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# BIOMECHANICAL EVALUATION OF SCAPULAR GIRDLE IN PATIENTS WITH CHRONIC ARM LYMPHEDEMA

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*ABSTRACT*

*The presence of arm lymphedema can induce alterations in motor functions and posture. Using an optoelectronic system (ELITE 2002), we evaluated these alterations during a set of tests involving walking, resting and fatigue. The results of our biomechanical analysis demonstrated a limited range of motion of the affected arm, particularly a reduction in swinging during walking tests, and in shoulder retroposition and abduction movements for all patients. After repeated cyclical movements, premature fatigue appeared in the pathological arm. Lymphedema does not appear to cause alterations to the posture of the spine in our study, but drooping of the shoulder homolateral to the lymphedema can occur. This kind of investigation, which is quick, easy, and comfortable for patients with lymphedema, can be a useful method to evaluate functional capacity, thus allowing a quantitative assessment of the loss of function and the optimizing of the rehabilitative protocol.*

**Keywords:** arm mobility, lymphedema, biomechanics, disability, functional analysis, optoelectronics

Post-surgical lymphedema is a chronic disease that tends to progressively worsen if not adequately treated. The increase in limb volume and consistency causes, in the course of time, important physical and functional problems that can, in many cases, result in pain, induce postural alterations and reduce motor capacities.

Patients with arm lymphedema often show a limited range of motion in the shoulder joint, tendinitis of the rotator cuff, hyposthenia, myofascial pain, muscle contractures, intercostobrachial neuropathy, pain in the scapular and shoulder regions, and postural alteration of the shoulder and the cervical-thoracic spine. In many cases, the patients report arm stiffness together with heaviness and excessive tiredness, which make it difficult to carry out normal everyday tasks and hinders occupational and social activities (1,2). Currently, there are no diagnostic procedures that give a quantitative evaluation of motor and/or postural conditions of patients with arm lymphedema, and investigations are usually limited to addressing range of motion and muscle strength. Moreover, very few publications in the literature (3-5) are dedicated to human locomotion and to the evaluation of biomechanical movements in healthy subjects. On the basis of what is known, we carried out this preliminary study on patients with arm lymphedema, working in collaboration with the Bioengineering Department of Polytechnic of Milan.

Our main objectives were to quantify the functional limitation of the affected arm and assess possible alterations in postural strategies and dissymmetry due to the increased weight and volume of the arm, and to provide useful information for a better rehabilitative program.

*MATERIALS AND METHODS*

The study was carried out on 17 subjects with arm lymphedema following axillary dissection for breast cancer: 13 patients underwent quadrantectomy, axillary dissection and radiotherapy (QU.A.RT) and 4 radical mastectomy, modified according to Patey, without radiotherapy after surgery. The mean age was 58.9 years. The subjects in the study were selected randomly from among a group attending a follow-up clinic at the Rehabilitation and Palliative Care Department of the National Cancer Institute, and all gave their informed consent for the study. In 12 subjects, the lymphedema appeared 1 to 3 years after surgery, while for 5 there was an interval of more than 3 years. The average was 24 months. The lymphedema involved the left arm of 7 subjects and the right arm of the other 10. All the subjects were right-handed. In 6 cases, the lymphedema was mild (mean difference between arms was 1.0 cm to 2.0 cm), in 10 moderate (mean difference 2.5 cm to 4.0 cm), and in 1 subject severe (mean difference >4.5 cm). Consistency was soft in 1 subject, medium in 15, and hard in 1, and of the 16 subjects with soft or medium lymphedema, 12 showed positive pitting. The functional activity of the shoulder girdle by ROM (Range of Motion) was normal in 14 subjects, 2 presented with a slight degree of limitation, and 1 with severe limitation of the shoulder joint due to rotator cuff lesion. 75% reported a sensation of excessive tiredness and heaviness, and 32% had difficulty in carrying out their daily tasks and normal occupations.

