GAIT DYNAMICS VERSUS ISOTONIC FOOT MOVEMENT IN EVALUATION OF EMG POSITIONING OF PERONEAL IMPLANTS

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Abstract

To test the reliability of EMG monitoring developed for the positioning of electrodes during implantation, a quantitative method for its evaluation has been investigated. It comprises determination of gait dynamics with and without the stimulation prior to and after the implantation, together with a description of isotonic foot movements with subcutaneous stimulation. Comparisons between the isotonic foot responses and gait dynamics during stance are a measure of the reliability of the electrode position monitoring during surgery. Gait dynamics were determined by the vertical component of the ground reaction force and its point of action on the sole of the measuring shoes during gait. Fifteen hemiparetic patients with previously implanted stimulators were evaluated. High correlation between gait dynamics and EMG responses (M-waves) in the stimulated muscles clarified the usefulness of the EMG monitoring method.

Introduction

In the last few years in Ljubljana over 30 hemiparetic patients have had a peroneal underknee electrical stimulator implanted (1). Clinical evaluations of patients with implants have shown that in several cases the quality of gait correction was not satisfactory. Although in certain cases gait correction is still functional, an excessive eversion can be observed.

To improve the quality of gait control by implantable peroneal stimulators, the EMG monitoring method for electrode positioning during implatation has been proposed (2). The method determines the desired EMG responses to surface stimulation in the tibialis anterior, peroneus longus and soleus muscles before the implantation. The EMG records are used as a guideline in electrode positioning during surgery.

To test the reliability of EMG monitoring a quantitative method for its evaluation was investigated. It comprises determination of gait dynamics with and without the stimulation prior to and after the implantation, together with a description of isotonic foot movement with subcutaneous stimulation. Comparisons between the isotonic foot responses and gait dynamics during stance are a measure of the reliability of the electrode position monitoring during surgery. Fifteen hemiparetic patients with previously implanted stimulators were evaluated. A high correlation between gait dynamics and EMG responses (M-waves) in the stimulated muscles was found.

Method

The method of evaluation of foot movement consists of description of foot response to stimulation pulses from the subcutaneous electrodes under isotonic conditions, and estimation of foot dynamics during gait with and without stimulation. Comparisons between responses are the measure of reliability of EMG monitoring for prediction of electrode position during surgery. Foot movement was described qualitatively as rotation about ankle joint axes in the medio-lateral direction: dorsal flexion, plantar extension and in the anterio-posterior direction: eversion, inversion. Gait dynamics were determined by measuring the vertical component of the ground reaction force and its point of action (POA) on the sole of the measuring shoes (3), and the goniometric function together with space and time gait parameters. Based on information obtained from the force measuring shoes and the goniometric system, the average values and standard deviations of the vertical component of the ground reaction force and its POA, goniometric functions, as well as the ankle joint torque in the sagittal and frontal plane, were computed. Deviations of the measured variables with respect to normal gait pattern and the symmetry between right and left variables are a measure of gait quality (4). The stimulation parameters were adjusted so that the patient's gait pattern approached the healthy pattern.

Results

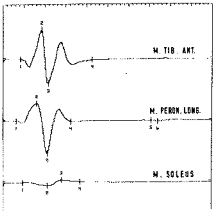

Fig.1 EMG responses of the tibialis anterior peroneus longus and soleus on single pulse stimulation of the common peroneal nerve of a hemiplegic patients

Fifteen hemiparetic patients with previously implanted stimulators were tested. Different combinations of M waves in the tibialis anterior, peroneus longus, and to a smaller extent in the soleus were recorded. The combination of M waves in the observed muscles is fairly well correlated with the direction of of the isotonic foot movement. As an example in Fig. 1 the M waves four superimposed responses in the tibialis anterior, peroneus longus and soleus are presented for case 11 (dex hemiplegic patient) with dorsal flexion (DF) and moderate eversion (m.EV) during stimulation with implanted electrodes in the standing position.

