The Double-Product-Break-Point Derived from Measurements with a Digital Automatic Sphygmomanometer

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Abstract. Previous studies have used an exercise stress testing blood pressure (BP) monitor to detect the double product break point (DPBP). However, not all clinical sites of physical therapy are equipped with an exercise stress testing BP monitor. Digital automatic blood pressure monitors (portable sphygmomanometer), which come in more compact, portable models, are becoming more common at general clinical sites. The purpose of this study was to investigate whether a portable sphygmomanometer can be used to derive the DPBP in healthy adults. Exercise stress tests were conducted on 11 healthy adults (8 male, 3 female), using a portable sphygmomanometer and ergometer. To investigate the double product (DP) reproducibility in derivation of DPBP by the portable sphygmomanometer, we repeated the exercise trials within one week. Moreover, using an exercise testing BP monitor, the exercise stress protocol was conducted again within 3 weeks under the same conditions. The results show that DP at DPBP calculated from measurements with a portable sphygmomanometer in the first and second exercise trials with the portable sphygmomanometer were 17084.9 ± 1109.4 and 17131.1 ± 979.2 mmHg × bpm, with an intraclass correlation coefficient of 0.84. The DP at DPBP calculated using measurements from an exercise stress testing BP monitor was 17533.9 ± 1459.2 mmHg × bpm, and the correlation coefficient with the DP value of the second trials with the portable sphygmomanometer was r = 0.80. The results of this study suggest that a comparatively accurate DPBP can be derived using a portable sphygmomanometer.

Key words: Double product break point reproducibility, Digital automatic sphygmomanometer

INTRODUCTION

The anaerobic threshold (AT) determined by expired gas analysis and the lactate threshold (LT) obtained by lactate measurement are useful not only for the measurement of physical fitness in athletes but also as indices of health in middle-aged and older individuals, and of optimal exercise intensity in patients with diabetes mellitus, ischemic heart disease, or stroke1–6). However, these approaches require an expensive expired gas analyzer and frequent blood sampling, and thus are difficult to implement at clinical sites of physical therapy.

Tanaka et al.7) developed the double-product break point (DPBP) method, which does not need expiration gas analysis for estimating AT and LT. The double-product (DP) is calculated as the product of heart rate (HR) and systolic blood pressure (SBP). When the independent variable is time or intensity of exercise during an incremental
exercise test and the dependent variable is DP, the intersection of two linear regression lines is be identified as the DPBP, the point at which the DP increases sharply during exercise. The intersection has been reported to be largely consistent with AT and LT determined by expired gas analysis. Because of its strong correlation with myocardial oxygen consumption and exponential increase with increasing exercise intensity, DP is used as an indirect index of myocardial workload during exercise. Tanaka et al.\textsuperscript{7} reported that the correlation coefficient between DPBP and LT or AT was 0.90, and Riley et al.\textsuperscript{8} reported that it was 0.86.

Previous studies using DPBP as an index have used high-precision blood pressure monitors such as non-invasive exercise testing blood pressure monitors that are resistant to vibrations and noises occurring during exercise\textsuperscript{7, 8}. However, these blood pressure monitors are not always available at clinical site of physical therapy, and the DPBP method is not commonly used in clinical practice of physical therapy. In contrast, digital automatic sphygmomanometers (portable sphygmomanometer), which come in more compact, portable models, are becoming more common at general clinical sites. No report has addressed the reproducibility of DPBP determined measurements from with an upper-arm automatic digital sphygmomanometer, and the purpose of this study was to attempt DPBP derivation using a digital automatic sphygmomanometer in healthy adults. The obtained DPBP was to compared the DPBP derived using an exercise test BP monitor.

\textbf{METHODS}

\textit{Subjects}

The study subjects were 11 healthy adults (8 men and 3 women). The investigation conformed to principles outlined in the Declaration of Helsinki and was approved by the Human Research Ethics Committee of Kunisada hospital. Written informed consent was obtained from all subjects before their participation.

The means and standard deviations of age, height, body weight, and body mass index (BMI) were 24.1 \pm 2.6 years, 164.3 \pm 11.6 cm, 58.3 \pm 18.2 kg, and 21.2 \pm 4.6 kg/m\textsupersquare{2}, respectively. The means and standard deviations of SBP, HR, and DP at rest were 115.3 \pm 8.9 mm Hg, 68.2 \pm 3.9 beats, and 8808.8 \pm 702.4 mm Hg \times \text{beats}, respectively. None of the subjects were on any form of medication, consumed alcohol, or smoked. The experiments were performed no sooner than 3 h after a meal and 12 h after ingestion of caffeine. The tests were performed in a temperature-controlled room (24°C, relative humidity 50%).