All subjects underwent physical and manual combined therapies consisting of manual or ultrasound drainage, mechanical pressure therapy (at 40 mmHg), and multi-layered bandaging and exercises. Each treatment cycle consisted of 10 days of sessions that was repeated once or several times throughout the year. Prior to recruitment for the present study, 6 subjects had completed 1 to 4 treatment cycles (1 subject had done 2 cycles, 2 subjects 1 cycle and 3 subjects 4 cycles) and 11 had done more than 4 cycles.

On completion of the last treatment cycle, the subjects underwent static and dynamic evaluations of the shoulder girdle and the cervical-thoracic spine.

*BIOMECHANICAL ANALYSIS*

The analysis was carried out at the "Luigi Divieti" laboratory of the Milan Polytechnic Institute using an 8-camera optoelectronic system (ELITE2002, Bts, Milan) and a force platform. The optoelectronic system, employing a set of markers at specific points on the subject's body, determined, through motor strategy analysis, the degree of ROM while the parameters of the platform were tied to the subject's postural oscillation.

Each camera was equipped with an infrared light and the reflection of the markers, illuminated at regular intervals, and was captured by a camera positioned coaxially in relation to the light source. As these cameras use infrared rays the system is totally non-invasive. The system measures the three-dimensional coordinates (X Y Z) of the markers on the subject's body and calculates the angles of flexion-extension, abduction-adduction and extra-intrarotation of the main joints, speed and acceleration. The kinematics of the body segment on which the markers are positioned is also determined. The markers, usually attached to the subject's body by bi-adhesive tape, are neither a source of hindrance nor of irritation.

To analyze subject postural attitude, a force platform was used to measure the system of ground-reaction forces. Once this system of ground-reaction forces is known

