Enduring Capacity of the Erectores Spinae Muscles in Static Work

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Abstract The enduring capacity of the erector spinae muscles for sustained back extension was investigated in 8 normal males at the tensions of 70, 50, 40 and 30% of the maximum strength with a specially devised dynamometer. Relatively prolonged endurance time was obtained at lower tensions; the critical tension endurable for 10-20 minutes was supposed to be 20-30% max., though muscular pain appeared already before the half of endurance. Heart rate increase was moderate. Conflicting trends were demonstrated between the mean amplitude and the slowing of EMG of the erector spinae. The work load suffered by the latter in upright standing was assessed electromyographically as less than 2-3% of the maximum activity, and at most 20% in the case of forward bending at 45-60 degrees.

INTRODUCTION

Bipedal standing is the basis of man's physical activities. Man, however, has not yet adapted so fully to this posture that those who complain of lumbar or back pain are not infrequent. Although the mechanisms responsible for the pain are still obscure, they might well be related with some impairments caused by the continuous loading of body weight on the vertebral column. Besides, human postures are not necessarily upright or static. Forward bending and dynamic postures are frequently experienced in daily life, in which the stress developed in the vertebral structures by sustained bending or bending-straightening move-

ments of the trunk is supposed to be so effective to give rise to the impairments in them. Since the main contributors to the movement of the vertebral column are the erector spinae muscles, their functions have to be elucidated if the physiological stress in standing posture is to be assessed.

The erector spinae, one of the so-called 'anti-gravities', are composed of several muscles such as the longissimus, the iliocostalis, the splenius and many other small ones, which are morphologically of the most primitive type in human skeletal muscles. As the posterior vertebral extensors, they stabilize the vertebral column and the pelvic joint. Electromyographic examinations reveal that, in nat-

ural standing, their activity is not conspicuous but rather feeble and intermittent, since their functions are limited to the maintenance of the body equilibrium. During the forward bending or the rotating motions, however, a vigorous activity is seen in them.

We have not a few works dealing with the functional aspects of the erector spinae mainly from kinesiologic or electromyographic point of view (FLOYD & SILVER 1955, JOSEPH 1960, MORRIS, BENNER & LUCAS 1962, TOKIZANE & SHIMAZU 1964). However, in order to evaluate the physiological cost of standing posture as the basis of human activities, it seems indispensable to know the working capacity of these muscles. In the present study, for the above-mentioned purpose, the enduring capacity of the erector spinae in static work was investigated in eight normal males aged 23-34. Besides, as a preliminary research, their work load in standing postures from natural standing to full flexion was assessed quantitatively by electromyogram (EMG), to be discussed from the view point of the enduring capacity.

EXPERIMENTAL PROCEDURES

In standing position, the activity of the erector spinae is so subtle that it is affected considerably by the poise of the head and/or by the carriage of the upper body. Consequently, if the exercise for these muscles is tried while standing, the experimental conditions might be not only complicated but also instable. To eliminate the influence of the weight

Fig. 1 Schematic illustration of back muscle-dynamometer. The arrows show the direction of force exerted. LC; pressure-type load cell. For explanation, see text.

of the head and the upper body, a special dynamometer was prepared (Fig. 1).

It was so designed as to make the subject, lying on his side with the upper and the lower part of the body mounted on separate platforms, and with the pelvic region and the legs fixed tightly, perform extension of his back at various degrees of flexion at the pelvic joint, exerting a force to a pressure-type load cell placed behind the middle part of the back around the level of the 7th thoracic vertebra. The platform mounted by the upper body was adjustable at a given angle of lumbar flexion. The friction derived from the upper body weight was removed by making the chest part of the trunk

mounted on a frame which was movable backward and forward freely with rollers. In consequence, the exerted force was transmitted indirectly by pressing the frame board against the load cell, which was connected to a strain meter. Since the indicator panel of the latter was set up just in front of the eyes of the subject for self-monitoring, it was possible to make him endure sustained extension of his back under the load of certain intensities.

I) Employing this apparatus, we performed the following procedures. The angle of flexion at the pelvic joint was fixed at 30 degrees in these experiments.

(1) Maximum force exerted in back extension was measured and assumed as giving the maximum strength of the erector spinae.

(2) Endurance time in the sustained contraction at the intensities of 30, 40, 50 and 70% of the maximum strength was measured respectively. At the same time, the onset period of muscular pain was inquired.

(3) While these exercises were tried, 'global' EMG was recorded from the contracting erector spinae bilaterally at the level of the 4th lumbar verte-

bra, and heart rate was monitored by ECG. Surface electrodes were employed in either case. Mean amplitude of EMG was converted to pulse counts with a digital integrator. Simultaneously, frequency analyses was applied to EMG by means of an automatic frequency analyzing integrator with band pass filters of 8-13, 13-20, 20-30, 30-40, 40-60, 60-80, 80-120 Hz respectively.

