Effects of Different Temporal Heel Support Patterns on Skin Blood Perfusion

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ABSTRACT

OBJECTIVE: It was hypothesized that a practical balance between pressurization and pressure-relief heel-support durations might minimize impacts of flow deficits during pressurization. Since this possibility depends on whether pressure-relief hyperemia adequately compensates for prior intervals of flow deprivation, the main objective was to determine how different temporal patterns of heel pressurization and relief would actually affect average skin blood perfusion (SBF).

DESIGN: SBF (laser-Doppler) was measured in heels of 20 healthy subjects while they lay supine for 80 minutes on a support surface. The end cell supporting the heel, produced three different cyclical patterns of pressurization and pressure-relief levels (full or partial). Each pattern (1,2 or 4-cycles) was in contiguous 20-minute intervals.
In two protocols of 10 subjects each, SBF was determined during full pressurization, and during pressure-relief. The main outcome measure was the overall average SBF in relation to baseline SBF.

RESULTS: The main findings show that full pressure-relief yields a significantly greater SBF than partial relief. However, whether full or partial, the average SBF of each cycle pattern was greater than baseline.

CONCLUSIONS: A cyclic pressure-relief that results in an average heel SBF that is greater than resting baseline is consistent with the proposed hypothesis. In the healthy subjects studied this occurs because the hyperemia during pressure-relief more than compensates for flow deficits during pressurization. The results are applicable when a normal physiological hyperemic response capability is present. Impacts of diminished hyperemic reserve is the next major investigative challenge

BACKGROUND

Previous work[4-5] showed that loading of heels for different durations with the same pressure, or different pressures for the same duration, causes a load and duration dependent hyperemia when pressure is relieved. But,little information is available as to the skin blood perfusion (SBF) dependence on heel load-relief temporal patterns. Of special interest is blood flow over full load-relief cycles since it is likely that the average blood flow deficit over time importantly contributes to heel skin breakdown.

Thus, SBF was measured in heels of 20 healthy subjects while they lay supine for 80 minutes on a dynamic support surface that was capable of producing different temporal patterns and magnitudes of heel pressure.

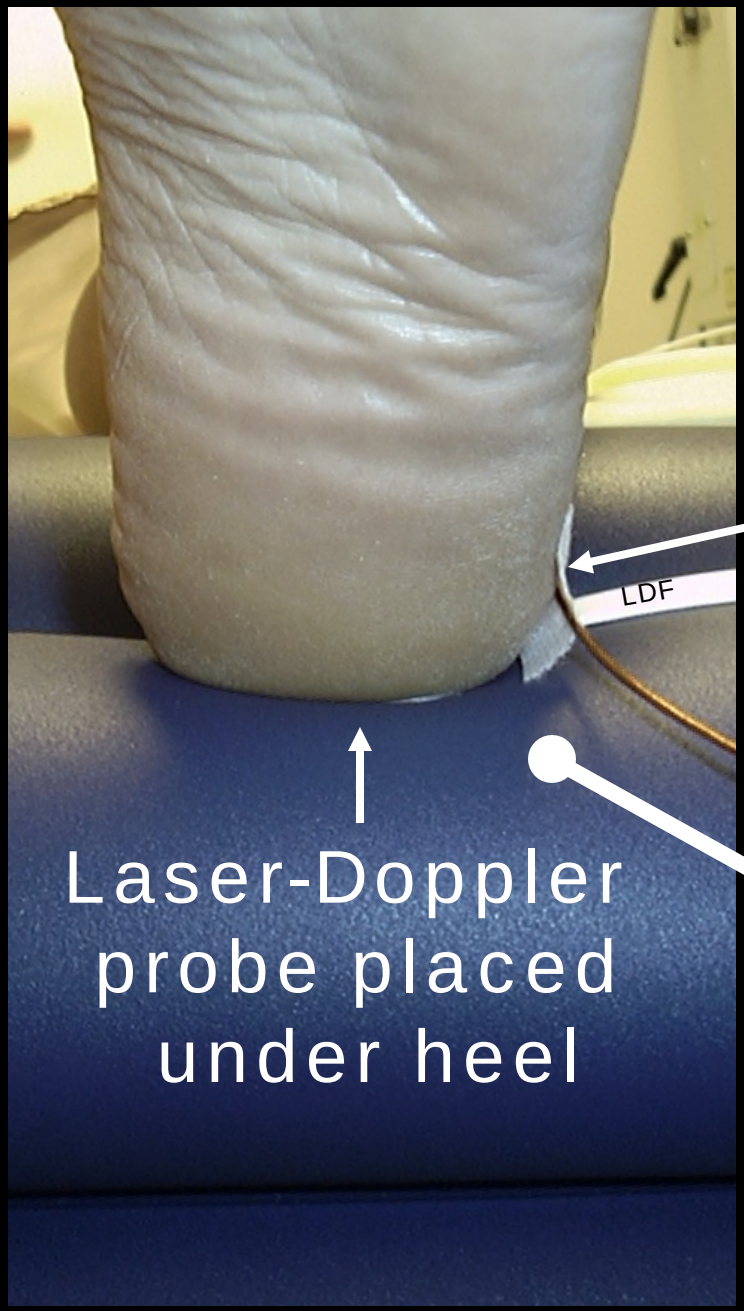
Our primary goal was to characterize the effects of dynamic heel support patterns that differed with respect to pressure amount and pressure-relief intervals.

METHODS

Subjects: Twenty volunteers were tested. None had lower extremity vascular disease nor took medications that would impact on vascular reactivity. They were randomly divided into Groups A and B according to the support pattern protocol they received as described below. For groups A and B respectively there were no significant differences in age (29.8±1.7 vs. 31.3±3.5 years), height (66.7±0.8 vs. 67.0±1.1 inches) or weight (140±30 vs. 140±26 pounds).