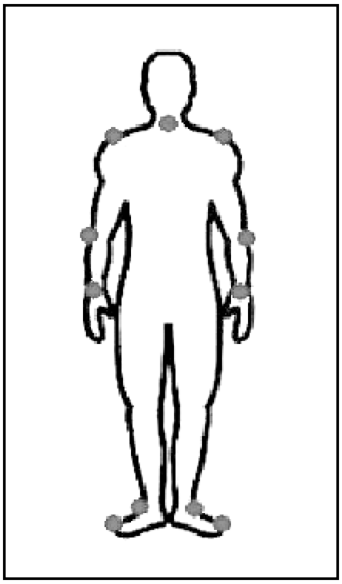

*Fig. 1. The points show the position of markers on patient's body.*

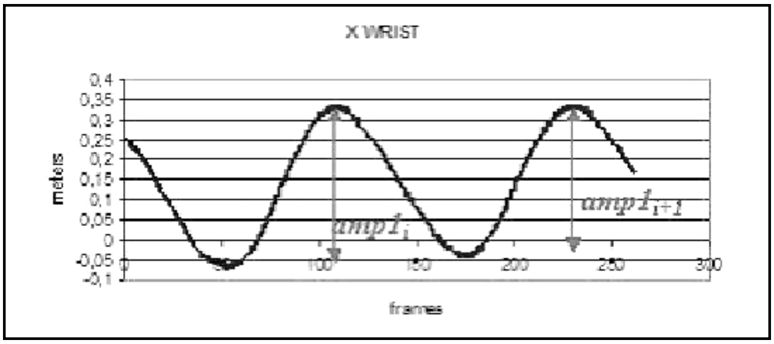


*Fig. 2. Trace of marker at wrist "amp1" along X axis during walking.*

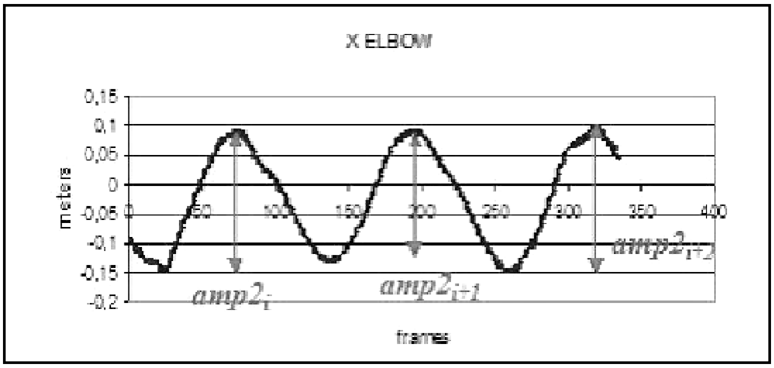


*Fig. 3. Trace of marker at elbow "amp2" along X axis during walking.*

and the kinematics parameters are assessed by the optoelectronic system, the moments and powers of the different joints can be calculated.

We used 11 markers positioned on the subject's body *(Fig. 1)* located on C7, each shoulder, the acromion, each elbow, the humerus epicondyle, each wrist, the ulna styloid, each foot, malleoli, and on the last metatarsi.

Once the markers were positioned, the subject executed various "tests" of walking, static posture, and movement. Initially there is a series of walks (10 in all), which the subject was asked to walk along a straight line, at varying speeds, and with as natural a gait as possible, to evaluate arm movement. Subsequently, the postural and motor data were assessed to study body balance and the threshold of tiredness. Two types of movement were selected: retroposition of the arm to quantify functional limitation and abduction to estimate the degree of fatigue in the pathological limb. The total length of the acquisition session was approximately 45 minutes. The first part of our analysis studied the swing of the arms during walking and in the resting position. We chose the amplitude of arm oscillation and the angle of flexion-extension of the elbow as the significant parameters and calculated them for both arms; the profiles are shown in the biomechanical pattern. To describe the swinging amplitude, we considered the X axis profile of walking progression, i.e., the trace of the markers at wrist "amp1" *(Fig. 2)* and elbow "amp2" *(Fig. 3)* and the flexion-extension angle "δ" between the upper arm and the forearm. Amplitude was standardized with respect to the walking speed of each gait because amplitude of movement increases with speed, the length of the whole limb (from acromion to wrist) for "amp1"; the length of the upper arm (from acromion to elbow) for "amp2". These indexes were calculated according to the formula:

$$amp1norm = \frac{\sum_{i=1}^{m} \frac{amp1_i}{velox_i}}{m} \times \frac{1}{l}$$

$$amp1_i = \frac{\sum_{j=1}^{n} amp1_j}{n}$$

In the formula "amp1" is the mean amplitude of oscillation for each test, "n" the number of oscillations for the test, "amp1j" the j-th amplitude of the movement in the i-th test, "l" the length of the subject's arm and "m" the number of tests carried out. In the case of "amp2norm," only the value of length "l" changes, becoming the length of the upper arm.

Postural strategies were analyzed considering the parameters of shoulder inclination (Δshoulder) and Center of Pressure (COP). Shoulder inclination was evaluated as the difference between the coordinates of the markers placed on the right and left acromion according to the formula:

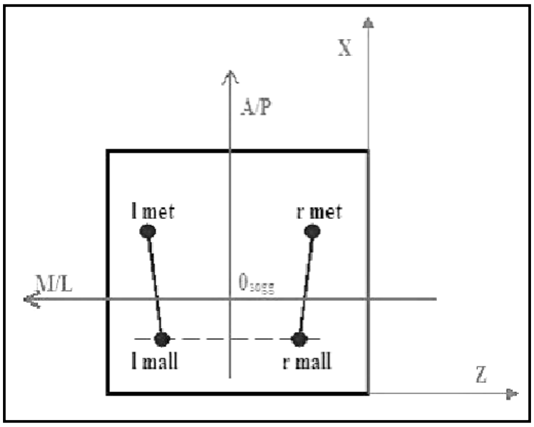


*Fig. 4. Maximum amplitudes (arrows) of COP swinging in medium-lateral (y) and antero-posterior (x) directions. quadrilateral area to calculate COP. A/P – antero-lateral direction; M/L – medio-lateral direction; Mall – malleoli (r= right   l= left); Met – metatarsi (r= right   l= left).*

$$\Delta shoulder = lshould - rshould$$

A positive value of Δy shoulder indicates inclination of the right shoulder, while a negative value reveals contralateral inclination.

