Physiological responses to prompt and sustained squatting¹

Measurement by systolic time intervals

VERONICA Q. LANCE AND DAVID H. SPODICK

From the Cardiology Division, St. Vincent Hospital, and the Department of Cardiovascular Medicine, University of Massachusetts Medical School, Worcester, Massachusetts, U.S.A.

Ten healthy men, ages 22 to 35, were studied non-invasively standing (control), at the onset of squatting ('prompt squat'), and at two minutes of squatting. Squatting produced decreases in heart rate, isovolumic contraction time, pre-ejection period, and pulse transmission time, and increases in the time from onset of depolarisation to the first heart sound, left ventricular ejection time, and the ejection time index. These results of systolic time intervals are consistent with the bradycardia and increased ventricular filling induced by squatting. Major changes from control measurements were found at the onset of squatting, showing the impact of prompt squat on left ventricular performance.

Prompt squat, a simple non-invasive challenge which acutely increases venous return, stroke volume, and systemic arterial pressure, has been applied in diagnosing obstructive cardiomyopathy, intracardiac shunts, and variants of the click-murmur syndrome. A variety of haemodynamic measurements have been made in both normal subjects and patients with appropriate findings, while non-invasive cardiography during squatting has been confined to phonocardiography of murmurs (O'Donnell and McIlroy, 1962; Nellen *et al.*, 1967, 1968; Fontana *et al.*, 1975).

The purpose of this investigation was to define the physiological effects of prompt and sustained squatting as expressed by changes in systolic time intervals and to compare the responses with the established haemodynamic consequences of squatting.

Subjects and methods

Ten healthy men, ages 22 to 35, volunteered for this study. A normal electrocardiogram, chest x-ray, medical history, and physical examination, together with signed informed consent were prerequisites for participation in the investigation.

Subjects entered the laboratory in the morning in the post-absorptive state. After application of the

external electrodes and microphones, subjects were given a 20-minute supine rest period.

RECORDINGS

Tracings were recorded on an 8-channel Hewlett Packard optical recorder No. 568-100A and included a simultaneous electrocardiogram, phonocardiogram, and carotid pulse curve (Spodick and Quarry-Pigott, 1973).

Three sequential recordings were made on each subject: (1) during standing (2 minutes after the subject stood up), (2) onset of squatting ('prompt squat'), and (3) at 2 minutes of squatting ('sustained squat').

BLINDING

To prevent observer bias, measurements were made separately and without knowledge of the results of the other recordings for each subject.

MEASUREMENTS

Five beats were measured on each of the 3 recordings for each subject. Time was measured from the 'q' wave on the electrocardiogram (zero point for all measurements) to the mitral component of the first heart sound ($q-I_m$), the second heart sound (II_A), the carotid upstroke (CAR_u), and the carotid incisura (CAR_{in}). The preceding RR interval of each beat measured was also determined. Heart rate and systolic time intervals were calculated from these points as previously described (Spodick and Quarry-Pigott, 1973).

¹Supported by a grant from the National Aeronautics and Space Administration.

STATISTICAL ANALYSIS

The mean values of the 5 beats measured for each subject during each of the 3 conditions (standing control, prompt squat, and sustained squat) were analysed.

The t test for paired comparisons was used to compare standing vs. onset of squatting, standing vs. 2 minutes of squatting, and onset of squatting vs. 2 minutes of squatting.

Results

Results are summarised in Tables 1 and 2.

