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Verification of an Altitude Decompression Sickness Prevention Protocol for Shuttle Operations Utilizing a 10.2-psi Pressure Stage

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Verification of an Altitude Decompression Sickness Prevention Protocol for Shuttle Operations Utilizing a 10.2-psi Pressure Stage

James M. Waligora, David Horrigan, Jr.,
Johnny Conkin, and Arthur T. Hadley, III, M.D.
Lyndon B. Johnson Space Center
Houston, Texas

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SUMMARY

Three test series involving 173 man tests were conducted in the process of defining and verifying a pre-extravehicular activity (EVA) denitrogenation procedure that would provide acceptable protection against altitude decompression sickness while minimizing the required duration of oxygen (O_2) prebreathe in the suit prior to EVA. The tests also addressed the safety, in terms of incidence of decompression sickness, of conducting EVA's on consecutive days rather than on alternate days.

The tests were conducted in an altitude chamber, subjects were selected as representative of the astronaut population, and EVA periods were simulated by reducing the chamber pressure to suit pressure while the subjects breathed O_2 with masks and worked at EVA representative work rates. The measured parameters were the presence and grade of venous bubbles as measured by a doppler bubble detector and the presence and grade of symptoms of decompression sickness reported by the subjects.

A higher than anticipated incidence of both venous bubbles (55%) and symptoms (26%) was measured following all denitrogenation protocols in this test. For the most part, symptoms were very minor and stabilized, diminished, or disappeared in the 6-hour Series 3 Tests. Instances of clear, possible, or potential systemic symptoms were encountered only after use of the unmodified 10.2 psi protocol and not after the modified 10.2 psi protocol, the 3.5-hour O_2 prebreathe protocol, or the 4.0-hour O_2 prebreathe protocol. The high incidence of symptoms is ascribed to the type and duration of exercise and the sensitivity of the reporting technique to minor symptoms. Repeated EVA exposures after only 17 hours did not increase symptom or bubble incidence.

The modified 10.2 psi denitrogenation provided protection equivalent or better than that provided by current insuit O_2 prebreathe procedures.

Repetition of a decompression after 17 hours did not increase the incidence of symptoms of decompression sickness or of venous bubbles. The incidence of altitude decompression sickness, although very mild, indicates the possibility of more serious responses and the need to pursue and prepare procedures for inflight treatment of decompression sickness.

INTRODUCTION

The advent of a 14.7 psi cabin atmosphere in Shuttle increased the potential for altitude decompression sickness to occur while performing extravehicular activity (EVA) at reduced pressure. Each time an EVA is conducted, there is a change in pressure and this is the provocative event in decompression sickness.

Altitude decompression sickness occurs when the sum of the dissolved gases in in the body tissues exceed the ambient pressure to the extent that bubbles grow and proliferate in the tissues. In practice, the principal gas of concern when crewmen are breathing air or an O_2/N_2 mixture is nitrogen. Breathing O_2 prior to EVA is an effective means of reducing tissue N_2 pressure. Tissue N_2 can also be reduced by breathing an atmosphere in which N_2

pressure is reduced as a function of a reduced total pressure or a reduced percent composition of N_2. A denitrogenation protocol based on the latter concept is desirable for operational Shuttle flights to preclude the necessity for a long (3-4 hrs) prebreathe in the pressure suit. An earlier study verified the acceptability of a 9.0 psi decompression stop denitrogenation procedure for the Orbital Flight Test Program (1).

This report presents the results of three series of altitude chamber tests conducted to verify the operational acceptability of denitrogenation protocols utilizing a 12-hour staged decompression to 10.2 psi with 74% N_2 combined with short O_2 prebreathe times. The protocol is evaluated in terms of its effectiveness in preventing altitude decompression sickness during simulated EVA at 4.3 psi suit pressures. Limitations of this protocol and other available denitrogenation protocols in preparation for repeated exposures to EVA are also addressed.

METHODS

Series 1 Protocol. Thirty-six male subjects, selected to be representative of the astronaut population in age, lean to fat ratio, and level of exercise (Table I), were exposed to variations of a stage decompression protocol involving a 12-hour stay at a 10.2 psi cabin pressure and a short O_2 prebreathe followed by decompression to 4.3 psi.

The tests were conducted in an altitude chamber with the general volume and geometry of the Shuttle mid-deck area. Subjects were exposed to the test protocol three at a time. The subjects entered the chamber after an evening meal. The chamber atmosphere was reduced to a pressure of 10.2 psi with 74% N_2 and maintained at this level. Sleeping pallets were provided in the chamber and the 12-hour stay at the decompression stop included an 8-hour sleep period. After a light breakfast and upon completion of the 12-hour period, the subjects donned masks and breathed 100% O_2 for the remainder of the test. After the subjects had breathed O_2 for 40 minutes, the chamber pressure was reduced to 4.3 psi to simulate the pressure suit pressure during EVA.

During the subsequent 3-hour period, the subjects simulated the EVA work period by a repeated 16-minute cycle of upper body exercise (lifting a small weight), lower body exercise (stepping on a 7 1/2 in. step), rest, and doppler sensor monitoring. The work period was 8 minutes in each 16 minutes and measurement of O_2 consumption on several subjects indicated an average metabolic rate during the work periods of 200 Kcal/hr. The method of doppler sensor monitoring was that described by Adams, et al (2), and the method of bubble grading was that described by Neuman, et al (3).

Three of the 36 subjects were exposed to the test protocol twice, resulting in a total of 39 man exposures. Variations of the protocol described, included an increase of the period of time at 10.2 psi to 18 hours, and an increase of the final O_2 prebreathe from 40 minutes to 90 minutes, and finally, exposure of 11 subjects to a 3.5 hour prebreath at 14.7 psi prior to the decompression to 4.3 psi. Subjects were removed from the chamber at the first indication of altitude decompression sickness.

Series 2 Protocol. This series was conducted specifically to compare the 10.2 psi stage decompression protocol with a 3.5 hour O_2 prebreathe. Nineteen male subjects were selected at random from those completing the Series 1 tests and 4 new male subjects were used. Twenty-one of the subjects were exposed to both the 10.2 psi protocol and a 3.5 hour prebreathe protocol prior to decompression to the 4.3 psi simulated EVA. A total of 44 man tests were conducted.

Series 2 tests were conducted like the Series 1 tests with the following changes:

a. The type of exercise was changed from a step test that emphasized use of anti-gravity muscles and concentrated stress on a single joint to an exercise protocol that involved 3 diverse upper body exercises in two seperate modes of operation that were deemed by the investigators and crew representatives as being representative of extravehicular activities (EVA). Exercise activities are shown in Figures 1 and 2.

b. A revised decompression sickness grading scale for limb bends was utilized, and the critical level for test cessation was changed from identification of aches, pains, or discomfort symptomatic of decompression sickness to the presence of clear limb pain associated with a decrement in performance.

c. A research mask replaced the Air Force mask used on the first test series. The use of this mask and the pre-test verification of zero N_2 leakage with this mask with a mass spectrometer insured that there was no break in the prebreathe periods prescribed by the two test protocols. (Table 2)

d. Each subject was exposed to two test protocols; the 10.2 psi protocol and a 3.5-hour O_2 prebreathe protocol so that the responses of the subjects on the 10.2 psi protocol could be compared with their response to a protocol with a history of operational effectiveness.