II) In standing position, with or without a load of 10-30 kg held in arms, the activity of the erector spinae at various degrees of forward bending posture from full flexion to upright position

Fig. 2 Endurance-Tension relations in sustained back extension. Both variables are expressed in logarithm. Different symbol represents the result of each subject.

were examined by EMG at L4 level and compared with that observed in the dynamometer exercises.

RESULTS

Maximum force exerted in back extension, given in kg through the calibration curve of the dynamometer (strain-pressure in kg), ranged from 70-110 kg among subjects, being short of the so-called 'back muscle strength' or 'lifting strength' by 30-40%. Setting apart the difference in mechanical conditions such as the working point of exerted force, the diminution was naturally due to the fact that muscles of arms and shoulders were not involved in our measurement. Hence, the force thus measured was assumed as approximating the maximum strength of

the erectores spinae.

In Fig. 2, the maximum endured time in sustained back extension is correlated to the tension in ratio to the maximum strength. Although individual value being scattered widely, at lower tension in particular, the logarithm of the maximum endured time is almost in a linear relationship with that of the tension, and the line representing the relationship has a considerably large gradient, meaning that the endurance time is relatively longer at lower tension as compared with those of the other muscles. At the tension of 30 % max., more than 30 minutes were endured by two subjects whose maximum strength was less than 80 kg.

As to the onset period of muscular pain, we failed to find definite relations be-

Fig. 3 Change of heart rate in each subject during endurance at each tension.

Fig. 4 Relations between tension and EMG amplitude of the erectors spinae in each subject during back extension. Tension shown in ratio to the maximum strength(%) and amplitude in an arbitrary unit (pulse counts).

tween the tension and the latter, owing to discordance among subjects in criteria for the degree of suffered pain. In general, however, pain appeared already before

the half of endured duration.

Heart rate increase was moderate in these exercises (Fig. 3). At the tensions of 70, 50 and 40% of the maximum

Fig. 5 Change of EMG amplitude, shown in percent of the initial value, in each subject during endurance at each tension.

strength, heart rate at the all-out point was 120–160, 100–140 and 90–130 per minute respectively. At the tension of 30% max., plateaus were reached at relatively early stages at the rate of 80–120 per minute.

It was found that the mean amplitude of the 'global' EMG recorded from the erector spinae was fairly, though not uniformly, proportional to the intensity of back extension (Fig. 4). Since LIPPOLD (1952) and other authors demonstrated that the mean amplitude of 'global' EMG bears almost linear relationship with muscular tension in the case of static

contraction, the above-mentioned result might prove the fact that the erector spinae is contributing proportionally to the intensity of back extension.

Although the mean amplitude increased during each exercise, the amount of increase was not remarkable. Furthermore, in majority of cases, after an increase seen at early stage of endurance, the amplitude decreased consistently to the initial level or, in a few cases, to a lower one (Fig. 5). Such a trend was conspicuous especially in the case of exercises at lower tension. These results

Fig. 6 Change of 'slow wave ratio', shown in percent of the initial value, in each subject during endurance at each tension.

Fig. 7. EMG amplitude of the erectors spinae muscles obtained at various angles of static forward bending (upper) and that obtained in straightening up from full flexion (lower). Amplitude given in an arbitrary unit. In the case of straightening up, either the amplitude in static posture at various angles and that in dynamic one at the transitional stage between the latter are shown by solid line. By dotted line are shown the same as in the upper figure. Tension-Amplitude relation of the erectors spinae is illustrated together.

are inconsistent with the increase of amplitude usually observed in fatigued muscles. These phenomena, probably caused by an alternation of active muscles due to muscular pain, might suggest the complicated compensatory mechanisms among the *erectores spinae*.

As reviewed by LIPPOLD, REDFEARN & VUČO (1960), it is well known that the wave form of 'global' EMG is altered with muscular fatigue, the lower frequency growing predominant. In the present study, as a tentative indicator of the frequency component specifics of EMG, the ratio of the components of 0-40 Hz to those of 40-120 Hz, so-called 'slow wave ratio' previously proposed by KOGI & HAKAMADA (1962), was adopted. In contrast with the mean amplitude, the 'slow wave ratio' increased steadily if not uniformly during each exercise (Fig. 6).

In a number of cases, it exceeded the initial level by 20-40% at the all-out point regardless of charged tension.

In standing position, though ready to vary according to the carriage, the electrical activity of the *erectores spinae*, starting with feeble one at an upright position, increased steadily along with the forward leaning, to reach the climax at around 60 degrees of pelvic flexion, then declining at 90 degrees and nearly disappeared at full flexion (Fig. 7). The above trend was valid regardless of the load held in arms.

