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CARDIOVASCULAR RESPONSES TO BRIEF STATIC CONTRACTIONS IN MAN WITH TOPICAL NERVOUS BLOCKADE

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SUMMARY

1. We tested the hypothesis that afferent nerves from working muscles are important in determining the heart rate and blood pressure responses to brief maximal static exercise.

2. In twenty human subjects, the heart rate and arterial blood pressure responses to a brief maximal voluntary handgrip were studied before and after axillary nerve anaesthesia or to maximal one-leg knee extension before and after epidural anaesthesia at L3–L4. Maximal knee extension could not be acomplished without performing a 'Valsalva-like' manoeuvre, but during handgrip it was possible to avoid the use of muscles other than those directly involved in the contraction. Heart rate and blood pressure were also monitored during a Valsalva manoeuvre of similar duration to the maximal voluntary contractions (4 s).

3. During handgrip with normal breathing, axillary nerve anaesthesia reduced the heart rate response but had no effect on the blood pressure response.

4. During a Valsalva manoeuvre, blood pressure increased but heart rate remained stable as long as expiratory pressure was maintained. During one-leg knee extension, epidural anaesthesia reduced the blood pressure response; however, the reduction in blood pressure was probably due to a reduction in the simultaneously performed 'Valsalva-like' manoeuvre.

5. The results of this study suggest that afferent input from the working muscles is of importance for the heart rate responses to brief static muscle contractions. That such influence may be important for the blood pressure response remains unproven.

INTRODUCTION

At the onset of a strong isometric (static) muscle contraction, heart rate increases and even the first heart beat comes faster (Hollander, 1975; Secher, 1985; Iwamoto, Mitchell, Mizuno & Secher, 1987). Vagal withdrawal is the efferent limb of this initial heart rate response (Freyschuss, 1970; Hollander, 1975). Because of the rapid onset Krogh & Lindhard (1913) proposed a purely central (cortical) origin of the heart rate

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response during dynamic exercise. However, sensory impulses arising in the contracting muscles may also be of importance since electrically stimulated muscle contractions elicit a heart rate response similar to that of voluntary contractions, although delayed one heart beat (Iwamoto *et al.* 1987).

Static exercise is also associated with an increase in blood pressure of very rapid onset (Freyschuss, 1970; Freund, Rowell, Murphy, Hobbs & Butler, 1979; Iwamoto *et al.* 1987). Freund *et al.* (1979) found that the blood pressure response to static leg contractions decreased in proportion to the reduction in muscle tension during epidural anaesthesia which induced sensory and motor blockade. On the other hand, electrically induced leg muscle contractions elicit only a small (11 mmHg) increase in blood pressure as compared with the voluntary contractions (61 mmHg) (Iwamoto *et al.* 1987), showing that the larger part of the blood pressure response is generated outside the contracting muscles. During voluntary contractions with partial neuromuscular blockade (Freyschuss, 1970; Iwamoto *et al.* 1987) the blood pressure response is reduced to approximately 50% of the normal response, arguing for the view that both central and reflex mechanisms are of importance.

In our studies, brief maximal leg muscle contractions cannot be performed without the subject simultaneously performing a 'Valsalva-like' manoeuvre. We, therefore, have monitored the effect of topical nervous blockade on the blood pressure and heart rate responses to static handgrip contractions where normal breathing was maintained throughout the contraction and the subjects were instructed not to tense muscles other than those directly involved in the handgrip. In addition, we monitored the blood pressure and heart rate responses in subjects performing maximal one-leg knee extensions with epidural anaesthesia. The results were compared with those seen during a Valsalva manoeuvre.

METHODS

Twenty healthy male and female subjects were studied, nine during one-leg knee extension and eleven during a unilateral handgrip each lasting 4 s. Their mean age was 26 years (range, 21–39 years), weight 75 kg (range, 58–89 kg) and height 178 cm (range, 168–193 cm). All were informed of the risks involved with the participation in the experiment before they gave verbal consent. The study was approved by the Municipal Ethical Committee of Copenhagen.

The experiments were carried out with the subject lying in a semi-supine position with the head-end of the table elevated to 20 deg. During knee extension the exercising leg was placed over the edge of the table in a vertical position with the foot dependent and the knee flexed at 90 deg. The leg was connected to a strain-gauge dynamometer with a strap above the ankle joint (Leonard, Mitchell, Mizuno, Rube, Saltin & Secher, 1985). Handgrip contractions were performed with the dominant arm using a strain-gauge dynamometer as described by Asmussen, Heebøll-Nielsen & Molbech (1959). A Peekel measuring bridge was used and force displayed on a Mingograf recorder.