Table 1 *Effects of prompt and sustained squatting*

		Standing	Squat onset	Squat 2 min
HR	$\bar{X}$	76.2	69.8	62.0
	SD	± 9.24	± 6.16	± 4.11
	SE	± 2.92	± 1.95	± 1.30
q-I _m	$\bar{X}$	58.3	66.8	67.0
	SD	± 5.14	± 10.04	± 12.25
	SE	± 1.63	± 3.18	± 3.87
IVCT	$\bar{X}$	81.8	47.9	60.3
	SD	± 5.47	± 12.78	± 9.72
	SE	± 1.73	± 4.04	± 3.07
PEP	$\bar{X}$	140.1	114.7	127.3
	SD	± 7.68	± 10.13	± 9.27
	SE	± 2.43	± 3.20	± 2.93
LVET	$\bar{X}$	232.2	277.8	290.1
	SD	± 19.79	± 19.05	± 14.98
	SE	± 6.26	± 6.02	± 4.74
ETI	$\bar{X}$	323.7	361.6	364.5
	SD	± 11.47	± 16.65	± 13.88
	SE	± 3.63	± 5.27	± 4.39
PEP/LVET	$\bar{X}$	0.607	0.414	0.441
	SD	± 0.0598	± 0.0414	± 0.0407
	SE	± 0.0189	± 0.0131	± 0.0129
PTT	$\bar{X}$	39.3	37.8	35.0
	SD	± 7.56	± 5.69	± 7.10
	SE	± 2.39	± 1.80	± 2.25

HEART RATE (FIGURE)

Subjects showed a mean, statistically insignificant, decrease in heart rate of -6.4 beats per minute at the onset of squatting (standing vs. onset squat: $P > 0.05$). Individual changes varied; e.g. 2 subjects had large rate reductions of -21 and -24 beats respectively, 3 subjects showed a decrease of only 1 beat per minute, 1 subject had no change, and another showed an increase of 4 beats per minute. However, when standing heart rate was compared with sustained squatting, uniform decreases resulted among all 10 subjects (mean decrease of -14.2 beats per minute; $P < 0.001$). This uniform decrease in heart rate was also apparent when prompt squat was

Table 2 *Comparison between values observed standing, at onset of squatting, and after squatting at 2 minutes*

		Standing vs squat onset	Standing vs squat 2 min	Squat onset vs squat 2 min
HR	mean Δ	- 6.4	- 14.2	- 7.8
	T	- 2.1624	- 4.7880	- 4.6284
	P	> 0.05	< 0.001	< 0.002
q-I _m	mean Δ	+ 8.5	+ 8.7	+ 0.2
	T	2.5071	2.0318	0.0700
	P	< 0.05	> 0.05	> 0.8
IVCT	mean Δ	- 33.9	- 21.5	+ 12.4
	T	- 7.0671	- 5.1866	3.5789
	P	< 0.001	< 0.001	< 0.01
PEP	mean Δ	- 25.4	- 12.8	+ 12.6
	T	- 9.5072	- 5.7142	4.0751
	P	< 0.001	< 0.001	< 0.005
LVET	mean Δ	+ 45.6	+ 57.9	+ 12.3
	T	15.8770	16.6458	5.9852
	P	< 0.001	< 0.001	< 0.001
ETI	mean Δ	+ 37.9	+ 40.8	+ 2.9
	T	11.0181	16.6627	1.7800
	P	< 0.001	< 0.001	> 0.1
PEP/LVET	mean Δ	- 0.193	- 0.166	+ 0.027
	T	- 10.8248	- 12.7567	2.5350
	P	< 0.001	< 0.001	< 0.05
PTT	mean Δ	- 1.5	- 4.3	- 2.8
	T	- 0.8527	- 5.0952	- 1.6813
	P	> 0.2	< 0.001	> 0.1

compared to 2 minutes of squatting (mean decrease of -7.8 beats per minute; $P < 0.002$).

Q-I_m

The initial increase in q-I_m from standing to onset of squatting was statistically significant ($P < 0.05$) while the comparison of standing vs. squatting at 2 minutes was not ($P > 0.05$). The actual differences among these comparisons, however, are very small: the mean increase for standing vs. onset of squatting was $+8.5$ ms ($t=2.5071$) while the mean increase for standing vs. 2 minutes of squatting was $+8.7$ ms ($t=2.0318$). In both cases 2 of the 10 subjects showed decreases in q-I_m while 8 showed increases. The scatter, however, was greater for standing vs. 2 minutes of squatting. The comparison of q-I_m at the onset of squatting vs. 2 minutes of squatting, showed no difference ($P > 0.8$).