The 10.2 psi protocol involved a period of 12 hours at a pressure of 10.2 psi with an O_2 concentration of 26%. This was followed by a period of breathing O_2 for 40 minutes at 10.2 psia, followed by a decompression to 4.3 psi over a 30-minute period representative of the operational change of pressure in the pressure suit prior to and during the first few minutes of an EVA (Figure 3a).

The 3.5-hour prebreathe protocol involved a period of 3.5 hours at sea level pressure breathing O_2 supplied to the research mask prior to the 30-minute period of decompression to a 4.3 psi pressure representative of EVA pressure suit pressure. (Figure 3b)

Following either prebreathe protocol, the subjects worked for 4 hours doing tasks to simulate EVA exercise. The first 10 minutes of this period began at a pressure of 5.3 psia which decreased to 4.3 psia as would occur during an operational EVA. The remainder of the 4.0-hour period was at a 4.3 psia pressure. The activity during this 4.0-hour period involved a 4-minute period of work on an arm cranking device, a 4-minute period of time working on a rope pull device, a 4-minute period of time working at a torque stand torquing against fixed studs, and a 4-minute period in which the subject was

monitored with a doppler bubble detector while the subject flexed his four limbs in sequence. The three exercises were then repeated with some change in the exercise at each exercise stand. After the second doppler monitoring in the sequence, a 4-minute rest period was taken by the subject. A complete sequence involved six 4-minute exercise periods, two 4-minute doppler measurements, and one 4-minute rest period. This sequence was repeated until the 4.0-hour exercise period was complete. Each subject experienced the 4.0-hour exercise period in the laboratory at sea level so they could identify any symptoms generated by muscle strain and so that measurements of the work rate could be made.

The subjects were encouraged to report any symptoms at the time of occurrence, and in addition, a formal question regarding the presence of any symptoms was asked at the beginning of the test and at the end of each 1-hour period.

Series 3 Protocol. In this test series, the 10.2 psi protocol was modified to include a 60-minute O_2 prebreathe prior to the initial change in pressure from 14.7 psi to 10.2 psi (Figure 3c). This addition was made to avoid the growth or formation of bubbles at this particular time which might precipitate the onset of altitude decompression sickness at the subsequent decompression from 10.2 psi to 4.3 psia. In this test series each of the modified 10.2 psi protocol tests was compared with a test on the same subject following a 4.0-hour O_2 prebreathe (Figure 3d). Also in this series, the effect of a second EVA after a 17-hour interval was evaluated both with the modified 10.2 psi protocol and the 4.0-hour O_2 prebreathe protocol. Thirty-five male subjects were used in this series. Twenty-three of the subjects were exposed to both the modified 10.2 psi protocol and to a 4.0-hour prebreathe protocol. Twenty-six of the subjects were exposed to second EVA simulations after 17 hours; 12 following the 10.2 protocol and 14 following the 4.0-hour prebreathe protocol. A total of 89 man tests were conducted in this series. A total of 173 man tests were conducted in the combined series.

Series 3 tests were conducted like the Series 2 tests with the following changes:

a. The activities of the subjects during the day prior to the test were more directly controlled by sequestering the subjects in the JSC health stabilization facility prior to the chamber test. The subjects reported to the facility at 5:00 p.m. the day prior to the beginning of the chamber exposure, and their meals and sleeping quarters were in the facility.

b. The exercise period simulating EVA was extended to 6 hours. A 20-minute rest period was inserted after 3 hours.

c. In those tests involving a repeated EVA, the following timeline was followed:

(1) If the test followed a 4.0-hour O_2 prebreathe, the subjects were returned to 14.7 psia at the end of the first EVA simulation. The subjects spent the intervening 17 hours in the health stabilization facility and then the chamber exposure was repeated.

(2) If the test followed a 10.2 psia protocol, the subjects were returned to 10.2 psia at the end of the first EVA simulation and remained in the chamber for the intervening 17 hours prior to a 40-minute O_2 prebreathe and depressurization to 4.3 psi for the second 6-hour EVA simulation.

RESULTS

Series 1 Protocol. The results of this series are presented in Table 3. During the first 5 test exposures, the 10.2 psi protocol described by Figure 1 was followed. Thirteen subjects underwent the test protocol and 3 experienced decompression sickness. In 10 of the 13 subjects bubbles were detected, and in 8 of the 13 subjects these bubbles were of Grade 3 or 4 (heavy showers of bubbles or bubbles in all heart cycles).

An incidence of decompression sickness symptoms of less than 10% had been expected based on analysis of tests reported in the literature (Figures 4 & 5). After five tests had been completed, the results were statistically incompatible with this incidence of decompression sickness. Modifications to the protocol were then tried in order to increase the effectiveness of the denitrogenation. In test #7, the period of stabilization at 10.2 psia was increased to 18 hours with the rest of the protocol remaining the same. In test #7, all these subjects had Grade 3 or 4 bubbles, and two subjects reported after the test that bends pain had occurred during the test.

In tests #6, #8, #9, and #10, the period of O_2 breathing after 12 hours at 10.0 psia was increased from 40 minutes to 90 minutes. In tests #6, #8, and #9, the rest of the protocol remained the same. Bends incidence in these tests was 3 of the 9 subjects, with Grade 3 or 4 bubbles occurring in 5 of the 9 subjects. In test #10, the lower body exercise was changed from an exercise involving stepping up a 7 1/2 inch step to a high step-in-place at the same rate. Bends incidence was 1 of 3. The other two subjects were bends and bubble free. The final four tests, (#11, #12, #13, and #14) were conducted using the backup operational protocol; 3.5 hours of prebreathing of O_2 prior to decompression to a suit pressure of 4.3 psia. Eleven subjects were exposed to the protocol, and 4 of 11 experienced bends pain and 7 of 11 had bubbles.

In all the tests in Series 1, symptoms of decompression sickness occurred in the lower limbs; either knees or feet.

Table 4 groups the tests of Series 1 into three categories by common features of the denitrogenation protocols and indicates a similar incidence of decompression sickness for each category.