For all studies heart rate was calculated beat-per-beat (R−R intervals) from a continuous electrocardiogram and recorded together with force, arterial blood pressure, respiration and electromyographic activity. For the leg contractions, a 1 mm arterial cannula was placed in the brachial artery of the non-dominant arm. In the handgrip contractions, a 1·2 mm cannula placed in the right femoral artery was used. Pressure was recorded by means of a Bentley transducer (800) positioned at heart level in the mid-axillary line and connected to a Simonsen & Weel machine (8041). Mean arterial pressure was calculated as one-third of the systolic pressure plus two-thirds of the diastolic pressure. Respiratory excursions were recorded using a strain-gauge pneumograph.

Electromyographic activity on the right thigh was recorded during a handgrip by means of surface electrodes and a DISA EMG amplifier ISOI.

In the handgrip study, axillary anaesthesia was established by the use of a 1 mm catheter placed in the perivascular space at the lateral border of the pectoral muscle. After control contractions, 37 ml 1% lidocaine (Xylocaine®, Astra) was given through the catheter. In addition, 3 ml 1% lidocaine was given as a radial block at the level of the elbow in order to secure anaesthesia on both sides of the forearm. The block was tested by pin prick. The force of the handgrip was monitored every fifth minute until control strength was re-established.

In the one-leg knee extension study, epidural anaesthesia was established by the use of a 20-gauge spinal needle inserted in the epidural space through the vertebral interspace L3–L4 employing the 'loss of resistance' technique. Epidural anaesthesia was induced by injection of 24 ml 1% lidocaine through the needle. In all studies, approximately $\frac{3}{4}$ l physiological saline was administered intravenously. The sensory loss was tested on both sides of the body by the pin-prick method. The force of one-leg knee extension was monitored every fifth minute until control strength was re-established.

Maximal one-leg knee extension was performed with both the right and left leg and the results averaged. In both handgrip and leg contractions, the values reported represent the average of three maximal contractions performed during control and after maximal reduction of muscle strength with epidural or with combined axillary and radial block. The subjects were instructed to breathe normally and not to tense other muscles than those directly involved in the handgrip. A few cases of handgrip contractions where normal breathing was not maintained or where electromyographic activity was detected in the leg were excluded.

A Valsalva manoeuvre was performed in eight of the subjects by exhaling in a tube connected to a manometer and keeping a pressure of 30 mmHg for approximately 4 s.

Values presented represent means $\pm$ S.E. of the mean. Friedmann's test was used to determine if significant changes occurred with time (Siegel, 1956) and such changes were then located by the multiple comparison procedure. Wilcoxon's ranking test (Pratt's modification) was used to evaluate differences between control experiments and experiments with local anaesthesia. Correlation coefficients were calculated according to the least-squares method. A P value of 0·05 was considered significant.

RESULTS

Handgrip contraction

After axillary and radial anaesthesia, parasthesia was present on both sides on the forearm. The force of maximal handgrip contractions was reduced from 491 N (range, 373–638 N) to 40% (range, 15–80%) of control. Heart rate and mean arterial pressure were similar at rest, before and after administering local anaesthesia: 66 ± 2 *vs.* 67 ± 2 beats min^{-1} and 97 ± 4 *vs.* 95 ± 3 mmHg, respectively (Fig. 1). During the handgrip contractions heart rate increased in the first cardiac cycle after the onset of both types of contractions ($P < 0{\cdot}05$), but the maximal increase in heart rate was largest during the control contractions: 19 ± 2 *vs.* 10 ± 2 beats min^{-1} ($P < 0{\cdot}01$). After exercise heart rate decreased with a one beat delay toward the resting value. Under both circumstances blood pressure increased immediately at the onset of the contraction ($P < 0{\cdot}01$), but in contrast to the heart rate response the maximal increase in mean arterial pressure was similar: 10 ± 2 *vs.* 10 ± 1 mmHg before and after local anaesthesia. After the contraction mean blood pressure decreased to the resting value over a few heart beats.

When the increase in heart rate is plotted against the remaining force of handgrip contractions after axillary and radial anaesthesia, the heart rate response is reduced as the strength is reduced (Fig. 2). The r value for the increase in heart rate is 0·66 ($P < 0{\cdot}05$). However, when the increase in blood pressure is plotted against the

remaining force, the blood pressure is not affected as the strength is reduced (Fig. 2). The r value is 0·56 (not significant).