\textit{Exercise protocol}

Exercise tests were performed on a portable ergometer (Rehab Trainer 881E; Monark). The protocol of the stepwise exercise test involved sitting at rest for 5 min, warming up at 0 W for 3 min, and exercise at an initial intensity of 30 W, increased by 10 W every 2 min. The subjects were instructed to pedal at 60 rpm. The end of testing was determined by either 1) attainment of the predicted maximal heart rate derived from the formula [220 – age], or 2) the subjects could no longer maintain 60 rpm due to fatigue, or 3) increase in SBP to 200 mmHg. During the test, subjects sat on the saddle at a height at which they were able to comfortably extend and flex the knees while pedaling.

\textit{Measurement index}

During rest, exercise, and recovery, SBP and HR were recorded at 30-s intervals with an upper-arm automatic digital sphygmomanometer (portable sphygmomanometer: HEM 757 Fuzzy; Omron), the cuff of which was placed over the right brachial artery. The SBP, HR, and DP data were analyzed at the end of exercise. The intersection of two linear regression lines was identified as DPBP on graphs in which the independent variable was exercise intensity or time and the dependent variable was DP. The DPBP was determined using a computer algorithm as follows. After excluding the first-stage data obtained at 30 W, the linear regression lines of DP as a function of W were calculated for all possible divisions of the data into two adjustment groups, and the break point was determined as the intersection of the two lines, represented by the minimum residual sum of the squares\textsuperscript{7}. In addition, The predicted maximal oxygen uptake (predicted VO\textsubscript{2}max) was calculated using the Astrand method\textsuperscript{9}, with HR being measured while increasing the ergometer load. The predicted VO\textsubscript{2}max was calculated from the regression line of load and HR and was calculated according to the formula 12.47 \times \text{physical work}
capacity (PWC) ÷ body weight (kg). PWC is defined as the exercise intensity at maximal heart rate\(^{10, 11}\). This is one of the physical characteristics of the subjects. There are reports that DP during exercise shows a third order regression equation for exercise load, so this study also investigated using a third order regression equation\(^{12}\).

To evaluate the reproducibility of DP at DPBP, HR at DPBP, load at DPBP, and the predicted VO\(_2\)max, the exercise with the portable sphygmomanometer was repeated within one week. The measurements were performed with an exercise stress testing BP monitor (BP-203; Colin Med Tech) within three weeks and compared with the portable sphygmomanometer. The use allowance of an exercise stress testing BP monitor was within 8 mmHg, and this value has been given official approval.

The measurement principles for the portable sphygmomanometer and exercise stress testing BP monitors used in this study were the same: both used oscillometric techniques. A major performance difference was that the exercise stress testing BP monitor had an arbitrary cuff pressure selection from 120 to 260 mmHg in 20 or 40 mmHg intervals. Subsequently, even if the preset pressure value was too low, the level is automatically recompressed about 40 mmHg higher. It making it possible to prevent a measurement error due to insufficient pressure. Furthermore, the system included a pulse check function using pulse wave measurements, making it difficult for the pulse to have any influence on blood pressure measurement. Conversely, the portable sphygmomanometer did not have an automatic recompression or pulse check function.

The statistical software SPSS (version 12.0 J for Windows XP) was used for statistical analysis. The intraclass correlation coefficient (ICC) was used to evaluate the reproducibility of DP at DPBP, HR at DPBP, load at DPBP, and the predicted VO\(_2\)max obtained with the portable sphygmomanometer. Pearson’s correlation coefficient was used to assess the validity of DP at DPBP, HR at DPBP, load at DPBP, and the predicted VO\(_2\)max obtained with the portable sphygmomanometer. \(P\) value of less than 0.05 considered statistically significant.

**RESULTS**

In Fig. 1, the change with load of subjects’ DP (mean value of all subjects), obtained using the portable sphygmomanometer and exercise stress testing BP monitor, is shown. The graph shows that DP calculated from measurements made using the portable sphygmomanometer, in the first exercise trials DP increased from a load of 40 W. The third-order regression equation shows two inflection points at high and low blood pressures and the increase in DP stopped at a load of 110 W. There was significant correlation between DP and exercise load (\(r=0.96\)). Similarly, in the graph measured by the exercise stress testing BP monitor, DP increased from a load of 40 W, and the third-order regression equation shows the increase stopped at 110 W. There was significant correlation between DP and exercise load (\(r=0.88\)). The second exercise trial with measurements using the portable sphygmomanometer, DP increased linearly from a load of 30 W until 110 W. There was significant correlation between DP and Watts (\(r=0.96\)). Although the trend of increase at the starting point was different, common features of the two trials include a third-order regression equation and 110 W of exercise load when the increase of DP stopped.