Series 2 Protocol. The overall incidence of symptoms of decompression sickness was 32% (7 of 22) for the 3.5-hour protocol and 27% (6 of 22) for the 10.2 psi protocol. (Figure 6 and Table 5 present this data in graphic and tabular format.) This incidence was very close to that experienced in the Series 1 testing. The preponderance of symptoms, 7 of 7 at 3.5 psi and 5 of 6 at 10.2 psi, involved the lower extremities; the feet, ankles, and knees (Table 6). This is also similar to the experience in the Series 1 tests. In the 3.5-hour prebreathe tests, there was one Grade 3 symptom resulting in a decision to remove the subject from the chamber at 2 hours and 30 minutes. In

the 10.2 psi test series, there was a Grade 3 symptom (effect on performance) resulting in removal of a subject from the chamber after 1 hour and 50 minutes, and a second subject completed the 4.0-hour exercise period but was classified as Grade 3 based on his post-test comments and the presence of limping during the last 30 minutes. A third subject was classified as Grade 2 but after pain in the lower limb had cleared several minutes after recompression, it reappeared one hour later. This subject was treated in the hyperbaric chamber. Symptoms were relieved at the 60 ft. level on a Table 5 treatment schedule.

Figure 7 illustrates the elapsed time to onset of symptoms following the two protocols. The mean time of incidence of symptoms occurring subsequent to the 3.5-hour prebreathe protocol was 138 minutes. The earliest report of symptoms was at 60 minutes and the latest report was at 180 minutes. In one case, symptoms disappeared during the 4.0-hour period. In three other cases, symptoms abated somewhat during the 4.0-hour period. In three other cases, symptoms reached a steady state and continued at that level until the end of the test.

The mean time of incidence of symptoms occurring subsequent to the 10.2 psi prebreathe protocol was 128 minutes. The earliest report of symptoms was at 18 minutes, and the latest report was at 210 minutes. In one case, symptoms disappeared but then reappeared at a more severe level which was ultimately graded level 3 although he completed the 4 hours. In one other case, symptoms abated somewhat during the test. In four cases, symptoms progressed or reached a steady state and persisted at this level. In one case, symptoms reoccurred after return to sea level pressure and treatment in the hyperbaric chamber was required to resolve the symptoms.

Series 3 Protocol. The incidence of decompression sickness and venous bubbles in Series 3 test is presented in Figure 8 and Table 7 and in the following paragraphs.

The overall incidence of symptoms of decompression sickness during first exposures following the modified 10.2 psi protocol was 23% (8 of 35). The overall incidence of symptoms during first exposures following the 4.0-hour prebreathe was 21% (6 or 28). The incidence of symptoms after the second simulated EVA was 17% following the 10.2 psi protocol. During the second simulated EVA following the 4.0-hour prebreathe, symptom incidence was 21%. All of the symptoms of decompression sickness in Series 3 tests began in the lower extremities as in the Series 1 and 2 Tests. Following the 4.0-hour O_2 prebreathe protocol, there was one incidence of Grade 3 symptom. This was knee pain which increased to the point that it interfered with the performance of the subject and caused him to favor that limb in moving about the chamber. This subject was removed from the chamber after 4 hours and 20 minutes exposure at 4.3 psi. This was the only occurrence of Grade 3 pain in the 89-man tests in Series 3, and the only test in this series in which the 6-hour simulated EVA was not completed.

Figure 9 illustrates the difference in the time to onset of symptoms between the two protocols tested in Series 3. Figure 10 illustrates the onset times for back-to-back runs.

The mean time of onset of symptoms subsequent to the 4.0-hour O_2 prebreathe protocol was 146 minutes compared to the mean time of onset of symptoms in Series 2 subsequent to the 3.5-hour O_2 prebreathe of 138 minutes. The mean time of onset of symptoms subsequent to the modified 10.2 psi protocol was 199 minutes compared to 128-144 minutes subsequent to the basic 10.2 psi protocol tested in Series 2 Tests. The mean time of onset of symptoms was 275 minutes in the repeated EVA runs using the 10.2 psi protocol and 192 minutes in the repeated EVA's using the 4.0-hour O_2 prebreathe procedure.

DISCUSSION

Incidence of Symptoms. The original plan for the 10.2 psi denitrogenation protocol called for 40-man exposures to the protocol to assure that symptom incidence was below what was believed to be a conservative projection of less tha 12% incidence of mild symptoms. After one-third of the initial test series was completed, an incidence of symptoms of 30% led to a decision to vary the protocol and finally to include in the tests a 3.5-hour O_2 prebreathe prior to decompression. The higher than anticipated symptom incidence continued and generated concern as to the validity of the test procedure.

The results of Series 2 and Series 3 tests were consistent with those of Series 1 as far as overall incidence of symptoms was concerned. The change from using a step test in Series 1 tests to upper body exercise in Series 2 tests had no effect on symptom incidence or on the location of symptoms which still occurred primarily in the lower extremities. The incidence of symptoms in Series 3 tests (21%) was somewhat lower than Series 1 and 2 tests but consistent with the increased denitrogenation provided by both the protocols tested in Series 3 and still higher than would be expected from an analysis of past studies (Figures 4 and 5).

Since the high symptom incidence was not a function of the use of a staged denitrogenation versus a 100% O_2 prebreathe, the high incidence rate in these studies must relate to the nature of the provocative exposure or to the detection and reporting of symptoms. The components of the provocative exposure include the protection provided prior to decompression by denitrogenation, the magnitude of the change in pressure, the activity of the subjects during the low pressure exposure, and the duration of the exposure. The data on change in pressure and on extent of denitrogenation is well reported in the literature, and these were the factors used in the predictive analysis. However, it is difficult to evaluate the work rates of some of the studies in the literature.

Work Rate. On most past studies, the intent has been to simulate the activity of a flight crew in an aircraft. As a result, when significant exercise was included in these studies, it was usually in the form of short periods of work with longer periods of rest between each work period. The EVA work environment is different. Although average work rates are not high, activity is almost continuous with short intervals of rest. This was the nature of the work during the current tests which involved repetitive upper body exercise.

In attempting to replicate the type of exercise done during extravehicular activity, attention was paid to the overall energy cost of the exercise,

the force of various muscle groups on different joints, and the rate of repetition of joint flexure. The measurements of the energy cost of the Apollo and Skylab EVA's were used as a guide in selecting the work energy cost of the activities. Observation of crews practicing EVA activities was used in determining the type and frequency of limb movement. The activities were then modified somewhat after crewmen who had performed actual EVA's evaluated these work tasks. It is likely that the incidence of symptoms in this test series is related to the exercise which we believe is representative of that to be expected during EVA.

Duration of Exposure. The first series of tests involved a simulated EVA period of three hours. In contrast, many of the studies that were used in the predictive analysis were two hours or less in length. The period of exposure in test Series 2 and 3 was extended because of the late appearance of symptoms. In Series 3, three of the 19 symptoms were reported in the sixth hour.