The position of COP was calculated with respect to the position of the foot. We measured the distance of COP from the center of the base support, represented by the quadrilateral area between the two malleoli and two metatarsi *(Fig. 4)* and estimated the maximum amplitude of COP swing in the medio-lateral and antero-posterior direction and the preferential oscillation angle.

In the case of the retroposition test, we measured the angle in the sagittal plane "ξ" that lay between the arm, considered as rigid segment, and the shoulder to ground vertical axis. This angle was calculated from the profile of the wrist marker in the sagittal plane by the formula:

$$\xi = arcsen \frac{\Delta wrist}{l}$$

In the fatigue test (25 repeated abductions prior to evaluation), we assessed movement amplitude (given by coordinate y of the wrist marker) and duration. A quantitative evaluation of these parameters made it possible to detect the exact moment of subject fatigue. Both arms were tested and the results relating to the two limbs were compared.

To validate our results statistically, we carried out the appropriate significance tests. First, for each subject, a normality test was done to verify Gaussian data distribution, followed by the t-test to compare the averages of the two Gaussian populations. If the distributions tests did not turn out to be Gaussian, the Mann-Whitney test was applied. T-tests were done to compare the results of the pathological and healthy arms groups. The level of significance for all the tests was $p<0.05$.

## *RESULTS*

All subjects completed the evaluation

**TABLE 1**
**Walking Test**

| | amp1norm | | amp2norm | | δ | |
|---|---|---|---|---|---|---|
| | pathological | healthy | pathological | healthy | pathological | healthy |
| 1 | 0.11 | 0.28 | 0.12 | 0.25 | 6.3 | 4.2 |
| 2 | 0.17 | 0.16 | 0.15 | 0.13 | 3.5 | 5.3 |
| 3 | 0.13 | 0.26 | 0.1 | 0.2 | 4.3 | 13.8 |
| 4 | 0.29 | 0.35 | 0.23 | 0.27 | 13.2 | 20.3 |
| 5 | 0.18 | 0.19 | 0.1 | 0.19 | 3.6 | 4.1 |
| 6 | 0.15 | 0.19 | 0.12 | 0.15 | 4.7 | 6.4 |
| 7 | 0.18 | 0.17 | 0.12 | 0.1 | 11.3 | 17 |
| 8 | 0.23 | 0.18 | 0.19 | 0.15 | 9.3 | 9.8 |
| 9 | | | | | 13.2 | 17.8 |
| 10 | 0.12 | 0.3 | 0.1 | 0.19 | 6.8 | 20.2 |
| 11 | 0.28 | 0.34 | 0.24 | 0.23 | 12 | 26.9 |
| 12 | 0.19 | 0.31 | 0.14 | 0.59 | 9.9 | 13.7 |
| 13 | 0.22 | 0.08 | 0.18 | 0.06 | 8.7 | 2.8 |
| 14 | 0.31 | 0.18 | 0.25 | 0.14 | 5.3 | 5.1 |
| 15 | 0.38 | 0.45 | 0.26 | 0.36 | 23.6 | 12.5 |
| 16 | 0.19 | 0.21 | 0.12 | 0.12 | 9.8 | 10.7 |
| 17 | 0.53 | 0.61 | 0.35 | 0.43 | 19.3 | 7.3 |
| Mean | 0.23 | 0.27 | 0.17 | 0.23 | 9.69 | 11.64 |
| SD | 0.11 | 0.13 | 0.07 | 0.14 | 5.52 | 6.99 |
| P value | 0.19 | | 0.11 | | 0.19 | |

tests of the study. In the walking and fatigue tests, we assessed both arms, pathological and healthy, of each subject and compared the results. In the postural analysis, particular consideration was given to the dissymmetry due to the presence of lymphedema.