Protocol: Subjects lay on a support surface with heels on the end cell (figure 1), which could alternate pressure between upper-lower limits on a cyclic basis under computer control. The dynamic patterns tested had three distinct sequential 20-minute intervals in which either one, two or four full cycles were applied (figure 2). In group A (N=10), the cell's internal pressure cycled from 20 mmHg to 0mmHg. In group B (N=10), the cell pressure cycled from 20 mmHg to 10 mmHg.

The half cycle length for one, two and four cycles was 10, 5 and 2.5 minutes respectively. The sequential order of the cyclic pattern was 4-2-1 cycles in half the subjects and 1-2-4 cycles in the other half in each group. The first pattern was initiated after a baseline interval of 20 minutes in which the heel was not loaded (0 mmHg).



Heel Blood Perfusion via Laser-Doppler

Thermocouple to measure skin surface temperature

Laser-Doppler probe placed under heel

Support Surface End Cell with computer controlled timing to generate alternating cell pressures between 0 and 20 mmHg

Figure 1

METHODS (continued)

Blood Perfusion: **Heel skin blood perfusion (SBF) was monitored with a laser-Doppler probe affixed to the heel with tape and connected to a perfusion monitor (Vasamedics model 403a). The position of the probe was at the site of contact of the heel with the support surface (figure 1). SBF was continuously monitored throughout the experimental sequence. Skin temperature was measured with a thermocouple near the site of SBF measurement.**

Interface Pressure **At the end of the 80-minute sequence heel interface pressures were measured with a pressure sensor that was placed between the heel and the supporting cell. The cells were pressurized to the levels corresponding to those used during the test-sequence. Six measurements of IP were made on each subject at 20 mmHg cell pressure and six additional measurements were made with the cell at 10 mmHg for group B subjects.**

METHODS (continued)

Assessment Parameters and Data Analysis

The main comparison parameter was average SBF during each 20-minute interval in relation to the baseline average SBF. For cyclic support intervals, average SBF was determined for each cycle by summing average SBF during maximum and minimum pressure phases. For two and four cycle patterns, average SBF in each cycle was used to characterize each patterns overall average. SBF in each cycle interval was compared with baseline SBF via the ratio $SBF_r = (SBF_j/SBF_{base})$ in which j =1-3 and corresponds to the 1, 2 and 4 cycle pattern intervals.