Reporting of Symptoms. Every effort was made to identify any and all symptoms of decompression sickness in these studies. It is possible that the procedures in these tests may have led to greater sensitivity to reporting minor symptoms of decompression sickness. In each of the test series, subjects were briefed extensively on decompression sickness. In Series 1 Tests, we relied on spontaneous reporting of symptoms. In Series 2 and 3 runs, subjects were asked a standard question before the test and at the end of each hour of the test. In addition, subjects were encouraged to report any symptom or sensation when it occurred. Subjects were instructed to report all unusual sensations and that the investigator would determine whether or not the symptoms were indicative of decompression sickness. All subjects in Series 2 and 3 tests were exposed to at least a 3-hour sea level dry run with the upper body exercises. During the dry run, the same standard questions were asked of the crewmen. Many of the symptoms reported in this test series during the altitude chamber exposures were quite mild (Grade 1) and may not have been reported in studies where a similar emphasis on symptom reporting was not stressed.

Validity of Symptoms. In order for symptoms to be identified as symptoms of decompression sickness, verification was required. The following signs were considered verification of symptoms.

(1) The clear disappearance of symptoms upon recompression.

(2) The detection of venous bubbles with a doppler bubble detector after movement of the same limb prior to the report of symptoms.

(3) Progression and extension of symptoms typical of simple limb bends.

In most instances there were multiple verification of symptoms and little doubt as to their nature. Subjects reported a completely different sensation from verified decompression symptoms as compared to sensations of muscle strain that were noticed during sea level dry runs and during some altitude chamber tests. There were two instances of suspicious symptoms in Series 3 that were not verified. They disappeared prior to the end of the 6-hour exposure and were not counted as decompression sickness.

Progression of Symptoms. Reports of decompression sickness in the literature frequently involve a fairly rapid progression of symptoms from mild to severe. This was not the case in these series of tests. In most cases, symptoms increased in severity slowly, if at all; and in some cases, the symptoms decreased in severity or disappeared.

Severity of Symptoms. In Series 1 tests, subjects were taken out of the chamber after identification of any symptom. However, even in Series 1 Tests, symptoms were mild and in some cases abort was delayed until it was certain that symptoms were indeed present. In Series 2 and 3, the symptom grading shown in Table 2 was utilized and most symptoms were Grade 1 or 2. In the combined 133 Series 2 and 3 Tests, four Grade 3 symptoms occurred (3%) that interfered with the ability of the subjects to perform their work tasks by causing them to limp or favor one limb in the exercise activities.

Comparison of Symptom Incidence Between Tests Involving 10.2 psi Stage Decompression and Tests Involving O_2 Prebreathe and Between Series 2 and Series 3 Tests. At the end of the Series 2 Tests, the overall incidence of symptoms after the 10.2 psi staged protocol was similar to the incidence of symptoms following the 3.5-hour O_2 prebreathe protocol. However, there were some causes for concern. One of the Grade 3 symptoms following the 10.2 psi protocol was a systemic response. This subject experienced a sudden onset of exhaustion in conjunction with a cold sweat and a red and white pattern of marbling on the chest. The subject was returned to sea level. The fatigue and cold sweat disappeared during recompression to 14.7 psi and the skin marbling diminished and disappeared over the next 10-15 minutes. These symptoms are indicative of a systemic response related to either the cardiopulmonary system or the central nervous system. A second Grade 3 symptom following the 10.2 psi protocol was due to simple limb bends pain. A third subject with Grade 2 symptoms of mild pain in the knee had a reoccurrence of pain one hour after pain disappeared upon recompression to site pressure. This subject was treated in the hyperbaric chamber where the symptom promptly disappeared. A fourth subject reported Grade 1 symptoms that were identified post test as slight sensations of numbness moving from one leg to the other during the fourth hour of the 4.0-hour exposure. These symptoms may have been indicative of neurological involvement. Both the subject with the systemic response and the subject who experienced reoccurrence of pain exhibited very high bubbling rates as measured by the doppler. The subject who experienced the systemic symptom and a subject in the first series reported heavy bubbling and symptoms within the first 20 minutes exposure to decompression after the 10.2 psi protocol. In contrast, after 3.5 hour O_2 prebreathing, only symptoms of simple limb bends were seen. Only one Grade 3 symptom was detected and the earliest instances of bubbling or symptoms were later than the comparable values following the 10.2 psi protocol.

After the completion of the Series 2 Tests, the decision was made to use the 3.5-hour protocol in preparation for the STS-6 EVA and to defer operational use of the 10.2 psi protocol pending additional testing on the protocol. The primary factor in this decision was the nature and severity of the symptoms in some subjects following the use of the 10.2 psi protocol. A theory as to the course of these instances of severe symptoms is that the initial decompression from 14.7 psi to 10.2 psi resulted in formation or growth of bubbles that were not resolved during the 12-hour period and resulted in early and rapid development of symptoms following the decompression from 10.2 psi to 4.3 psi. Series 3 tests were conducted to obtain more data on the effectiveness of the 10.2 psi denitrogenation protocol. The protocol was modified by the addition of one hour of O_2 prebreathe prior to the initial decompression from 14.7 psi to 10.2 psi to reduce the possibility of any bubble formation. Figure 11 compares the symptom incidence following the use of the 10.2 psi Series 2 protocol with the modified 10.2 psi Series 3 protocol. Although there was a reduction in overall symptom with the use of the modified protocol, what is more significant is that the symptoms encountered were milder, there were no Grade 3 symptoms, and no indications of symptoms other than those of simple limb bends. Additionally, there was an increased time of onset of both bubbles and symptoms using the modified protocol (Table 8), and also a decrease in the average grade of bubbles (Figure 12). The combination of all these factors indicates that the modified 10.2 psi protocol is comparable to the use of a 4.0-hour prebreathe and has no tendency to result in the more severe symptoms seen after use of the 10.2 psi protocol in the Series 2 tests.

Figure 13 compares the symptom incidence following the 3.5-hour protocol with the 4.0-hour protocol. There was a reduction in the overall incidence of symptoms with the addition of a 30-minute prebreathe period, but no reduction in incidence of Grade 2 and 3 symptoms, and not much difference in the average time of onset of symptoms. Some decrease in symptoms was anticipated and obtained with the addition of 30 minutes prebreathe. There was no indication from this data of a critical O_2 prebreathe duration at 4 hours that dramatically effects the incidence or severity of symptoms.

Due possibly to the relatively low number of subjects, a comparison of symptom incidence of the four protocols tested in Series 2 and 3 does not show a statistically significant difference between the protocols; however, when all the data on these tests are considered, there is a basis for a conservative judgment that the modified 10.2 psi and the 4.0-hour O_2 prebreathe are the most operationally acceptable of the protocols.

Venous Bubbles. An important data measurement during this study was the detection of bubbles passing through the pulmonary artery after having traversed the heart. The grading system used in the measurement technique provides a semi-quantitive assessment of the number of bubbles passing through the heart. The measurement procedure involves sensing of bubbles after sequential movement of limbs with a short, quiet period after each limb movement. Typically, bubbles are detected passing through the pulmonary artery within a few seconds of limb movement as though the bubbles were released into the venous blood stream upon movement of the limb.