Collated with the Amplitude-Tension diagram already mentioned, the activity of the *erectores spinae* in upright standing

without load-holding proved to be less than 2-3% of that accompanying the maximum exertion tried in the dynamometer, and at most 20% at 45-60 degrees of forward flexion. Even in the case of load-holding, the amplitude never exceeded 50% of the maximum if the posture was a static one. On the other hand, a vigorous activity was seen during the dynamic phase in a returning movement from the fully flexed position at a fairly low speed (Fig. 7). At the pelvic angle of 60 degrees with the load of 30 kg, the activity accompanying the transitional stage of straightening up exceeded 60% of the maximum, though it is hardly justified to compare a result in a static work with that in dynamic one.

DISCUSSION

The enduring capacity for sustained contraction has been studied by many authors since WACHHOLDER (1930), MÜLLER (1932) and FESSARD, LAUGIER & NOUEL (1933). Recently, MONOD & SCHERRER (1965) reviewed their analytical studies of the work capacity for local muscular exercise from theoretical view point, in which they assumed that in continuous static work the relation between the maximum endured time and the charged tension in ratio to the maximum strength (E-T relation) was hyperbolic one answering a definite formula, provided that the exercise was 'local', that is, performed by less than a third of the whole muscular mass. They also postulated that the hyperbolic relation was valid regardless of muscle or group of muscles concerned,

and the critical tension for a long-lasting sustenance was 15% max. These results were supported by ROHMERT (1960) and COLDWELL (1965). A little higher limit time value was obtained by KOGI & HAKAMADA (1962) for the biceps brachii.

Comparing the endurance among three types of static works, namely, elbow flexion, lower leg extension and lifting in stooping posture, MORIOKA (1964) pointed out that, although the respective E-T relations were linear with both variables expressed in logarithm, they differed graphically in position and gradient among these exercises, especially at lower tension. Thus, the critical tension endurable for 10-20 minutes was as high as 20-30% max. in elbow flexion, while in lifting as well as in lower leg extension less than 20% max., so providing the E-T relations superimposable on that of MONOD & SCHERRER (1965). MORIOKA (1964) attempted to explain these discrepancies by the difference of the functional state of each muscle such as the degree of the training effect.

In our results, the critical tension for the erectors spinae is supposed to be a little higher than those of the above authors, the E-T relation rather resembling that found in elbow flexion by MORIOKA (1964). But if one considers the effects of local pain which will appear already at the first half of maximum endurance, the critical tension for a fatigueless contraction should be substantially lower than 20-30% max. This consideration is particularly the case with anti-gravity muscles as the erectors

spinae, whose contraction tends to be sustained very long.

For the comparison of our results with those of the above authors, it should be confirmed whether the exercise performed in our experiments satisfy the condition of 'local muscular work'. Judging from the moderate increase of heart rate, steady rise of EMG 'slow wave ratio' to reach a maximum value at the all-out point and the localized muscular pain, the endurance is considered to be restricted by local factors in our experiment, although in back extension are involved not only the back muscles but also the hip and the leg ones.

As is obviously suggested by the decrease of EMG amplitude observed at the latter stage of exercise, the prolongation of the endurance time in our results might be primarily attributable to the shift of active part in the erectors spinae. This must be caused by unconscious changes in posture by the subject for all his effort to keep the initial one, presumably owing to muscular pain as well as to the fact that it was quite difficult to fix the pelvic region sufficiently. MORIOKA (1964) also found the decrease of EMG amplitude of the erectors spinae during lifting exercise accompanied by the shift of muscular activity from lumbar to shoulder part probably on account of severe lumbar pain.

The erectors spinae being composed of numerous muscles as described above, and therefore ready to give rise to an alternation of active ones, it is difficult to assess the exact endurance of indi-

vidual portion of them. However, supposing that the fatigue suffered in the present experiment is not general one developed in the whole body but, as the steady rise of 'slow wave ratio' is suggesting, local one originated in the erector spinae as a whole, the involuntary alternation of active muscles instead of recruiting new motor units of the same one as such might be the functional characteristic of the erector spinae in continuous static work. If speculations be allowed, there might exist some inhibitory mechanisms reflexly acting to prevent the excessive exhaustion of the back muscles. In view of the differentiation of functions of skeletal muscles demonstrated by TOKIZANE & SHIMAZU (1964), it seems not inconceivable that the E-T relations differ among muscles.

It seems noteworthy that, as shown in Fig. 2, two groups of subjects are distinguishable as to the limit time value at lower tension, that is, in one group the maximum endured time was around 10 minutes at the tension of 30% max., while in the other it exceeded 30 minutes at the same tension. The former correspond to those endowed with superior maximum strength, the latter with inferior one. These results make us suspect that the static muscular effort performed at the tension in an identical ratio to the maximum strength does not necessarily provide the uniform work load for each individual. At present, however, it is impossible to explain the above supposition evidentially but only to assume that the degree of intra-muscular blood

occlusion during contraction might be different among individuals.