One-leg knee extension

After epidural anaesthesia cutaneous parasthesia was present to T11–T12 on both sides of the body. The force of maximal one-leg extension was reduced from 224 N m (range, 102–357 N m) to 47% (range, 34–85%) of the control. There was no effect

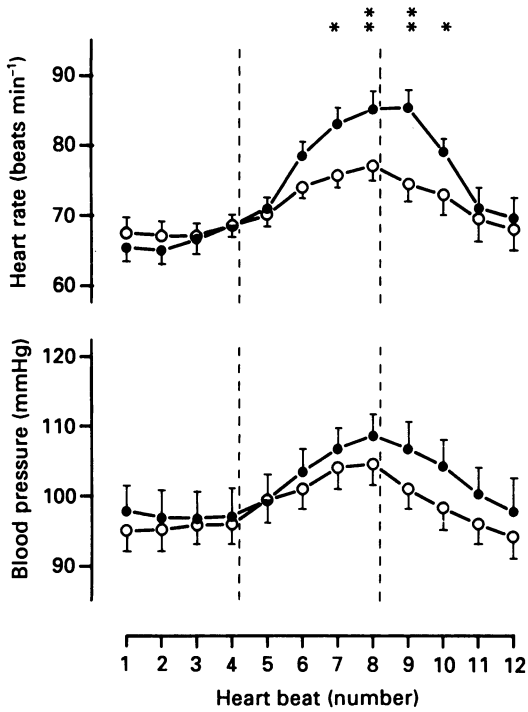

Fig. 1. Heart rate and mean arterial pressure followed during a 4 s maximal voluntary unilateral handgrip. ●, control; ○, local anaesthesia. Values are mean ± S.E. of mean, $n = 11$. In comparison between control and axillary anaesthesia, $*P < 0·05$; $**P < 0·01$.

of epidural anaesthesia on resting heart rate (control *vs.* epidural, 71 ± 4 *vs.* 69 ± 4 beats min^{-1}) and arterial pressure (94 ± 3 *vs.* 96 ± 4 mmHg) (Fig. 3). During one-leg knee extension an immediate increase ($P < 0·01$) was seen in heart rate under both circumstances and the increases were similar with maximal values of 82 ± 4 and 80 ± 3 beats min^{-1}, respectively. After the end of the contraction heart rate continued to increase under both circumstances, but the increase was significant ($P < 0·01$) only after the control contractions.

Mean arterial pressure increased immediately ($P < 0·01$) at the onset under both circumstances, but the increase was larger in contractions during the control than during epidural anaesthesia: 40 ± 4 *vs.* 30 ± 4 mmHg ($P < 0·01$), respectively. After exercise mean arterial pressure decreased almost immediately reaching a level below the resting value for a short period.

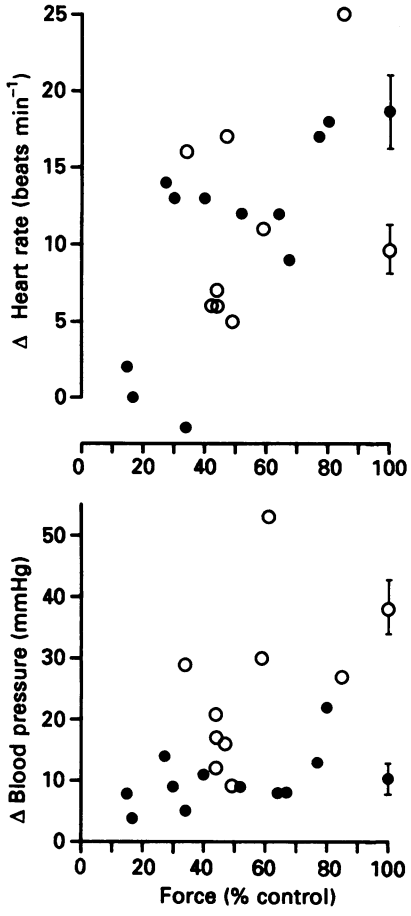

Fig. 2. Increase in heart rate (upper panel) and mean arterial pressure (lower panel) during a 4 s handgrip or one-leg knee extension related to the strength remaining after motor block by local anaesthesia. ●, handgrip; ○, knee extension. For handgrip, heart rate: $y = 0{\cdot}4 + 1{\cdot}1x$, $r = 0{\cdot}66$ ($P < 0{\cdot}05$); blood pressure: $r = 0{\cdot}56$ (not significant). Values given corresponding to 100% control represent the mean ± S.E. of mean of the responses seen in the control experiments.