The significance of the presence and quantity of venous bubbles is related to the source of these bubbles and to the competing theories of the etiology and relationship of different types of altitude decompression sickness. The most persuasive theory as stated by Hills[4] is that simple limb bends pain is caused by extravascular bubbles forming in tissues such as tendon that restrict the bubbles from expansion and that the pain is the result of pressure on nerve endings. He has also suggested that venous bubbles may originate from soft tissue with a high nitrogen solubility and poor perfusion such as fat, and that gas expansion in such a tissue would not apply pressure on nerve endings but could result in rupture of cell walls and release of bubbles into capillaries and then through the venous system. If this were the case, there would be no cause and effect relationship between limb bends pain and venous bubbles, and any correlation of bubbles and symptoms would be due to parallel formation or growth of bubbles.

An alternate theory as to the etiology of limb bends pain is that the symptoms are (in whole or in part) a result of ischemia from bubbles formed or released into capillaries and blocking oxygenation of tissues. If this were the case, there might be a cause and effect relationship or at least a close relationship between venous bubbles and limb bends pain; however, some of the characteristics of limb bends are not explained by the ischemic theory.

Adams[5] has reported a strong, almost perfect correlation between the limb from which bubbles were detected and the limb in which symptoms later appeared. This data is very suggestive of a close relationship between bends symptoms and venous bubbles.

The more serious symptoms of altitude decompression sickness are also likely to be related to venous bubbles. The lungs can filter large quantities of bubbles, but there is evidence[6] that an overload of bubbles to the lungs can result in bubbles passing into the arterial circulation. Arterial bubbles causing ischemia are very likely the initial cause of central nervous system symptoms of decompression sickness.

Bubble Incidence. All of the denitrogenation protocols in Series 1-3 resulted in a high incidence (46% to 66%) of venous bubbles as detected by the doppler detector. Of the subjects who experienced bubbles, 47% experienced symptoms in the same test. Only 1 of the 45 subjects who experienced decompression sickness symptoms did not have bubbles in the same limb prior to the initial report of symptoms or within a 16-minute doppler sensor measurement cycle. This individual had bubbles detected after movement of the left leg prior to report of Grade 1 symptoms in the right arm but never had bubbles detected after movement of the right arm. This is the same type of relationship between site of bubbles and site of symptoms reported by Adams[5]. In most cases, bubbling was first detected in the lower limbs; however, it was very common for bubbling to spread to other limbs, particularly when Grade 3 and 4 bubbles were detected.

The average bubble grade experienced in test Series 1, 2, 3 is presented as a function of test elapsed time in Figures 14, 15, and 16. The mean bubble grade was about the same after use of the 3.5-hour O_2 prebreathe protocol, the 10.2 psi staged decompression protocol, and the 4.0-hour O_2 prebreathe. The 10.2 psi protocol resulted in a lower $\bar{x}$ bubble grade. It was not until

exposure time was extended to 6 hours in Series 3 that a clear pattern of bubbles diminishing and disappearing became clear (Figure 16). Since many subjects experienced no bubbles and since there is some initiation of bubbling late in the chamber test, Figure 17 is not representative of a pattern of bubble development in an individual subject. Figure 18 is a plot of the average bubble grade in subjects who experienced bubbling. The time base is from the initial detection of bubbles in each subject. This figure accentuates the difference in bubble grade between the 10.2 psi protocol and shows the course of bubble grade increase and decrease in an exposure where bubbles are detected. The significance of this plot is an indication that in decompressions of the type in these test series, the process of formation or release of bubbles to the blood stream and transport and removal from the blood in the lungs depletes the store of dissolved nitrogen in the body so that after a period of 4 to 5 hours bubbling has greatly diminished or disappeared. This decline and disappearance of venous bubbles has not been previously reported.

The Significance of Very Heavy Bubbling Detected by the Doppler Sensor. Very heavy, continuous bubbling may serve as a warning of the possibility of the occurrence of more serious forms of decompression sickness. The one subject in Series 2 who experienced systemic symptoms and the one subject who had reoccurrence of symptoms at 14.7 psi both had very heavy Grade 4 bubbling as detected by the doppler sensor. The bubbling was continuous with and without limb movements, and the doppler audio signal due to the bubbles was of such volume as to completely cover the normal doppler audio signal due to heart movement. Adams (personal communication) has detected the same type of heavy bubbling in one subject prior to an incidence of central nervous system altitude decompression sickness.

Repeatability of Response in an Individual. Table 9 presents the data from Series 2 with the subjects arranged in order of the severity of symptoms in the test exposure of Series 2. This table shows the tendency of subjects experiencing no symptoms or mild symptoms on one protocol to have a similar response on the second protocol and for those experiencing more serious symptoms to experience more serious symptoms on the second protocol. These tests were conducted with an interval of 5 days to 3 weeks.

Table 10 presents the data on those subjects who participated in both Series 2 tests and Series 3 tests in a similar format arranged in order of severity of symptoms. The repeatability of response appears to be less predictable when the interval between exposure is 6 months rather than 1 or 2 weeks.

Effect of Back-to-Back EVA's on Incidence and Severity of Bubbles and Symptoms. Repeated daily exposure to altitude exposures requiring denitrogenation have been operationally prohibited by both the Air Force in its operations and by NASA for chamber exposures. A nominal 40-48 hour interval between exposures has been required. Adams[7] reported an increased incidence of altitude decompression sickness during zero prebreathe exposures to chamber flights at 22,000 feet when a physiological training type chamber exposure was conducted with subjects the preceding day. The basis for concern regarding repeated decompressions on consecutive days is that bubbles or bubble nuclei generated or increased in size during the first exposure might remain in body tissues and precipitate a rapid growth of bubbles during the second exposure.

The results of our back-to-back exposures, both after 4.0-hour prebreathe protocols and after modified 10.2 psi protocols, do not lend credence to a concern regarding daily exposures to our test protocols. The incidence of bubbles and symptoms during back-to-back exposures is no greater than during first exposures (Figure 8). The lower mean grade of bubbles seen in the repeat tests (Figure 18) and the longer time to onset of both bubbles and symptoms (Figure 19 and Table 8) indicate that the reaction to the repeated exposure after 17 hours is more benign than that to the original exposure.

Operational Impact of Reported Symptom Incidence. The overall incidence of symptoms in the 173 combined man tests in Series 1, 2, and 3 was 26%. This is a much higher incidence of symptoms than had been anticipated. However, the majority of these symptoms were minor and did not interfere with the completion of the simulated EVA. Grade 1 symptoms would have no operational impact on an EVA. It is very doubtful if these symptoms would be perceptable to a crewman in a pressure suit. Grade 2 symptoms would have at most a minor impact on EVA simply due to the presence of another minor ache or pain to contend with in the pressure suit. Finally, the presence of Grade 3 symptoms would have an effect on EVA through impaired performance or the need to abort the EVA. Of the 132 man runs in the combined Series 2 and 3 Tests, there were four Grade 3 symptoms or 3% of the total.