Protocol for Support Cell Pressurization Sequences

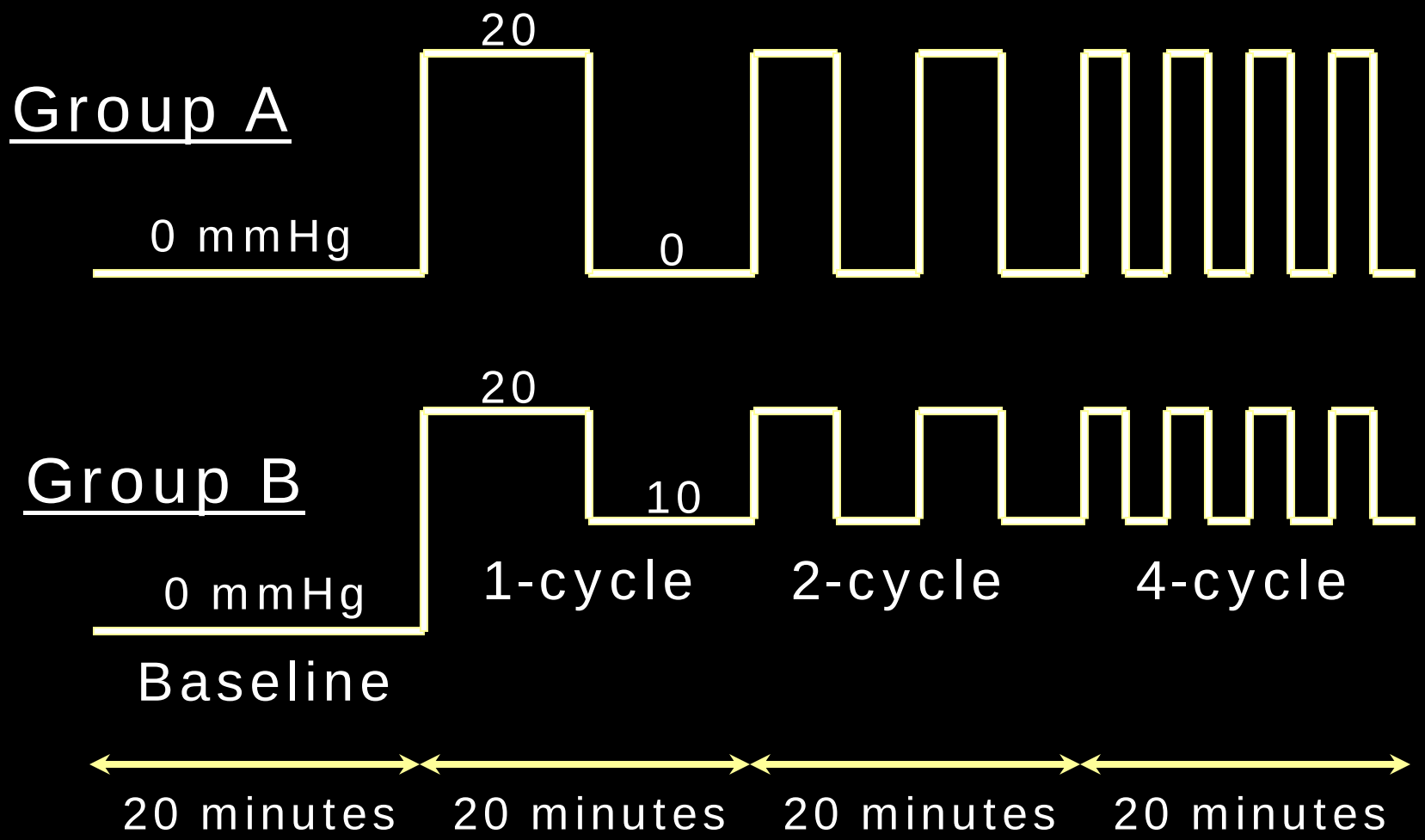


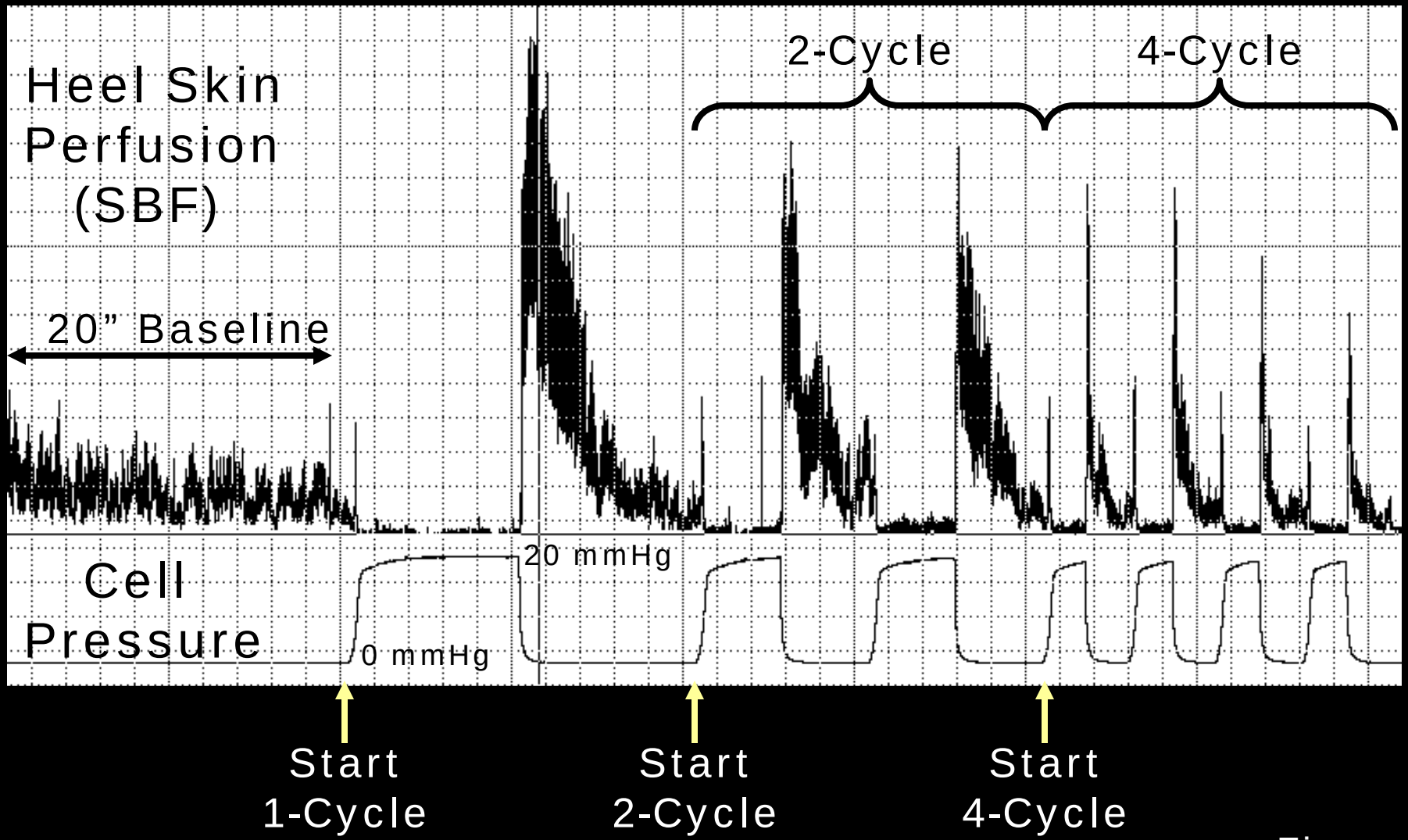
Figure 2

Typical Response Features

Interface Pressures: At a 20 mmHg cell pressure, IP ranged between 55-147 mmHg, (92±5 mmHg, N=20). Group B IP was significantly less than for group A (81.8±4.6 vs. 101.2±7.4, p=0.016 Mann-Whitney). For a cell pressure of 10 mmHg (group B only), IP ranged from 35-74 mmHg with a mean (48±4 mmHg, N=10). This was about half of that at a cell pressure of 20 mmHg. For group A (but not group B) there was a significant ($p<0.01$) correlation between IP and subject height ($r=0.775$) and weight ($r=0.765$). For group B there was a similar tendency for IP, but it was not significant. In spite of these variations there was no detectible overall correlation between IP and SBF responses for any of the support cycles or patterns.

Typical SBF Responses: Cell pressurization caused a decrease in SBF and pressure relief resulted in an hyperemic response (figure 3). The amount of increase in SBF depended on whether the release was full (to 0 mmHg) as in protocol A or partial (to 10 mmHg) as in protocol B (figure 4). Release to 0 mmHg was associated with a greater hyperemic response (figures 5a and 5b).