For the walking test, we took into account the following indexes: amplitude of wrist oscillation (amp1norm), amplitude of elbow oscillation (amp2norm) and flexion-extension angle "δ" between the upper arm and forearm.

Subject 9 was later excluded from some tests ("amp1norm", "amp2norm", retroposition test) because of a complete rotator cuff lesion. Thus, the results for these tests reflect 16 subjects.

*Table 1* shows the data obtained from the analysis of parameters "amp1norm", "amp2norm" and "δ" for each subject as well as the mean, standard deviation and the p-value of the data relating to the pathological and healthy groups.

During the walking test, we observed that most subjects had reduced swinging amplitude in the arm with lymphedema. This finding is a reflection of the limited anteroposition movement of the forearm, the loss of movement in elbow flexion-extension and the loss of mobility because of the increased weight and the volume of the arm itself.

In 11 of 16 subjects studied (68.75%) the amplitude of the "amp1norm" variable was smaller in the pathological arm than in

**TABLE 2**
**P-Value Walking Test**

| | Amp1norm | amp2norm | δ |
|---|---|---|---|
| 1 | < 0.0001 | < 0.0001 | 0.1009 |
| 2 | 0.5173 | 0.0008 | 0.0733 |
| 3 | < 0.0001 | < 0.0001 | 0.0001 |
| 4 | < 0.0001 | < 0.0001 | 0.0344 |
| 5 | 0.5556 | < 0.0001 | 0.5985 |
| 6 | < 0.0001 | 0.0041 | 0.1071 |
| 7 | 0.6157 | 0.0467 | 0.0622 |
| 8 | < 0.0001 | < 0.0001 | 0.8127 |
| 9 | | | |
| 10 | < 0.0001 | < 0.0001 | 0.0001 |
| 11 | < 0.0001 | 0.1416 | 0.0001 |
| 12 | < 0.0001 | < 0.0001 | 0.0534 |
| 13 | < 0.0001 | < 0.0001 | 0.0017 |
| 14 | < 0.0001 | < 0.0001 | 0.8802 |
| 15 | < 0.0001 | < 0.0001 | 0.0001 |
| 16 | 0.058 | 0.736 | 0.7519 |
| 17 | < 0.0001 | 0.0024 | 0.0004 |

the healthy one, and there was a statistically significant difference ($p<0.05$) in the amplitudes of the pathological and healthy arms in 9 of these subjects (56.25%) *(Table 2)*. For 4 subjects (1,3,10,12), the amplitude of the pathological arm was less than 2/3 that of the healthy arm. Although the difference between the pathological and healthy arms groups was not statistically significant ($p= 0.19$), this may be due to both groups including subjects with different physiological and pathological characteristics of age, weight, involvement of right or left arm, muscular tone, physical constitution, motor behavior and the low numbers in each group.

Also, the amplitude of the "amp2norm" variable was smaller in the pathological arm in most of the subjects (9 total). Indeed, the data for each individual subject revealed the difference between the pathological and healthy arms to be statistically significant ($p<0.05$) for all of these subjects. In 5 subjects (1,3,5,10,12) the amplitude of the pathological arm was less than 2/3 that of the healthy one.

The trend of variable "δ" overlapped other variables in the study with 70.6% of the subjects (12 subjects) presenting with a lower "δ" amplitude in the pathological arm than in the healthy one. 41.2% of the observations (7 of 17) showed statistically significant difference.