All of these numbers refer to symptoms of simple limb bends and to a symptom scale that emphasizes performance impact. However, the rate of occurrence of simple limb bends in a population at risk to decompression sickness may be an indicator of increased risk of more serious forms of altitude decompression sickness involving the lung and cardiovascular system or the central nervous system. There was one clear incident in this test series in which the limiting symptoms were systemic rather than those of simple limb bends and two less clear incidences of possible systemic response or presystemic response related to either the cardiopulmonary system or the central nervous system. These three incidents all occurred after the use of the unmodified 10.2 psi protocol. There were no similar incidents following use of the modified 10.2 psi protocol, the 3.5-hour O_2 prebreathe protocol, or the 4.0-hour O_2 prebreathe protocol.

Altitude chamber tests have been conducted at JSC over the past 18 years with a minimum requirement for O_2 prebreathing of 3 hours. In this time period, several hundred (conservatively more than 600) chamber tests have been conducted with only two incidences of bends symptoms, both of which were associated with breaks in prebreathe. There have been no incidences of decompression sickness reported in the last 10 years. Many of these tests involved short exposures and little activity, but at least one-third of these exposures involved exposures and activities comparable to those in the current study. Although some minor symptoms may have gone unnoticed or unreported, there can be no doubt that significant cardiovascular or central nervous symptoms would have been detected and were not.

It is difficult to estimate the potential incidence of more serious forms of decompression sickness from the results of this study, but the increased

incidence of limb bends in all of the protocols used in these studies relative to the incidence of limb bends in studies of shorter duration and lower exercise level is a cause for concern as to the potential for incidence of cardiopulmonary or neural symptoms.

CONCLUSIONS:

a. A denitrogenation protocol (the modified 10.2 psi protocol) that minimizes O_2 prebreathe in the EMU and facilitates EVA has been defined and verified to provide protection equivalent or better than that provided by the 3.5-hour O_2 insuit prebreathe used on STS-6.

b. Repetition of a decompression simulating that of an EVA after 17 hours did not increase the incidence or severity of symptoms or doppler detected venous bubbles nor did it decrease the time of onset of symptoms or bubbles.

c. Symptoms of decompression sickness in these tests involved primarily the lower limbs whether exercise included lower body exercise or was limited primarily to upper body exercise.

d. In tests involving 6-hour simulated EVA's, there was diminishment or disappearance of doppler detected venous bubbles and stabilization diminishment or disappearance of minor symptoms of limb bends.

e. The incidence of altitude decompression sickness in all four of the major protocols examined in this test series was higher than anticipated prior to the test initiation. Based on the overall incidence of symptoms in Test Series 1, 2, and 3 and on the incidence of symptoms involving performance decrement in Test Series 2 and 3, there is probability (20-30%) of very mild symptoms of decompression sickness, and a possibility (2-3%) of symptoms that, if occurring during an EVA, would require EVA abort.

RECOMMENDATIONS:

a. It is recommended that the modified 10.2 psi protocol, (consisting of 1 hour prebreathe at 14.7 psi, prior to decompression to a 10.2 psi cabin pressure with a 26% O_2 concentration followed by a 12-hour exposure and completed by a 40-minute O_2 prebreathe in the pressure suit) for pre-EVA denitrogenation be baselined for Shuttle EVA.

b. That the 3.5-hour O_2 prebreathe protocol used on STS-6 be retained as an acceptable bends prevention procedure for single EVA's.

c. That the requirement for a 40-hour interval between EVA's be eliminated; that EVA's be allowed on consecutive days; and that a 17-hour interval between EVA's be required pending further tests to evaluate shorter intervals.

d. That we pursue and prepare procedures for inflight treatment of decompression sickness, should it occur, and that we include the use of hyperbaric pressures to the extent that can be attained.

e. That we pursue as a goal the development of procedures, equipment, and techniques that will eliminate the need for any prebreathing prior to EVA and eliminate any symptom, regardless of type or level, of decompression sickness.

Table 1

PHYSICAL CHARACTERISTICS

	SUBJECTS			Male Astronauts
	Series 1	Series 2	Series 3	
NUMBER OF SUBJECTS	36	23	35	
Age - yrs.				
Range	21 - 46	21 - 44	22 - 50	28 - 57
$\bar{X}$	33	32	31	42
% Body Fat				
Range	6.0 - 23.0	5.9 - 23.3	6.4 - 25.2	3.0 - 25.6
$\bar{X}$	12.3	11.8	14.2	15
Physical Activity Scale 0-7				
Range	1 - 7	1 - 7	1 - 7	1 - 7
$\bar{X}$	5.1	5.3	4.9	6.1
Weight - lbs.				
Range	123 - 205	128 - 194	140 - 213	124 - 207
$\bar{X}$	164	163	173	166
Height - in.				
Range	65 - 76	65 - 74	65 - 74	65 - 72
$\bar{X}$	70	70	69	70

Table 2

SYMPTOM SCALE

0 - No pain or discomfort. No report of pain or discomfort.

1 - Joint awareness. Reports of awareness or fullness of joints. Subject does not have discomfort and may not be certain that sensation is other than a normal feeling due to fatigue.

2 - Threshold of pain. Reporting of discomfort, ache, or intermittent pain. The sensation does not interfere with activity. This feeling may be likened by the subject to the transient pain or stiffness that occurs during warmup exercises.

3 - Pain. Reports of continuous pain rather than ache or discomfort. Subject indicates that pain is just starting to interfere with activity. Some favoring of affected limb is reported or noticed by observers.

4 - Progressive pain. Reports increased intensity of pain. Subject reports that pain is affecting performance up to 10%. Pain is definitely worse with exercise. Observer notices subject to have reluctance in moving a joint. Subject may try to modify exercise regimen to avoid pain.

5 - Substantial pain. Subject reports very definite substantial pain in joints. Performance decrement estimated to be in range of 10-25%. Observer notices a change in activity pattern and favoring of affected limb is readily discernible.

6 - Threshold of tolerance. Subject reports that pain is really bad. The subject prefers to be still and not move. Subject can move extremities but only with effort. Definitely does not want pain to increase.

7 - Disabling pain. Pain is of such intensity that the subject requires assistance in order to move.