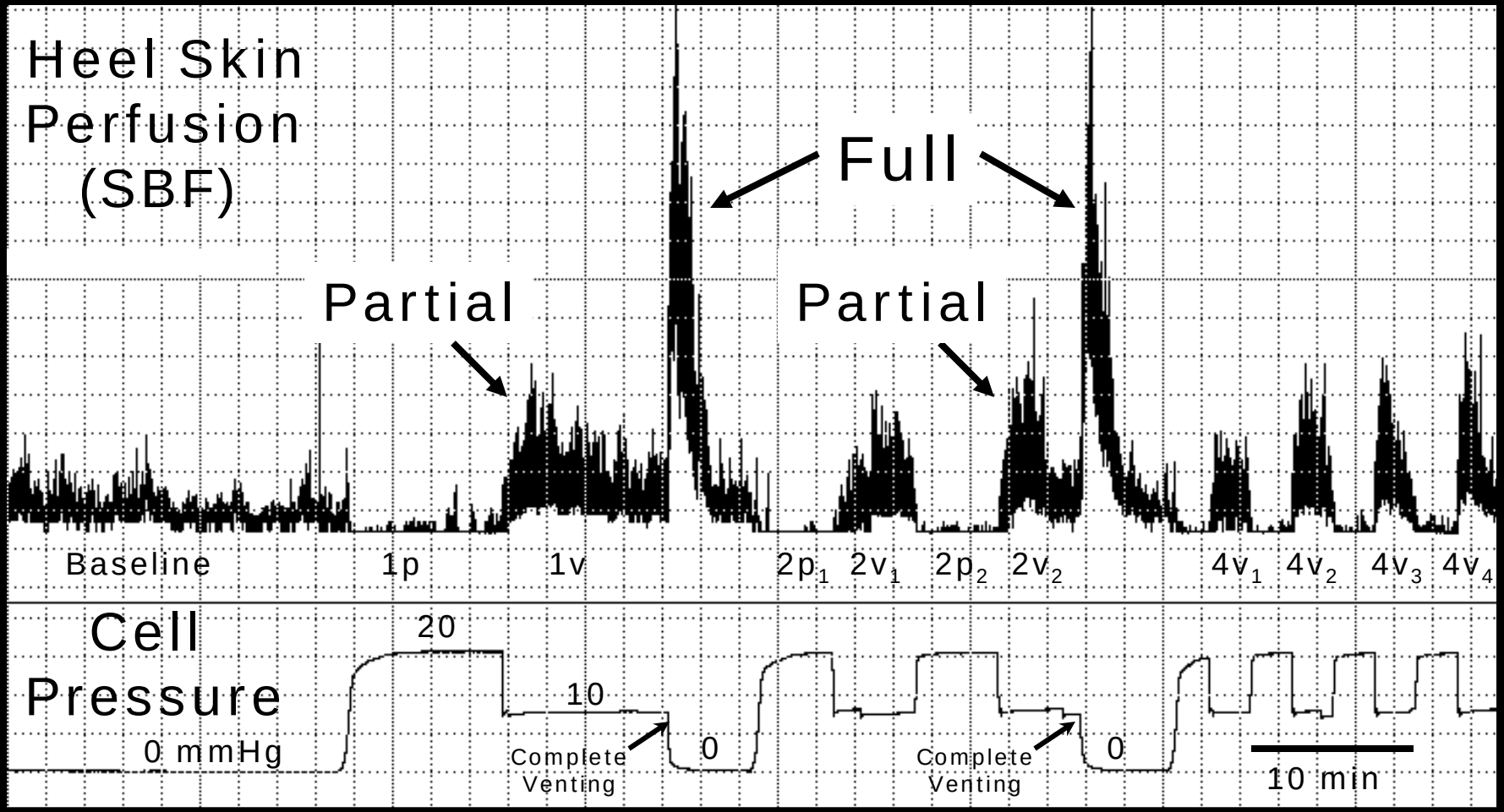
Protocol A Sequence Example Responses



Subject #09

Figure 3

Partial vs. Full Pressure Relief

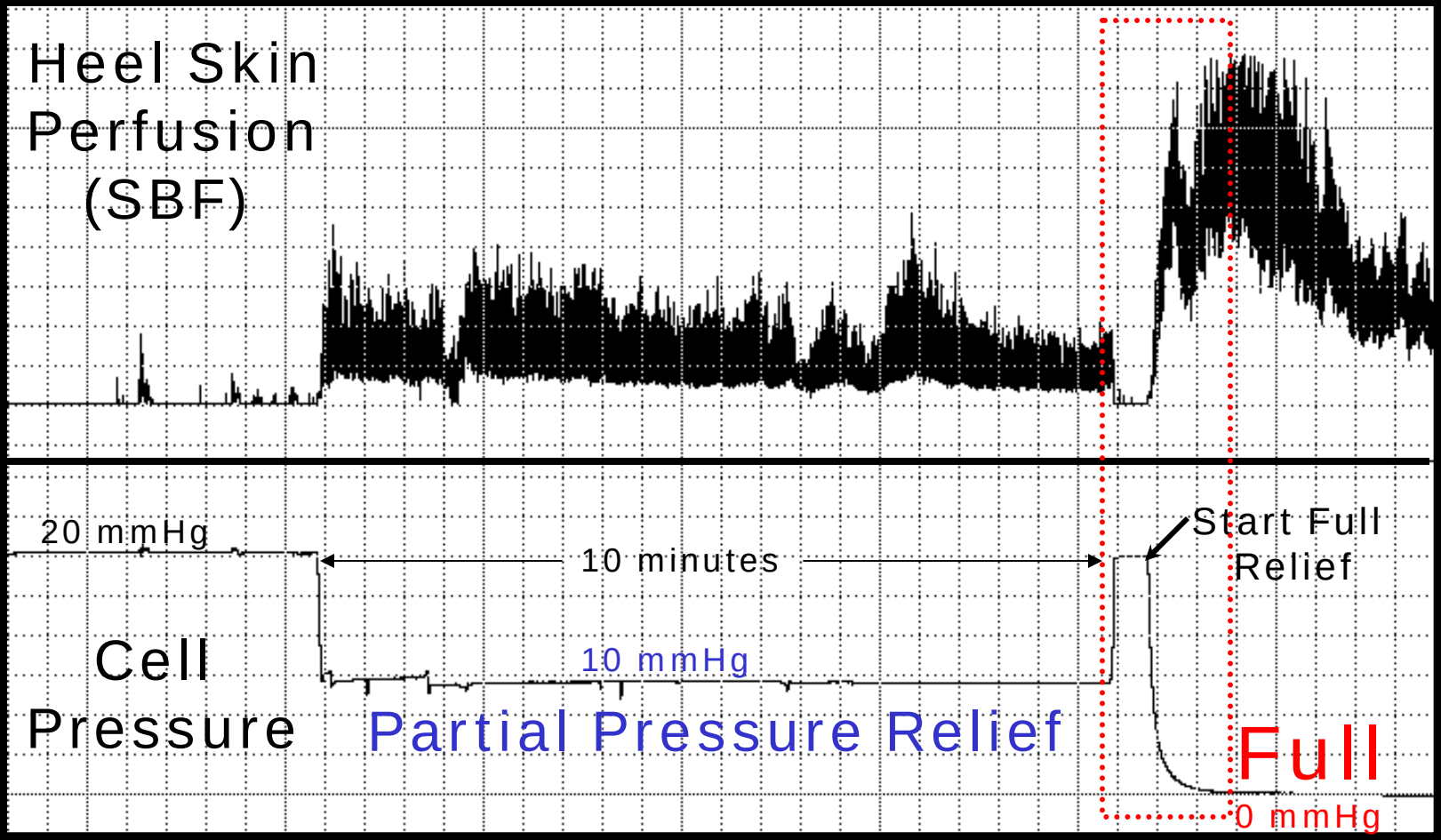


Protocol B Example

Subject #11x

Figure 4

Maximum SBF Hyperemia With Full Pressure Relief



Subject #17 Protocol B

Figure 5a

SBF Response Expanded

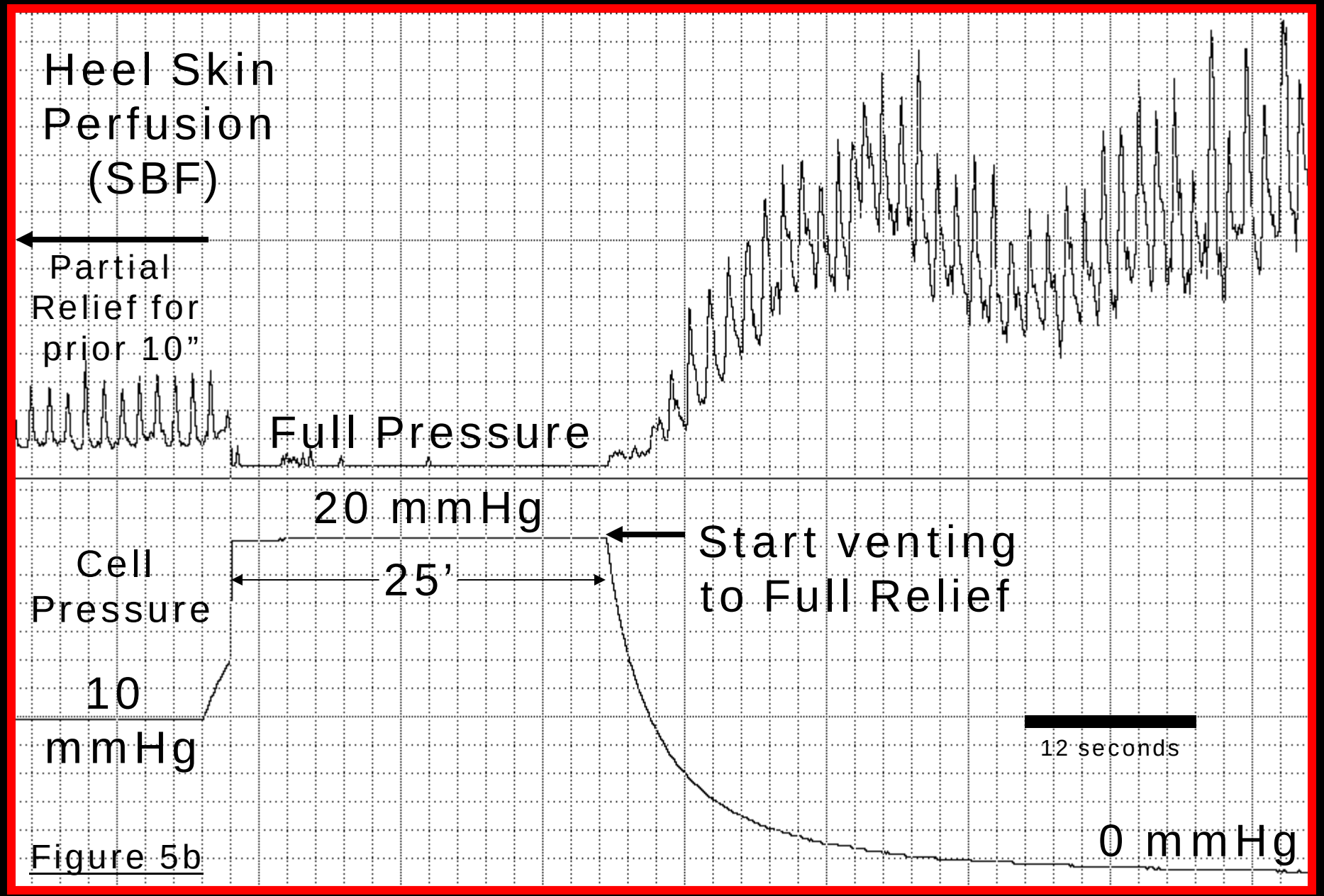