In evaluating posture, the degree of shoulder droop and sliding was taken as an index of limb dissymmetry due to lymphedema and the position of COP was assessed to verify the influence of lymphedema on the body weight distribution. The analysis did not reveal any postural alterations of the spine due to the presence of lymphedema. Indeed the percentage of kyphosis and scoliosis among the subjects was similar to that in healthy subjects of the same age with the same

**TABLE 3**
**Retroposition Test**

| | Pathological | Healthy |
|---|---|---|
| 1 | 68.3 | 66.6 |
| 2 | 48.6 | 63.2 |
| 3 | 42.9 | 61.8 |
| 4 | 56.01 | 72.19 |
| 5 | 41.47 | 51.05 |
| 6 | 32.95 | 51.08 |
| 7 | 46.3 | 44 |
| 8 | 34.78 | 39.44 |
| 10 | 37.85 | 38.65 |
| 11 | 44.14 | 53.94 |
| 12 | 33.59 | 49.89 |
| 13 | 36.725 | 40.47 |
| 14 | 57.52 | 71.76 |
| 15 | 53.46 | 55.67 |
| 16 | 51.36 | 51.84 |
| 17 | 50.07 | 62.51 |
| Mean | 46.00 | 54.6 |
| SD | 9.91 | 10.9 |
| P value | | 0.009 |

physical characteristics. However, we did observe drooping of the shoulder homolateral to the lymphedema in 11 subjects.

An analysis of the COP position (Center of Pressure) revealed that all subjects had a medio-lateral movement of this COP point towards the side of the pathological arm.

In the retroposition test, the pathological arm had very evident limited movement with decreased ROM compared to the healthy arm. *Table 3* shows the angles "ξ" for pathological and healthy arms of the 16 subjects (subject 9 again being excluded because of cuff lesion). In 87.5% of the cases (14 subjects) the pathological arm had a smaller range of motion than the healthy one. The difference between the pathological and the healthy groups was statistically significant (p=<0.009).

For the fatigue test, we considered the trace of the wrist marker. Its tracing was approximately sinusoidal with each curve maximum corresponding to a point of maximum arm abduction and each minimum to the position of the straight arm hanging in a relaxed position alongside the body. To estimate the results of this test we carried out a qualitative analysis of the time course of the y-coordinate of the wrist marker, "ywrist," the representative curve being the course of the maximum *(Fig. 5)* as oscillation amplitude was not constant throughout the test. Also the interval "Δt" between two subsequent maxima was considered *(Fig. 6)*.

These parameters are represented in the formula:

$$\Delta ywrist = ywrist_i - ywrist_{i+1}$$

where '$ywrist_i$' is the amplitude of the i-th abduction and '$ywrist_{i+1}$' is the amplitude of the i+1-th one; and

$$\Delta t = t_i - t_{i+1}$$

where 'Δt' is the time that separates the two repetitions.

In normal conditions, the fatigue phenomena are manifested as a lessening in movement amplitude, the "Δt" constant being followed by an abduction of greater amplitude but at shorter time intervals.

We excluded 6 subjects from the fatigue test evaluation *(Table 4)* because of technical problems. For this test, no individual mean and standard deviations were calculated as the subjects repeated the test only once, and there was only one numerical value for each subject. Furthermore, the degree of fatigue was totally individual, depending on the physiological and pathological characteristics of each subject. On comparing both arms of the 11 subjects, fatigue phenomena were observed in 70% of the cases. For 2 subjects, the same number of repetitions resulted in fatigue in both arms, for 7 it appeared first in the pathological arm, probably due to the loss of muscular tone and the sensation of heaviness perceived during the test; for the other 2 subjects, the fatigue appeared first in the healthy arm.