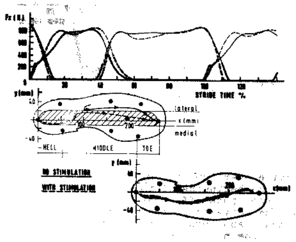

Fig.2 Average ground reaction force and its POA of gait of a hemiplegic patient without stimulation (solid line) and with stimulation (dashed line). The marked area of the shoe sole represents the region of normal POA.

In Fig. 2 average vertical ground reaction force F and its POA along the X,Y axes with and without stimulation of the same patient are shown. For this purpose different events on the POA trajectory have been denoted as follows: H, begining of POA at heel contact; M, midfoot area, while T means that the POA runs through the toe off phase. In the case when the trajectory of the POA runs laterally or medially on the sole (out of marced area), indices l or m are added to standard notation. However, the first index in the fourth column always means foot contact and the last index foot off. The trajectory of the POA of the impaired leg is shifted from the lateral side of the midfoot to the heel contact, in the direction of the long axis of the shoe sole, to resemble the trajectory of the unimpaired leg, and is in good correlation with isotonic foot respons.

Ankle moments arround the x and y axes of the same patients are shown in Fig. 3, where the left and right leg are the same as in Fig. 2. The significant influence of stimulation on the patient's gait can be seen from the moments around the x axis of the left (impaired) leg. This moment was corrected by stimulation

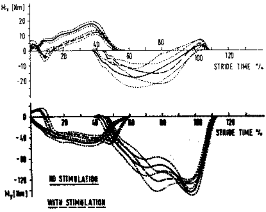

Fig.3 Average time dependence of ankle torques without stimulation (solid lines) and with stimulation (dashed lines). Dotted lines represent = one standard deviation.

from distinctive eversion (max Mx=17Nm) to slight inversion (max Mx=-5Nm) at the beginning of the stance phase to eversion (max Mx=10Nm) at the push-off phase. This correction could be explained by the activity of the m. tibialis anterior and the m. peroneus longus and brevis in the swing phase caused by the stimulation of the n. peroneus communis. More important is the significant change of My of the impaired leg in the heel contact phase, where the positive moments represent the activity of the stimulated m. tibialis anterior in preventing drop foot. Differences in other parts of the trajectory are not significant due to large variations. Results obtained in moment computation are in good agreement with the data obtained by other workers (5,6), even though the horizontal component of force and moment of inertia of the foot are neglected.

The results of the experiments are shown in Table I. All patients were implanted 2 to 3 years prior to the tests and EMG muscle responses were not recorded before. Comparision of the attributes describing gait events in columns three and four are a measure of the correlation index. For example, isotonic foot movement described by set: DF,m.EV and the trajectory of the POA represented by set: H,M,T, which is characteristic of good gait, have the same range as the attributes of sets: e.EV and H,M1,T although the latter represents poor gait. From the 15 patients studied, a fairly good correlation between predicted isotonic foot movement and the trajectory of the POA during gait can be observed. Thirteen of them (90%) have the same attributes describing gait in both columns.

Discussion

To highlight the influence of the proposed electrical stimulation on gait corection, the characteristics of the POA of the same patients without stimulation are shown in the fifth

TABLE I

CORRELATION OF ISOTONIC STIMULATED FOOT MOVEMENT AND TRAJECTORY OF THE POINT OF ACTION (POA) DURING GAIT WITH SUBCUTANEOUS STIMULATION.