Figure 5b

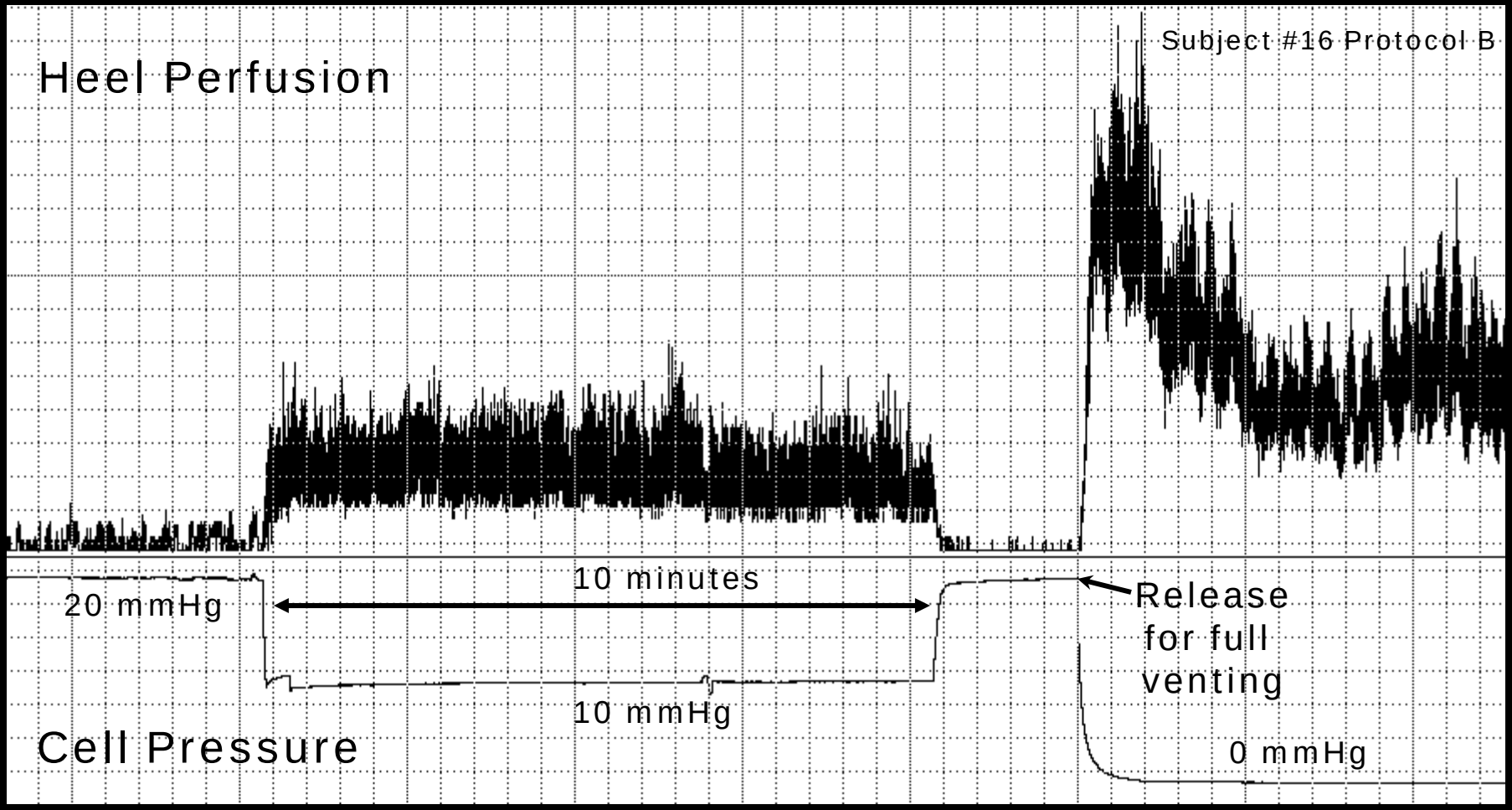

Heel Perfusion
Subject #16 Protocol B
10 minutes
20 mmHg
Release
for full
venting
10 mmHg
Cell Pressure
0 mmHg

Figure 5c

Main Results

SBF During Full Pressurization:

Pressurizing the support cell to 20 mmHg resulted in a decrease in heel SBF to a level that ranged from 0.12 ± 0.05 to 0.44±0.13 of baseline (figure 6). Although group A and B subjects were exposed to equal cell pressures, the mean decrease observed in group B was larger, although only for the 1-cycle pattern was the difference statistically significant (p=0.028, Mann-Whitney test). The greater SBF reduction can not be explained by differences in interface pressure since SBF of group B was significantly less than for group A.