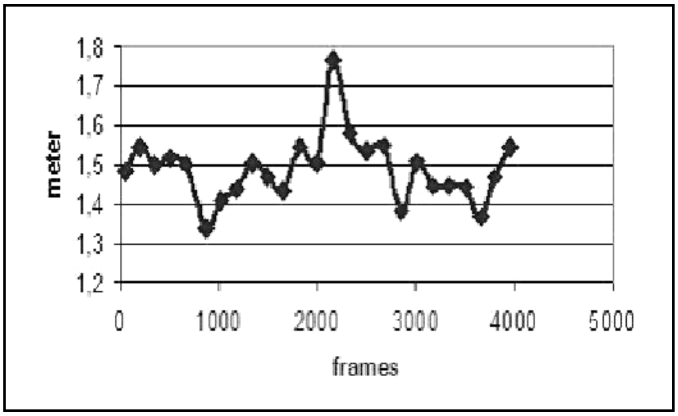


*Fig. 5. The curve represents the course of maximum in fatigue test.*

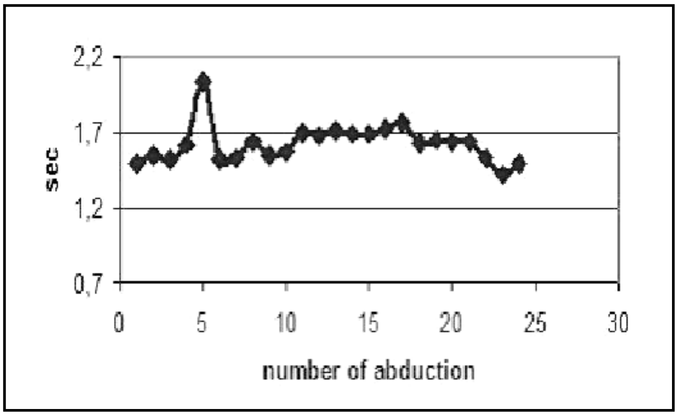


*Fig. 6. Interval 'Δt' between subsequent maxima.*

*CONCLUSIONS*

The present study, although carried out on a limited sample, allowed us to obtain relevant information and to formulate new working hypotheses. The results of this preliminary study show that the presence of lymphedema causes limitation in the range of arm motion during involuntary movement e.g., swinging during walking, and in voluntary movements such as retroposition and abduction. Moreover, premature fatigue appears in the pathological arm after repeated cyclical movement. However, in our subjects, the arm lymphedema did not appear to cause alterations in the posture of the spine.

The statistical analysis revealed significant difference for the retroposition test ($p=<0.009$) but not for the walking test ($p=0.19$). The t-test, calculated on the pathological and healthy groups, showed no significance for oscillation movement during walking also because the subjects of the two groups had different motor behavior. Instead, when looking at the individual subject and comparing the data of the two arms (concerning "amp1norm", "amp2norm", "δ"), a statistically significant difference is observed in all the cases.

Given the small number of subjects in our sample, we made no attempt to look for relationships between our results and the

**TABLE 4**
**Fatigue Test**

| | Pathological | Healthy |
|---|---|---|
| 4 | 13 | 13 |
| 5 | 10 | 12 |
| 6 | 10 | 13 |
| 7 | 13 | 14 |
| 8 | 11 | 15 |
| 9 | 9 | 12 |
| 10 | 18 | 18 |
| 14 | 17 | - |
| 15 | 15 | 21 |
| 16 | 22 | 19 |
| 17 | 10 | 23 |
| Mean | 13.45 | 16.0 |
| SD | 4.13 | 3.97 |
| P value | 0.167 | |

other characteristics of lymphedema like volume and consistency.

In conclusion, the data of this study are of interest in that they provide an insight into the motor condition of subjects with lymphedema and helps to better define the degree of disability of this pathology.

The biomechanical analysis can be useful to evaluate the total functional capacity of patients, to prevent the onset of postural and motor problems in the shoulder joint and spine, to optimize rehabilitative protocol aimed at functional recovery of the pathological arm, and to allow the physiotherapist to identify particular sites of limited movement and to assess, quantitatively, function loss.

The investigation is comfortable, relatively quick (45 minutes), easy to reproduce and compare, and needs only one session for an operator to evaluate superior girdle, arm and spine.

In the future, it will be possible to study other movements for both arm and spine and to correlate the range of motion parameters to the volume and consistency of lymphedema and to the tonometric measures of the affected area.

Finally, this evaluation method could also be applied to patients with leg lymphedema, particularly to evaluate the alterations in foot support, gait, and in posture of the spine.

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