If the increase in heart rate is plotted against the remaining force of one-leg knee extension, the heart rate responses are quite variable (Fig. 2). However, when the increase in blood pressure is plotted against the remaining force, the blood pressure response is reduced (Fig. 2).

Valsalva manoeuvre

The Valsalva manoeuvre did not affect heart rate for as long as expiratory pressure was maintained but an increase in heart rate of 10 ± 4 beats min^{-1} was seen after the manoeuvre ($P < 0{\cdot}05$, Fig. 4). Mean arterial pressure increased immediately ($P < 0{\cdot}01$) at the onset of the Valsalva manoeuvre (Fig. 4), but tended to return towards the resting value in the fourth cardiac cycle. The increase averaged

16±3 mmHg ($P < 0.01$) during the manoeuvre and after exercise the pressure fell promptly to a level below the resting value for a few heart beats.

DISCUSSION

The blood pressure response to static leg exercise was reduced by epidural anaesthesia as also reported by Freund *et al.* (1979). However, most probably the blood pressure response to one-leg knee extension was dominated by a con-

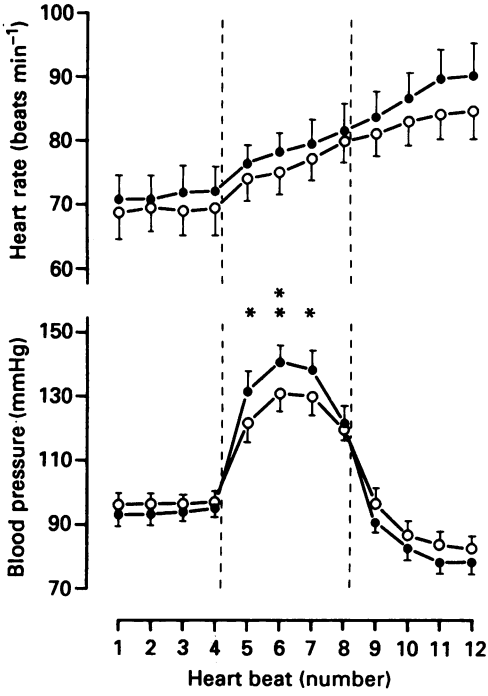

Fig. 3. Heart rate and mean arterial pressure followed during a 4 s maximal voluntary one-leg knee extension. ●, control; ○, epidural anaesthesia. Values are mean±S.E. of mean, $n = 9$. In comparison between control and epidural anaesthesia, $*P < 0.05$; $**P < 0.01$.

comitantly performed 'Valsalva-like' manoeuvre (Lind, 1983). As shown in the present study (Fig. 4), an inadvertent Valsalva manoeuvre will have significant influence on the blood pressure, but not on the heart rate response to static exercise. Indirectly, this conclusion is supported by the finding that blood pressure, as during the Valsalva manoeuvre, tended to decrease towards the end of the knee extension (Fig. 2). If metabolites in the working muscles were dominating the pressure response we would expect blood pressure to continue to increase throughout the contraction as seen during handgrip. Furthermore, as after the Valsalva manoeuvre, heart rate continued to increase after the end of the one-leg extension, but rapidly decreased toward the resting value after the handgrip. It should also be mentioned

that maximal electrical stimulation of leg muscles induces only a small increase in blood pressure compared with voluntary contractions (Iwamoto *et al.* 1987). These arguments suggest that the reduction in the blood pressure response to brief static leg exercise with epidural anaesthesia is due to a reduction in the subject's ability to perform a maximal Valsalva manoeuvre corresponding to the reduction in strength even of the abdominal muscles (Freund *et al.* 1979). With emphasis on normal breathing during a handgrip and without involvement of other muscles than those

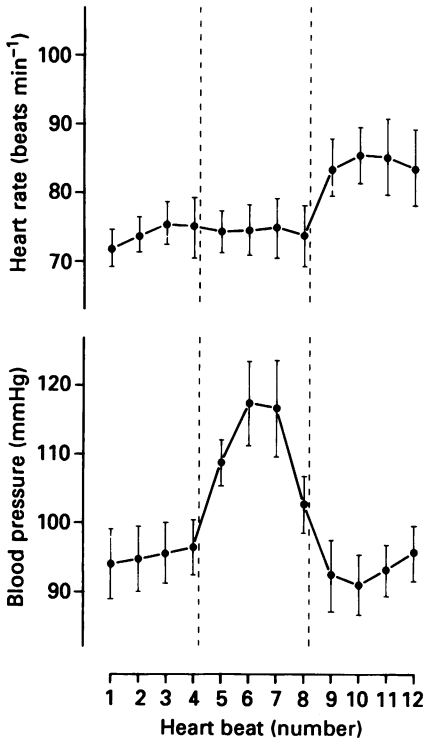

Fig. 4. Heart rate and mean arterial pressure followed during a 4 s Valsalva manoeuvre. Values are mean ± S.E. of mean, $n = 8$. In comparison with rest, $*P < 0{\cdot}05$; $**P < 0{\cdot}01$.