ISOVOLUMIC CONTRACTION TIME

All comparisons were statistically significant and all subjects uniformly showed changes in the direction of the mean change with only one exception (i.e. 9 subjects showed decreases in isovolumic contraction time from standing to 2 minutes of squatting, but 1 subject showed a small increase of $+2$ ms).

Fig. Changes in principal measurements from standing control to prompt and sustained squatting. HR=heart rate. PEP=pre-ejection period. ETI=ejection time index. PEP/LVET=ratio of pre-ejection period to left ventricular ejection time.

The mean decrease in isovolumic contraction time from standing to onset of squatting was -33.9 ms ($P < 0.001$); the mean decrease from standing to 2 minutes of squatting was -21.5 ms ($P < 0.001$); the mean increase from onset of squatting to 2 minutes of squatting was $+12.4$ ms ($P < 0.01$).

PRE-EJECTION PERIOD (PEP) (FIGURE)

All comparisons for pre-ejection period were statistically significant and all but one subject showed directional changes which were consistent with the mean change (the one exceptional subject showed no change from onset to two minutes of squatting). The mean decrease from standing to onset of squatting was -25.4 ms ($P < 0.001$); the mean decrease from standing to 2 minutes of squatting was -12.8 ms ($P < 0.001$); the mean increase from onset to 2 minutes of squatting was $+12.6$ ms ($P < 0.005$).

LEFT VENTRICULAR EJECTION TIME (LVET)

Left ventricular ejection time progressively increased from standing to onset of squatting to 2 minutes of squatting. All subjects, without ex-

ception, showed increased ejection time and all comparisons were statistically significant ($P < 0.001$): the mean increase from standing to onset of squatting was $+45.6$ ms; from standing to squatting at 2 minutes was $+57.9$ ms; from onset to 2 minutes of squatting was ± 12.3 ms.

EJECTION TIME INDEX (FIGURE)

When left ventricular ejection time was corrected for heart rate, the results show uniformly significant increases for standing vs. onset of squatting (mean increase $+37.9$ ms; $P < 0.001$) and for standing vs. 2 minutes of squatting (mean increase $+40.8$ ms; $P < 0.001$). The comparison of onset of squatting vs. 2 minutes of squatting showed no significant difference (mean change $+2.9$ ms; $P > 0.1$ —with individual changes ranging from $+10$ to -7 ms).

PEP/LVET (FIGURE)

All subjects showed decreases in PEP/LVET for standing vs. onset of squatting (mean decrease -0.193 ; $P < 0.001$) and for standing vs. 2 minutes of squatting (mean decrease -0.166 ; $P < 0.001$). The small difference ($+0.027$) between onset of squatting and 2 minutes of squatting was less significant ($P < 0.05$); here 6 subjects showed increases ranging from $+0.02$ to $+0.08$, 2 subjects showed no change, and 2 showed decreases of -0.01 .

PULSE TRANSMISSION TIME

The decrease in pulse transmission time from standing to 2 minutes of squatting was significant (mean decrease -4.3 ; $P < 0.001$) but the other two comparisons were not (standing vs. onset of squatting -1.5 ms; $P > 0.2$ and onset of squatting vs. 2 minutes of squatting -2.8 ms; $P > 0.1$).

Discussion

Our subjects' decreases in heart rate represent the expected bradycardia which occurs with squatting (O'Donnell and McIlroy, 1962; Nellen *et al.*, 1967, 1968; Fontana *et al.*, 1975). The large increases in ejection time were clearly disproportionate to the decreases in rate (Figure), as further documented by the increase in ejection time index, i.e. when heart rate effects on LVET were accounted for, the resultant index still shows a large increase over standing control with prompt squat and this was sustained over 2 minutes of squatting. Thus, the increases in ejection time are not solely the result of the squatting bradycardia, in which case the ejection time index would be stable (Weissler *et al.*, 1969), but appear also to reflect the known increases in stroke volume with squatting (O'Donnell and McIlroy, 1962; Nellen *et al.*, 1967).