		ISOTONIC STIM.	POINT OF ACTION	
CASE	DGN.	FOOT MOVEMENT	STIM.	NO STIM.
1	HEM.D.	DF,m.EV	H,M,T	H,M,T
2	HEM.D.	DF,m.EV	H,M,T	Mm,Tm
3	HEM.S.	e.EV,m.DF	H,Ml,T	H,Mm,T
4	HEM.S.	DF,m.EV	H,M,T	H,Mm,T
5	HEM.S.	e.EV	H,Ml,T	H,M,Tl
6	HEM.D.	DF.m.EV	H,M,Tl	Mm,T
7	HEM.D.	DF,m.EV	H,M,T	Mm.T
8	PP.TH7	e.EV,m.PF	H,M,Tl	Mm,T
9	HEM.S.	DF,e.EV	H,Ml,T	Mm,T
10	TP.C7	EV,DF,m.EV	H,M,T	M,T
11	HEM.S.	DF,m.EV	H,M,T	Ml,T
12	HEM.S.	e.EV	Hl,M,T	Hl,M,T
13	HEM.D.	e.EV	H,M,T	Hl,M.T
14	HEM.D	EV	H,M,T	Hl,M,T
15	HEM.S	e.EV,PF	Hl,M,T	Hl,M,T

DF: dorsal flexion, EV: eversion, PF: plantar flexion e.EV: excesive eversion, m.EV: moderate eversion, H: heel contact, M: midfoot, T: toe off, l: lateral, m: medial

column of Table I. It is obvious that in most cases the measured gait patterns of the POA are significantly changed by the use of electrical stimulation, but only 7 had good gait In the case 1, 12 and 15 no difference between stimulated and non-stimulated gait was observed. Although the stimulation response is correct, there is no difference in the gait pattern with and without stimulation in case 1 at the time of the experiments One year ago the results were quite different: non-stimulated gait was characterised by Mm,T for the unimpaired and Hm,M,Tm for the impaired leg, and for stimulated gait H,M,T for the unimpaired and Hl,M,Tl for the impaired leg. The observed phenomenon could be explained as carry-over effect or by a learning process. In cases 12 and 15 there is no change in gait patterns due to poor fixation of the implanted electrodes. Therefore a final judgement about gait has to be carefully considered, at least from the point of view of biomechanics and neurocontrol.

An almost linear relationship between electrode position, foot responses and gait dynamics was found. The results from a population of three typical patients are shown in Table II. It is obvious that in case 11 for good muscles respons there is highly significant improvements of POA and space and time gait parameters as well as gait symmetry. In case 14, partially satisfied muscles response has resulted in significant improvements of POA and gait parameters and some components of gait symmetry. Finally, in case 15 for poor muscle response there is no change either in POA pattern or in the gait parameters and symmetry.

TABLE II.

GAIT PARAMETERS AND SYMMETRY VERSUS POINT OF ACTION WITH AND WITHOUT STIMULATION

PATIENTS	CASE 11		CASE 14		CASE 15	
STIMULTION	NO	YES	NO	YES	NO	YES
POINT OF ACTION	M1,T	H,M,T	H1,M,T	H,M,T	H1,M,T	H1,M,T
FOOT MOVEMENT		DF,m.EV		EV		e.EV,PF
GAIT PARAMETERS:						
STRIDE TIME (s)	1.60	1.32	2.08	1.67	1.28	1.30
STRIDE LENGTH (m)	.94	1.23	.93	1.02	.97	.93
VELOCITY (m/s)	.59	.93	.45	.61	.76	.72
CADENCE (step/s)	.63	.76	.48	.60	.78	.77
GAIT SYMMETRY:						
STEP TIME	.59	.78	.53	.59	.63	.64
STEP LENGTH	.82	.87	.57	.67	.80	.81
STANCE TIME	.79	.88	.78	.74	.82	.82
SWING TIME	.57	.79	.54	.53	.64	.63
DOUBLE SUPPORT	.69	.77	.52	.73	.63	.65

The high correlation between ankle dynamics and EMG responses of stimulated muscles clarify the usefulness of the EMG monitoring methcd for electrode positioning during implantation. The methodology described is useful for quantitative gait evaluation and the follow-up of its evolution with time

Acknowledgements

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