Table 3

TEST RESULTS

12 hours at 10.2 + 40 minutes O_2 N = 13		
Bends incidence	3/13	23%
Bubble incidence Grade 3 or 4	8/13	62%
Bubble incidence Any Grade	10/13	76%
18 hours at 10.2 + 40 minutes O_2 N = 3		
Bends incidence	2/3	66%
Bubble incidence Grade 3 or 4	3/3	100%
12 hours at 10.2 + 90 minutes O_2 N = 9 Step		
Bends incidence	4/9	44%
Bubble incidence Grade 3 or 4	5/9	55%
Bubble incidence Any Grade	6/9	66%
12 hours at 10.2 + 90 minutes O_2 N = 3 Step-in-place		
Bends incidence	1/3	33%
Bubble incidence Grade 3 or 4	1/3	33%
3.5 hours prebreathe on O_2 N = 11		
Bends incidence	4/11	36%
Bubble incidence Grade 3 or 4	7/11	63%

Table 4

BENDS INCIDENCE IN BENDS PREVENTION TEST

	N	Bends	Incidence
12 hours or more at 10.2 psia + 40 min O_2	16	5	31%
12 hours at 10.2 + 90 min O_2	12	4	33%
3.5 or more hours O_2 at SL	11	4	36%

Table 5

DECOMPRESSION SICKNESS SYMPTOMS SERIES 2

3.5 Hour Prebreathe Protocol

	Incidence Ratio	% Incidence	95% Confidence Limits %
Grade 1 symptoms and bubbles	2/22	9.0%	1 - 29
Grade 2 symptoms and bubbles	4/22	18.0%	5 - 40
Grade 3 symptoms and bubbles	1/22	4.5%	0 - 23
Overall symptom incidence	7/22	32.0%	14 - 55
Bubble incidence without symptoms	7/22	32.0%	14 - 55
Overall bubble incidence	14/22	64.0%	41 - 82
Subjects bubble free	8/22	36.0%	17 - 59

10.2 psi Prebreathe Protocol

Grade 1 symptoms and bubbles	2/22	9.0%	1 - 29
Grade 2 symptoms and bubbles	2*/22	9.0%	1 - 29
Grade 3 symptoms and bubbles	2/22	9.0%	1 - 29
Overall symptom incidence	6/22	27.0%	11 - 50
Bubble incidence without symptoms	4/22	18.0%	5 - 40
Overall bubble incidence	10/22	45.0%	24 - 68
Subjects bubble free	12/22	54.0%	32 - 76
Grade 3 symptoms and Grade 2 requiring treatment	3/22	14.0%	3 - 35

* One case reoccurred post test requiring hyperbaric treatment

Table 6

SITE OF SYMPTOM OCCURRENCE

Initial Location of Symptoms	% of Total Symptoms Involving Each Area		
	Series 1	Series 2	Series 3
Lower Body	100%	86%	100%
Upper Body	0%	7%	0%
Simultaneous Upper and Lower Body	0%	7%	0%

Table 7

BENDS TEST III

				%
TOTAL	Symptoms	all	(19)	21
N = 89		Gr 1	(5)	6
		Gr 2	(13)	15
		Gr 3	(1)	1
	Bubbles		(43)	48%
10.2 psi 1st Run	Symptoms	all	(8)	23
N = 35		Gr 1	(5)	14
		Gr 2	(3)	9
		Gr 3	(0)	0
	Bubbles		(20)	57%
10.2 psi 17hr Repeat	Symptoms	all	(2)	17
N = 12		Gr 1	(0)	0
		Gr 2	(2)	17
		Gr 3	(0)	0
	Bubbles		(5)	42%
4hr Prebreathe	Symptoms	all	(6)	21
N = 28		Gr 1	(0)	0
		Gr 2	(5)	18
		Gr 3	(1)	4
	Bubbles		(13)	46%
4hr Prebreathe 17hr Repeat	Symptoms	all	(3)	21
N = 14		Gr 1	(0)	0
		Gr 2	(3)	21
		Gr 3	(0)	0
	Bubbles		(5)	36%
Combined 17hr Repeats	Symptoms	all	(5)	
N = 26		Gr 1	(0)	0
		Gr 2	(5)	19
		Gr 3	(0)	0
	Bubbles		(10)	38%

Table 8

TIME OF ONSET OF OF BUBBLES AND SYMPTOMS

PROCEDURES	N	TIME OF FIRST BUBBLE DETECTION $\bar{X}$	RANGE	N	TIME OF FIRST PAIN REPORT $\bar{X}$	RANGE
10.2 STAGED	10	50	(1-143)	6	128	(18-210)
3.5 HR. PB	15	119	(20-221)	7	138	(60-180)
10.2 STAGED + 60 MINUTE PB	20	126	(24-261)	9	199	(90-329)
4.0 HR. PB	13	73	(4-149)	7	146	(50-354)
10.2 B TO B	5	145	(106-194)	2	275	(215-336)
4.0 B TO B	5	142	(72-221)	3	192	(105-271)

Table 9

REPEATABILITY OF SYMPTOMS SERIES 2

X = Result with 3.5 hours prebreathe
O = Result with 10.2 equilibr.
† = 4 hours prebreathe

NUMBER	BUBBLES					SYMPTOMS							
	0	1	2	3	4	0	1	2	3	4	5	6	7
11	X				O	†O							
10	O		X			†O							
7	XO					XO							
5	XO					XO							
15	XO					XO							
22	O			X		XO							
16	O			X		XO							
17	XO					XO							
6				XO		XO							
14				XO		XO							
18	XO					XO							
4	XO					XO							
21	X					X							
8			X		O	X	O						
13					XO	O	X						
19	O			X		O	X						
1			O	X		X	O						
3	O				XX	XO		X					
12	O				X	O		X					
2					XO			†O					
20				X	O			O	X				
9					XO			X	O				
23					O				O				

Table 10

REPEATABILITY OF SYMPTOMS SERIES-TO-SERIES

	Series 2		Series 3			
Subject No	3.5	10.2	4.0	Repeat 4.0	10.2	Repeat 10.2
41	0	0	0		0	
33	0	0	0			
30	0	0	0			
29	0				0	
37	0,2	0			0	
5	2	0			0,0	0
31	0	1	0			
13	0	0	2			
10	0	0	0	2	0	
8	0	0			2	0
27	0	0	0		2	0

Symptom Grade 0, 1, 2 or 3

Figure 1.- Series 1 test exercises.

Figure 2.- Series 2 and 3 test exercises.