Since it was shown that the activity of the erector spinae in easy standing was less than 2-3% of that accompanying a maximum effort, the physiological load of upright posture is to be evaluated as low enough in regard of the E-T relations. However, in the case of the forward bending position or of the dynamic posture during rising from the latter in particular, the activity of these muscles are vigorous enough to imply a severe loading in these postures. In addition, as being anti-gravity muscles, the erector spinae make the eccentric contractions not infrequently, in which the strength beyond that of the concentric one can be exerted as reported by SINGH & KARPOVICH (1966), thus leading in consequence to a rupture or other impairments in the structures of the vertebral column.

SUMMARY

In order to assess the physiological load suffered by the erector spinae muscles in standing posture as the basis of man's physical activities, their enduring capacity for sustained back extension was investigated in 8 subjects at the tensions of 70, 50, 40 and 30% of the maximum strength. A specially devised dynamometer, which was so designed as to eliminate the influence of the upper body weight, was employed for the exercise. Simultaneously, the activity of the erector spinae at the dynamometer exercise as well as in stand-

ing position including forward bending was examined by 'global' EMG, to which were applied a digital integration and an automatic frequency analysis.

1) The maximum strength exerted by subjects in the back extension ranged between 70 and 110 kg, short of the 'lifting strength' by 30-40%.

2) A linear correlation was proved between the logarithm of the maximum endured time and that of the tension expressed in ratio to the maximum strength. Endurance time was relatively longer especially at lower tensions as compared with those reported by the other authors, yet local muscular pain generally appeared already before the half of endured time. The critical tension for a prolonged sustenance of 10 or 20 minutes was supposed to be 20-30% max.

3) Increase of heart rate, as monitored by ECG, was moderate in the exercise. At the tensions of 70, 50, 40 and 30% max., it reached 120-160, 100-140, 90-130 and 80-120 per minute respectively.

4) Mean amplitude of EMG was fairly proportional to the force exerted in the back extension.

5) Although the EMG amplitude increased to some extent at early stage of endurance, it rather decreased persistently at latter one in majority of cases. It was considered as suggesting the alternation of active part in the erectors spinae, owing to involuntary changes of posture on account of muscular pain. On the other hand, the slowing of EMG progressed steadily as the extension endured.

6) In standing position, the electrical

activity of the erectors spinae varied with the degree of forward bending. In reference to the relations between the tension and the EMG amplitude, the tension endured by them without added load proved to be less than 2-3% of the maximum at an upright position, and at most 20% max, in forward bending at 45-60 degrees.

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体幹直立筋の静的持久能について

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ヒトの身体的活動の基礎としての起立姿勢に伴う生体負担を評価するためには、姿勢保持に関与する筋の持久性を知る必要がある。著者らは体幹直立筋の静的持久能を知る目的で側臥式体幹伸展用ダイナモメーターを作製し、男子被検者8名につき前屈30°での最大筋力測定及び最大筋力比70, 50, 40, 30%の静的伸展負荷における最大持久時間、心拍数、EMG、筋痛の出現等についてしらべた。EMGは表面電極を用いてL4レベルより記録し、デジタル積分装置による積分処理及び自動周波数分析を行った。さらに立位において前屈度を段階的に変えた場合の筋負荷についてEMGから評価することを試みた。

1) 側臥体幹伸展における最大筋力は70-110 kgであり、いわゆる背筋力(lifting strength)より30-40%低い値を示した。

2) 伸展負荷強度(最大筋力比)と持久時間の関係は両対数ではほぼ直線になるが、従来の報告に比しとくに低負荷において持久時間が多少延長する傾向がみられた。

3) 筋痛出現時間はいたみ判定の個人差によるバラツキが大きく、伸展強度、EMGとの間に一定の関係を見出すことができなかったが、一般に持久時間の半ばに至る以前に出現することが多かった。

4) 心拍数は最大筋力比70%で150, 50%で130, 30%で120どまりであつた。30%ではplateauに達する。

5) EMG平均振幅は伸展強度にほぼ比例する。各負荷強度での持口中、振幅は一応増えるが増え方は大きくなく途中からむしろ減少することが多い。これは筋痛による不随意的姿勢変化に伴う直立筋の活動交代によるものと思われる。

6) 一方、EMG徐波比(0-40 Hz/40-120 Hz)は各負荷強度において持久とともに直線的に増加した。

7) 立位においては姿勢によりEMGの出方は異なるが、直立位より前屈を強めるに従い振幅は漸増し、前屈約60°付近で最大となり、90°で減弱し最大前屈では全く消失する。これを張力-EMG振幅関係からみると、直立位では最大筋力比2-3%以下、60°付近で20%以下の負荷に相当すると考えられる。