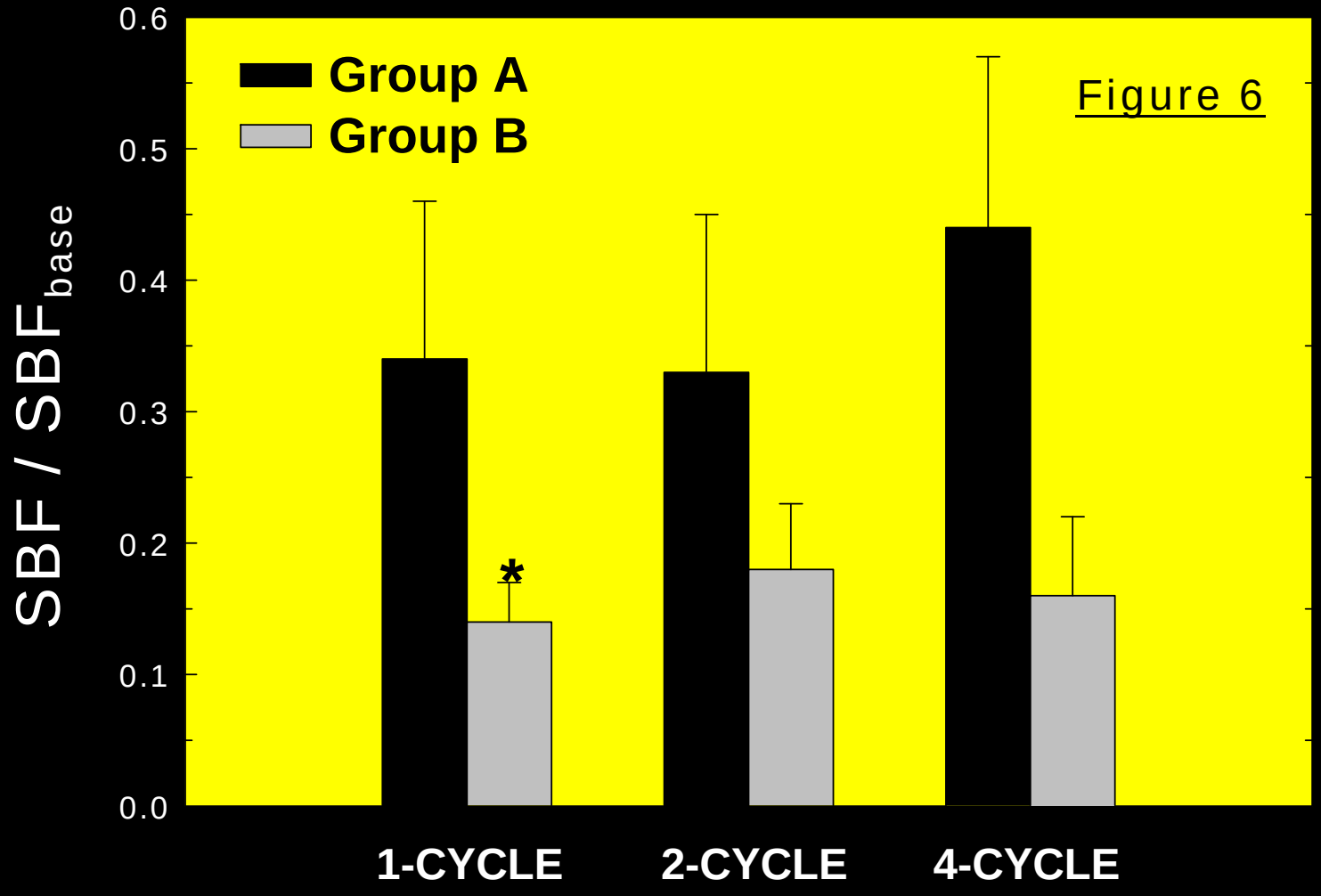
SBF During Pressure Release: Reduction in cell pressure resulted in a hyperemic response relative to the average SBF during baseline (figure 7). For 1-cycle patterns, the relative hyperemia was significantly less for group B partial-releases (1.3 ± 0.25) than for group A full-releases (2.2±0.28, p=0.03). For 2-and 4-cycle patterns, group A vs. B differences were similarly present, but neither difference quite attained statistical significance.

SBF During Full Cycles

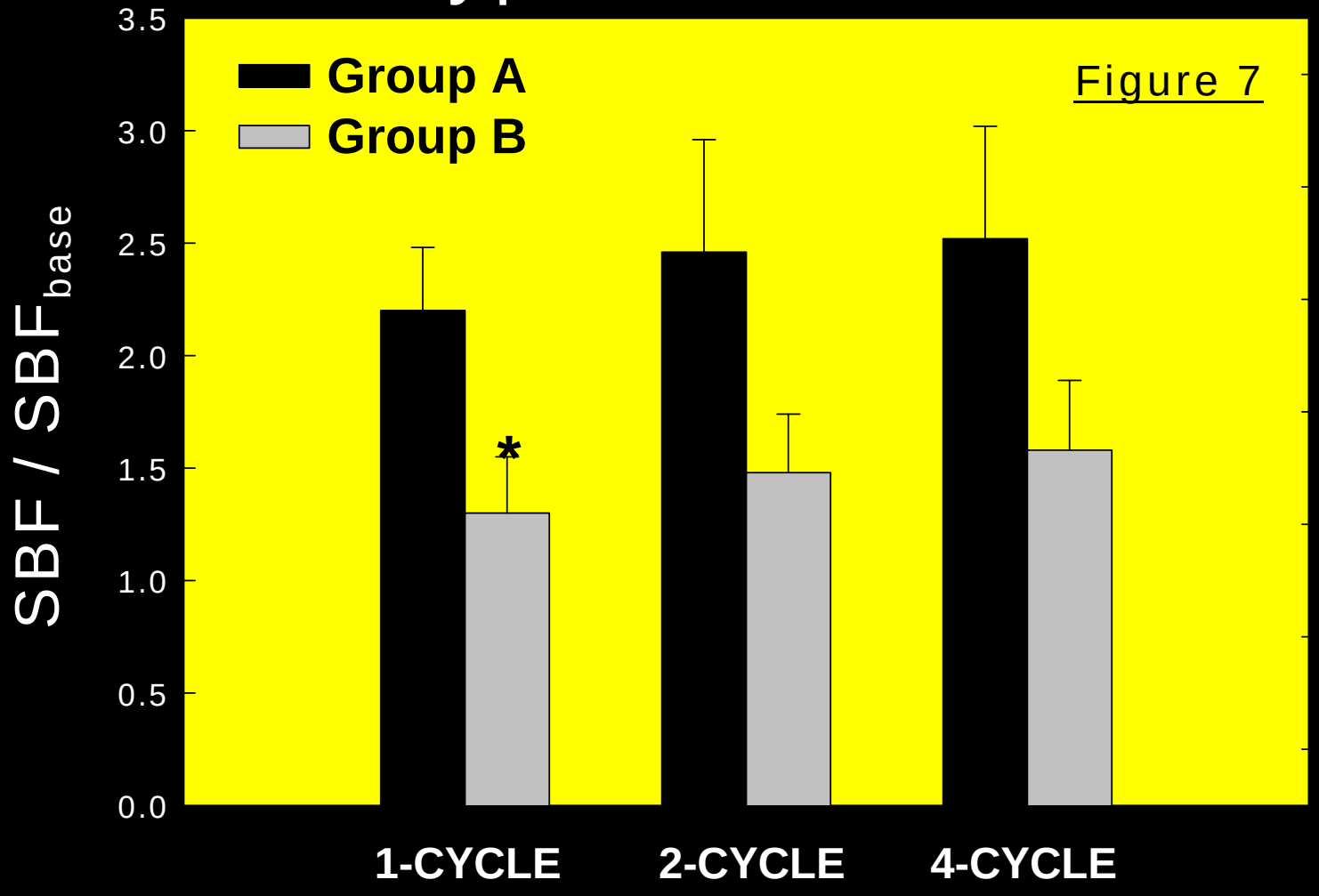
Average SBF for each entire cycle test interval (pressurization+relief) was greater than SBF during baseline for all cycle patterns of each protocol (figure 8). However, values were uniformly lower for group B in comparison to group A. Based on analysis of variance, an overall statistically significant difference *between* groups was detected. The associated p-values for 1, 2 and 4-cycle patterns were 0.005, 0.049 and 0.042 respectively.