![Fig. 1. DP (mean value of all subjects) obtained using a portable sphygmomanometer (first. \(\bullet\): first. \(y = -0.03x^3 + 6.9x^2 - 268.5x + 16251, \ r = 0.96\); second. \(\circ\): second. \(y = -0.01x^3 + 1.68x^2 + 120.9 + 6759.9, \ r = 0.96\) and exercise stress testing BP monitor (\(\triangle\): second. \(y = -0.03x^3 + 6.6x^2 - 285.5x + 15495, \ r = 0.88\)). The trend of increase at the starting point was different, but common features of the curves include third-order regression characteristics and 110 W of exercise load when the increase of DP stopped.)](image-url)
0.84. The values of the first and second trial HR at DPBP were 120 ± 4.6 beats/min and 118 ± 8.0 beats/min, respectively which was 61.4 ± 2% (first) and 60.0 ± 4% (second) of maximum heart rate (220 – age). The ICC was 0.40. The values of the first and second trial exercise load at DPBP were 66.3 ± 7.4 W, 67.2 ± 7.8 W. The ICC was 0.73. The values of the first and second of trial the predicted VO₂max were 39.8 ± 12.3 ml kg⁻¹ min⁻¹ and 39.4 ± 13.3 ml kg⁻¹ min⁻¹, respectively. The ICC was 0.93.

The DPBP derived with the exercise stress testing BP monitor was 17533.9 ± 1459.2 mmHg × bpm, and the Pearson’s product-moment correlation coefficient with DP at DPBP obtained using measurement from the portble sphygmomanometer was 0.83, which is a significant correlation. The exercise load at the detection of DPBP was 66.7 ± 7.0 W, and a significant correlation with a correlation coefficient of 0.65 was found. Further, the estimated maximal oxygen uptake was 39.3 ± 12.3 ml kg⁻¹ min⁻¹, and a significant correlation coefficient of 0.83 was observed. The HR at DPBP was 119 ± 8.8 beats/ min, which was 60.4 ± 2% of maximum heart rate (220 – age). The correlation coefficient was 0.77, which indicates a significant correlation.

**DISCUSSION**

Because of vibrations accompanied with body motions that may adversely affect the cuffs during measurement, sphygmomanometry may be difficult. Therefore, blood pressure monitoring devices that are hardly influenced by body motions and vibrations are used in laboratories. However, by our results, we have shown that in an exercise tolerance test, the DPBP can be derived with a portable sphygmomanometer. The shift of DP calculated using measurements from a portable sphygmomanometer (the first exercise trial) and the exercise stress testing BP monitor obtained in this study is consistent with that of previous studies. However, the shift of DP obtained by the portable sphygmomanometer in the second trial could also be represented by a third-order regression equation, even though the graph showed a linear decrease against the exercise load from the starting point of measurement, and the increase stopped beyond the load of 110 W (Fig. 1). Although we could not reveal in this study, some patients had great differences in the HR values in the first and second incidence. It can be considered that, as DP is the product of SBP and HR, the low HR value may be supplemented with the increase of SBP, that might have influenced the increase process of DP to some extent.

In a previous study, Tanaka et al. reported that the DPBP determined with a bicycle ergometer in 20 healthy adults (13 men, 7 women) was 14,700 ± 2500 mmHg × bpm. However, Kyu et al. determined DPBP in 11 healthy male adults and found that some subjects had break points close to 20,000 mmHg × bpm. Our values are intermediate between those of previous studies. Regarding this, it can be considered that due to the use of a portable ergometer, quantitative differences in the muscle groups that participated in the exercise might have influenced the circulation response. Previous studies have revealed that the HR at the detection of the DPBP is nearly 60% (1, 8, 13). The exercise load at DPBP has been reported to be about 60 W (7, 8, 13). In this study, the HR was 61.4 ± 2% (the first trial) and 60.0 ± 4% (the second trial) of the maximum heart rate. The exercise tolerance at the detection of DPBP had little difference: 66.3 ± 7.4 W in the first trial and 67.2 ± 7.8 W in the second. However, the ICC of the HR at the detection of the DPBP at the first and second trial as measured by the commercially available sphygmomanometer was as low as 0.40. In addition, as the ICC of the SBP at DPBP was 0.63, we cannot assert that the reproducibility is high. Regarding this, as we described above, there was a wide range in HR at DPBP in the two trials. There are some cases...
reported by Ballarin et al.\textsuperscript{14) and Baradli et al.\textsuperscript{15) that included female subjects. There is one study comparing males and females by Gaisl et al.\textsuperscript{16) in which they have focused on the heart rate threshold (HRT). They claimed that 13.3\% of males and 7.4\% of females did not show HRT. In other words, the considered that circulation response differs with sex, and in the case of trials that include men and women, as in this study, the mixture of subjects has an influence on the results of circulation responses. We would like to investigate this further.

In this study, the derivation DPBP was based on the change in DP, so was believe that a further study, which including an analysis of exhaled gases is necessary. The results of the present study, however, suggest that the derivation of a comparatively accurate DPBP using a portable sphygmomanometer is possible in this study.

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