The pre-ejection period is comprised of $q-I_m$ and the isovolumic contraction time. Changes in $q-I_m$ are small compared with those in isovolumic contraction time and the similarity in results of the contraction time and the pre-ejection period clearly suggest the dominant influence of the duration of isovolumic contraction time on the pre-ejection period during squatting. The pronounced reductions in these 2 intervals, with the increases in ejection time index are typical of stroke volume increases (Lewis *et al.*, 1974) and indicate a Starling effect via increased venous return. During sustained squatting reductions in the isovolumic contraction and pre-ejection periods from standing control levels were not as great as those seen at the onset. Changes in venous return, contractility, and after-load could all influence this change but invasive procedures would be required for further documentation.

There was a mean decrease in pulse transmission time at the onset of squatting. While chronic shortening of pulse transmission time in conditions such as atherosclerosis is well known and understood, reasons for changes in pulse transmission time during acute interventions remain more obscure. Among the many challenges investigated in our laboratory, the pulse transmission time has nearly always remained stable despite large changes in heart rate and systolic time intervals (Lance and Spodick, 1975). The largest exception in our experience occurred with isometric exercise (Quarry and Spodick, 1974). Since diastolic pressure increases significantly with isometric exercise but not with many of the other challenges investigated, it was suggested in previous investigations that increases in arterial diastolic pressure might be influential in effecting the decrease in pulse transmission time (Lance and Spodick, 1975). Since diastolic pressure tends to increase with squatting (Nellen *et al.*, 1967), this same relation may again be suggested.

Finally, the overall effects of prompt versus more

prolonged squatting must be considered. Nellen *et al.*, in studying the effect on the systolic murmur in hypertrophic obstructive cardiomyopathy, report that squatting had to be prompt to achieve the optimum results (Nellen *et al.*, 1967, 1968). While our results for heart rate and pulse transmission time indicate that not all maximal values are achieved at the onset of squatting, the greatest changes do occur promptly.

References

- Fontana, M. E., Wooley, C. F., Leighton, R. F., and Lewis, R. P. (1975). Postural changes in left ventricular and mitral valvular dynamics in the systolic click-late systolic murmur syndrome. *Circulation*, **51**, 165-173.
- Lance, V. Q., and Spodick, D. H. (1975). Constant-load versus heart rate targeted exercise: responses of systolic intervals. *Journal of Applied Physiology*, **38**, 794-800.
- Lewis, R. P., Leighton, R. F., Forester, W. F., and Weissler, A. M. (1974). Systolic time intervals. In *Noninvasive Cardiology*, pp. 301-368. Ed. by A. M. Weissler. Grune and Stratton, New York.
- Nellen, M., Gotsman, M. S., and Schrire, V. (1968). The influence of certain drugs and of prompt squatting on the systolic murmur in hypertrophic obstructive cardiomyopathy. *American Heart Journal*, **76**, 295-296.
- Nellen, M., Gotsman, M. S., Vogelpoel, L., Beck, W., and Schrire, V. (1967). Effects of prompt squatting on the systolic murmur in idiopathic hypertrophic obstructive cardiomyopathy. *British Medical Journal*, **3**, 140-143.
- O'Donnell, T. V., and McIlroy, M. B. (1962). The circulatory effects of squatting. *American Heart Journal*, **64**, 347-356.
- Quarry, V. M., and Spodick, D. H. (1974). Cardiac responses to isometric exercise. Comparative effects with different postures and levels of exertion. *Circulation*, **49**, 905-920.
- Spodick, D. H., and Quarry-Pigott, V. M. (1973). Effects of posture on exercise performance. Measurement by systolic time intervals. *Circulation*, **48**, 74-78.
- Weissler, A. M., Harris, W. S., and Schoenfeld, C. D. (1969). Bedside technics for the evaluation of ventricular function in man. *American Journal of Cardiology*, **23**, 577-583.

Requests for reprints to Dr. D. H. Spodick, Division of Cardiology, St. Vincent Hospital, 25 Winthrop Street, Worcester, Massachusetts 01604, U.S.A.