Examination of *within* group effects using general linear manova analysis for repeated measures indicates no significant differences among cycle patterns detectible for either group A or B. However, nonparametric comparisons between 1-cycle and 4-cycle intervals indicate a near significant difference (p=0.074, Wilcoxon signed ranks) for group B.

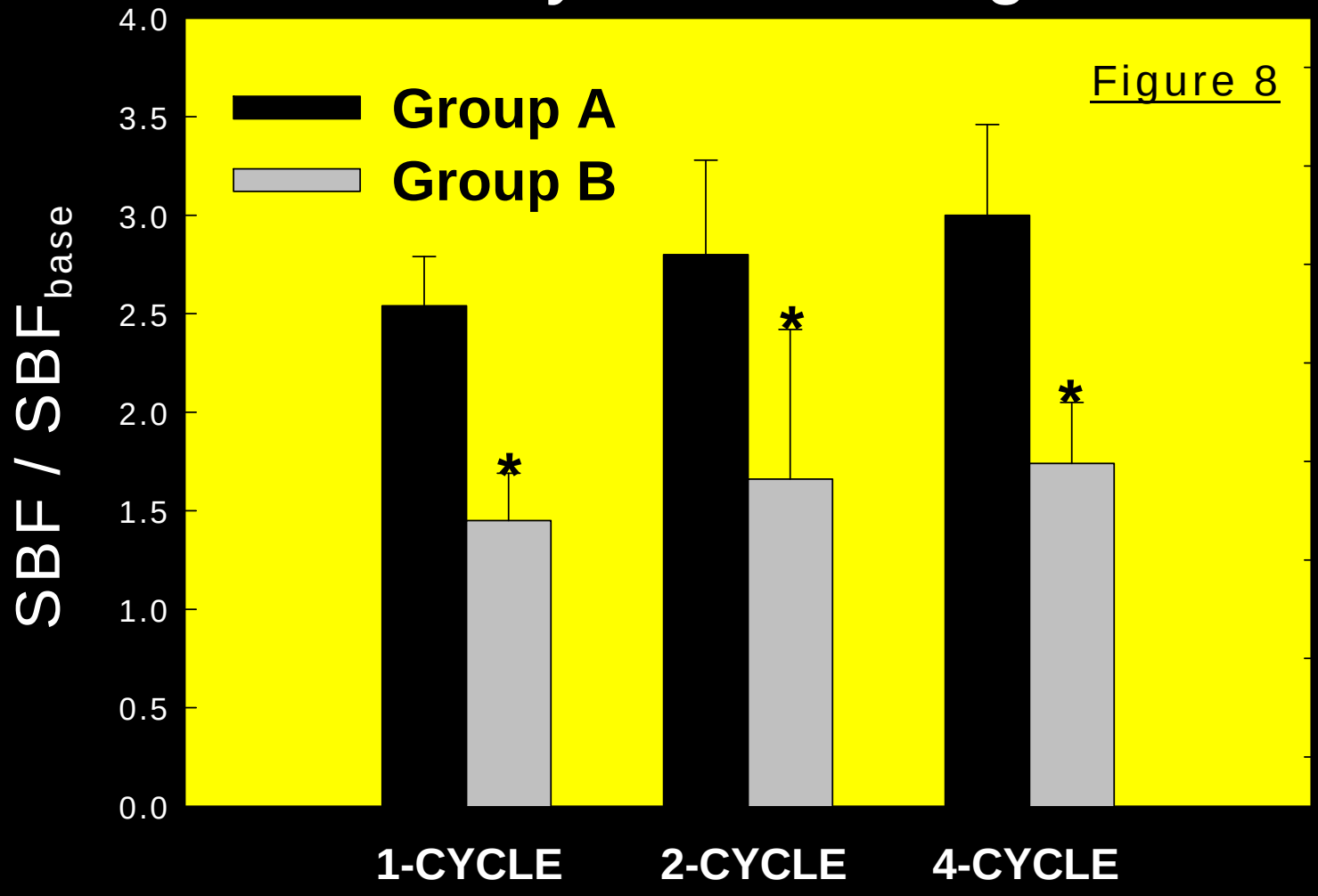
Perfusion (SBF)
Full Pressure Phase



Perfusion (SBF)
Hyperemic Phase



Perfusion (SBF)
Full Cycle Averages



CONCLUSIONS

- **This investigation of the effects of various cyclical alternating pressure patterns for supporting the heel has demonstrated clear differences between full and partial pressure-relief approaches**
- **The full relief approach results in an average heel blood perfusion that is actually greater than that during resting baseline. This increase arises because the hyperemic response during the relief phase more than compensates for the flow deficit during heel loading.**
- **Partial relief blunts this normal response causing less hyperemia, but still results in an average perfusion that exceeds baseline.**
- **No specific cycle length tested showed a significant advantage with respect to achieving a higher relative perfusion. The slight upward trend in relative perfusion from 1-through 4-cycle patterns suggest a benefit for the 4-cycle approach, but this is not supported by adequate statistical evidence as yet.**

CONCLUSIONS

The results are strictly applicable when a normal physiological hyperemic response capability is present.
It is unknown what impact depressed vascular responsiveness and/or diminished hyperemic reserve would have on the blood perfusion findings.This issue represents the next major investigative challenge

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