 4. Comparison of pulling power before and after the injection.

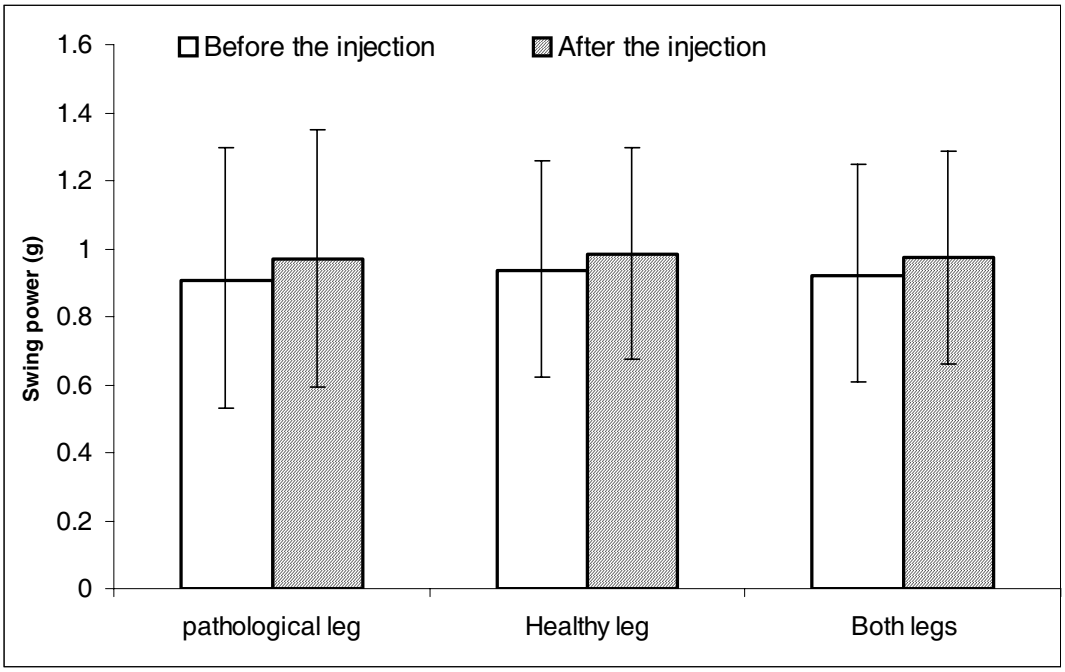


FIGURE 5. Comparison of swing power before and after the injection.

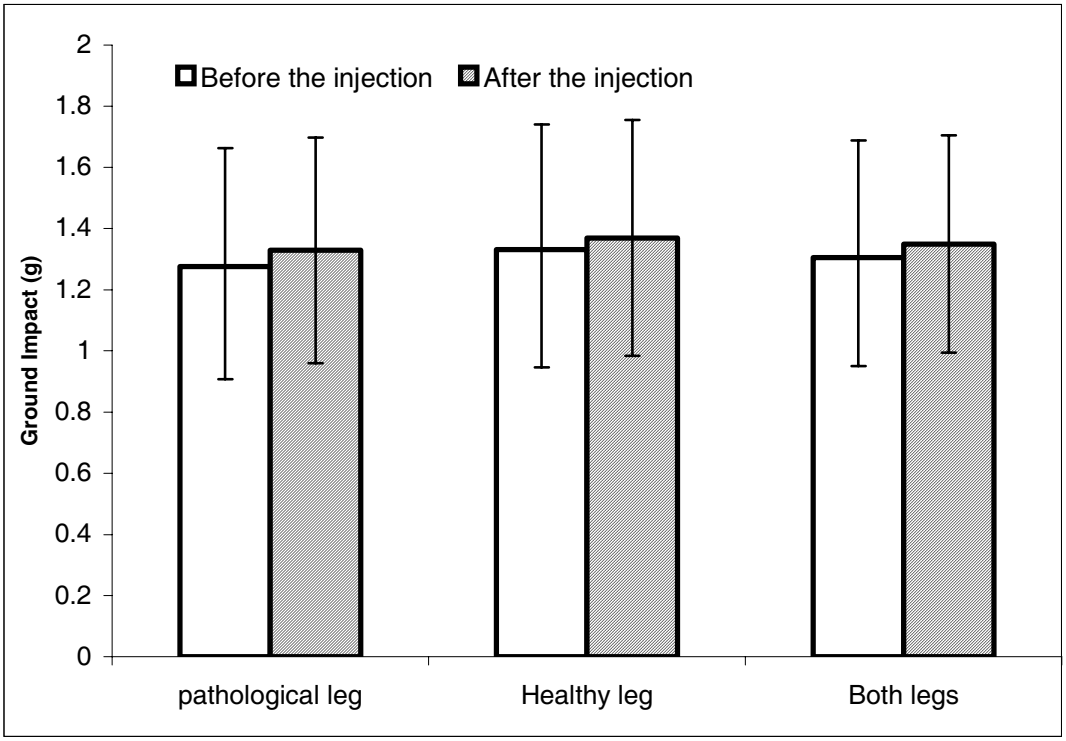


FIGURE 6. Comparison of ground impact before and after the injection.

ever, here it has been described in terms of accelerations rather than actual ground reaction force, which would require a laboratory setting and a force plate that is less convenient, unnatural, expensive, and time-consuming.

It is possible that the injected mixture of lidocaine 1%, bupivacaine 0.25%, and methylprednisolone 40 mg affected the knee joint in ways other than anesthesia. We could have used a smaller volume of injected fluid than 12 mL. Barrack et al.[23] found no change in gait pattern or proprioception after injection of lidocaine 2%, 10 mL injected into the normal knee. However, the added benefit of the bupivacaine and methylprednisolone was intended to provide longer pain relief. Knee joint effusion and/or loss of proprioception may have affected gait changes in ways that we had not anticipated. We currently had no way to measure the manifold other manners in which the medications may have affected the joint. A larger number of subjects with a more homogeneous level of arthritis may improve the value of future studies. We accept these as limitations of our study.

The more commonly measured single limb support time, double limb support time, step length, stride length, cadence, ground impact, and velocity remain of significant interest. With the PMA device these parameters were measured as in a gait lab. However, with this device the "laboratory" can be brought to the orthopedic office or to the patient who can use it in a natural environment such as home or worksite. Tests can be easily done for greater distances and longer duration. In this study the office setting was used for approximately 1 hour as a matter of convenience. However, the PMA device can record up to 7 days. This offers the physician better feedback for enhanced clinical evaluation.

Other applications of the PMA may provide objective comparisons for clinical interventions, including arthroscopy, hyaluronic acid fluid therapy, unispacer inserts, unicompartmental knee replacements, and prosthetic joint type of fixation (or loss). It may be useful to determine the optimal placement of incision, length of incision, and types or duration of physical therapy. Furthermore if the PMA were to gain wide use, comparison of consecutive studies in the same patient may indicate early functional failure owing to failing fixation of implants of lower extremity implants.

V. SUMMARY

The resolution of pain within the arthritic knee allowed patients increased velocity and cadence, relatively increased single limb support time (i.e., increased SLS/DLS despite decreased absolute measured SLS), greater power of pulling, greater power of swing (i.e., momentum), more rapid weight acceptance (i.e., ground impact deceleration), and decreased fatigability. Stride length and step length did not change. The greatest gait phase changes were noted in initial and terminal swing and rate of weight acceptance. These subtle parameters of altered gait may represent a benchmark of attainable goals for various therapies of the chronically painful arthritic knee, and help identify underlying determinants that can improve locomotion.

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