in the forearm, axillary anaesthesia did not affect the blood pressure response to brief handgrip contractions. Furthermore, the blood pressure response to a handgrip was not significantly reduced with the reduction in muscle strength (Fig. 2). It thus appears that sensory feed-back from contracting muscles has little if any effect on the blood pressure response to brief static muscular contractions.

A crucial point in interpreting the results of this study is an evaluation of the effectiveness of the applied topical anaesthesia in developing sensory nervous blockade. In the case of the axillary anaesthesia we have found that the cold pressor test is markedly attenuated or absent when the hand on the treated side is placed in ice-cold water (D. Friedman, in preparation). Also the reduction in handgrip strength indicates a simultaneous blockade of small myelinated and unmyelinated sensory fibres (De Jong, 1977). In the case of the epidural anaesthesia three

additional observations are relevant to the induced sensory blockade. First, the maintenance of blood pressure after dynamic exercise when an arterial cuff is inflated before the end of exertion (Alam & Smirk, 1937) is attenuated or eliminated by epidural anaesthesia (Freund *et al.* 1979; Kjaer, Secher, Bach, Mitchell & Galbo, 1988). Second, the β-endorphin response to dynamic exercise which is related to peripheral rather than to central neural mechanisms (Kjaer, Secher, Bach & Galbo, 1987) is eliminated by epidural anaesthesia (Kjaer *et al.* 1988). Finally, neurological examination of subjects after epidural anaesthesia reveals a gross impairment of deep pain and temperature perception.

The heart rate response to a brief static handgrip is dependent upon sensory feedback from the working muscles. However, during one-leg knee extension the heart rate response was not reduced by the nerve block. This finding may be explained by the involvement of muscles outside the blocked area during knee extension. Heart rate increased markedly in the first beat after onset of the knee extension only, while with handgrip a delay of one heart beat was seen before heart rate increased substantially. The discrepancy may be explained by the emphasis on maintaining normal breathing and not tensing muscles other than those of primary importance for the handgrip. Therefore, most probably, the handgrip may have been initiated less vigorously than the onset of one-leg knee extension. Thus, maximal handgrip is usually associated with an immediate approximately 9% increase in heart rate while submaximal contractions show a smaller or no increase in heart rate over the first cardiac cycle after the onset of the contraction (Secher, 1985).

The maximal handgrip with local anaesthesia reducing the force to 40% (average value) of control showed a mean increase in heart rate of 53% of the control response. This suggests that the response is dependent on muscle afferents. The importance of muscle afferent nervous activity for the heart rate response to static exercise in man has previously been demonstrated by electrical stimulation of muscles combined with partial curarization. With partial curarization and reduced muscle strength the heart rate response became smaller despite constant stimulation intensity (Iwamoto *et al.* 1987).

Further evidence that sensory input from the working muscles is important for the heart rate response to brief maximal contractions was obtained in the present study. If the increase in heart rate is plotted against the remaining force after topical anaesthesia (Fig. 2) it appears that the heart rate response diminishes with the reduction in strength. With a reduction in strength to approximately 20% of control obtained in two subjects, there was no increase in heart rate at all. If the reduction in muscle strength is taken to indicate the completeness of the block, these results suggest that no heart rate response would be seen with complete sensory block.

The present finding of a heart rate response to maximal voluntary contractions with topical nervous blockade which diminishes with reduction of muscle tension apparently contrasts with the observations made during partial curarization. With an intact sensory input from the muscles the heart rate response is constant despite reduction of muscle strength as long as the effort is kept constant (maximal) (Freyschuss, 1970; Secher, 1985; Iwamoto *et al.* 1987). Taken together these observations suggest that sensory input from the working muscles is needed to elicit

the central influence on the heart rate response. This was also suggested by Hobbs & Gandevia (1985) in discussing their findings that intended leg contractions in paraplegics are associated with no increase in heart rate and blood pressure while the increases were seen during handgrip in these patients, even with an anaesthetized arm.

In conclusion, the results of the present study are compatible with the hypothesis that afferent input from the working muscles is of importance for the heart rate response to brief static muscle contractions. That such influences may be important for the blood pressure response remains unproven.

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