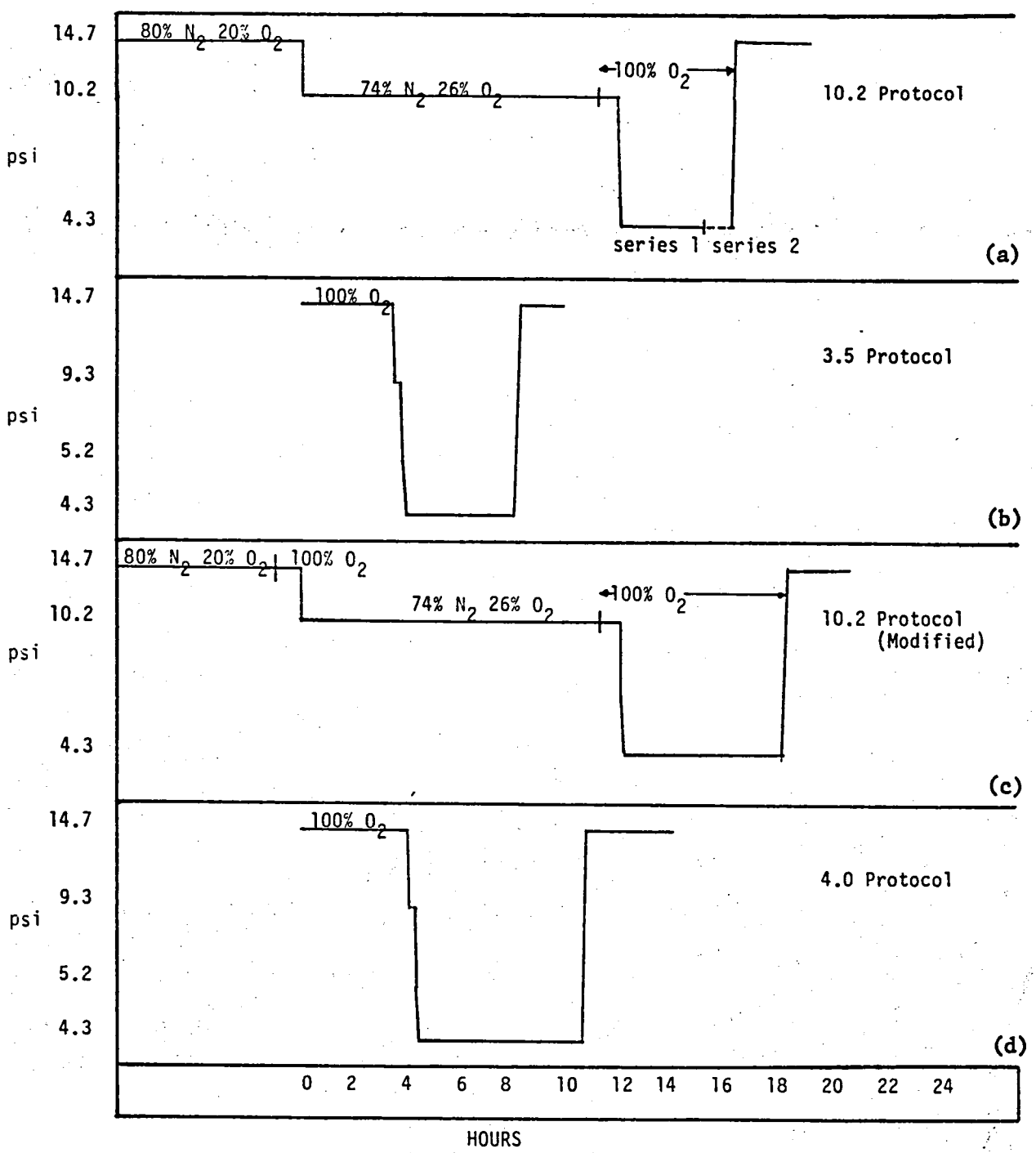

Figure 3.- Denitrogenation protocols.

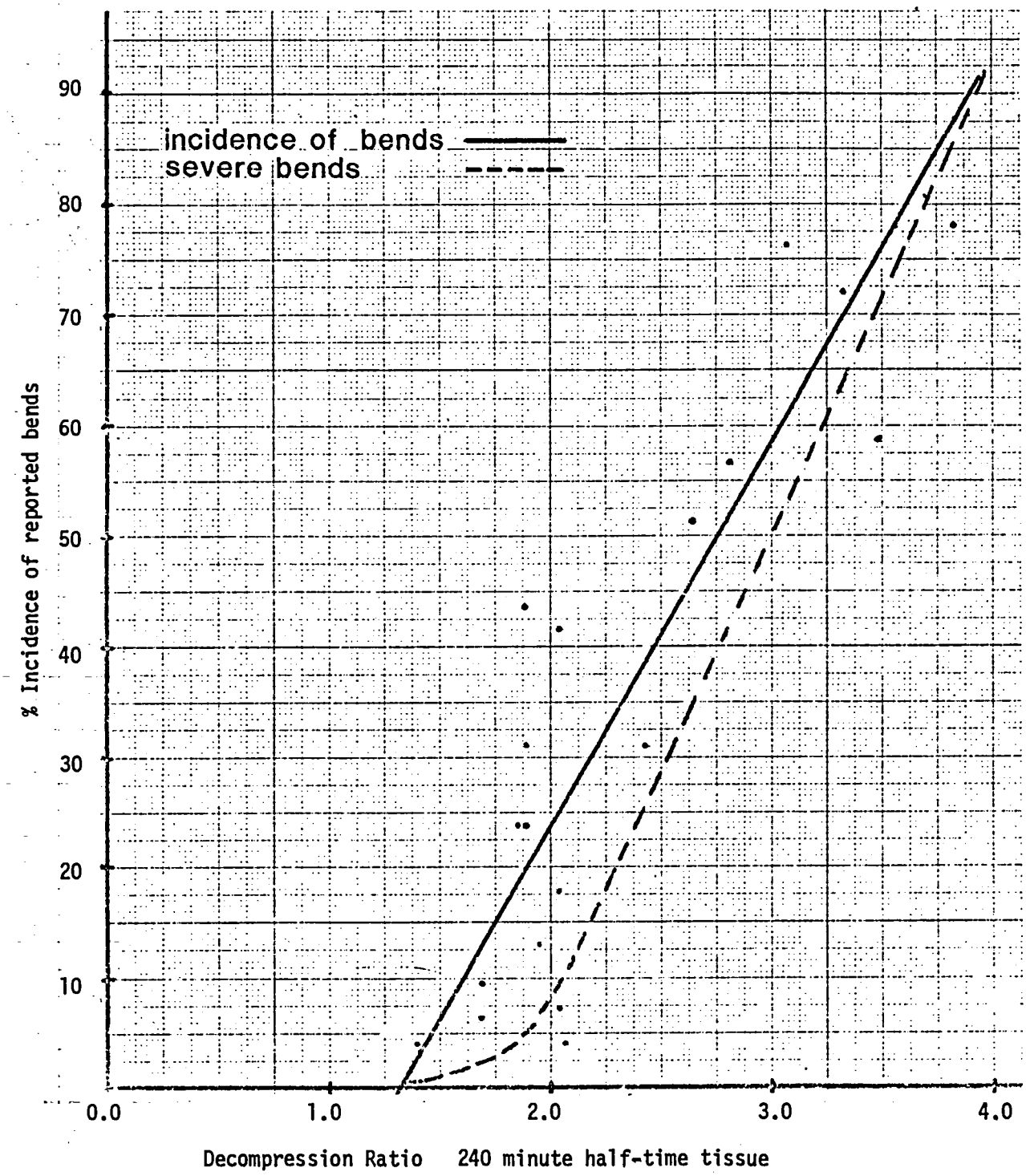

Figure 4.- Bends incidence vs. tissue N_2/final pressure (240-minute tissue).

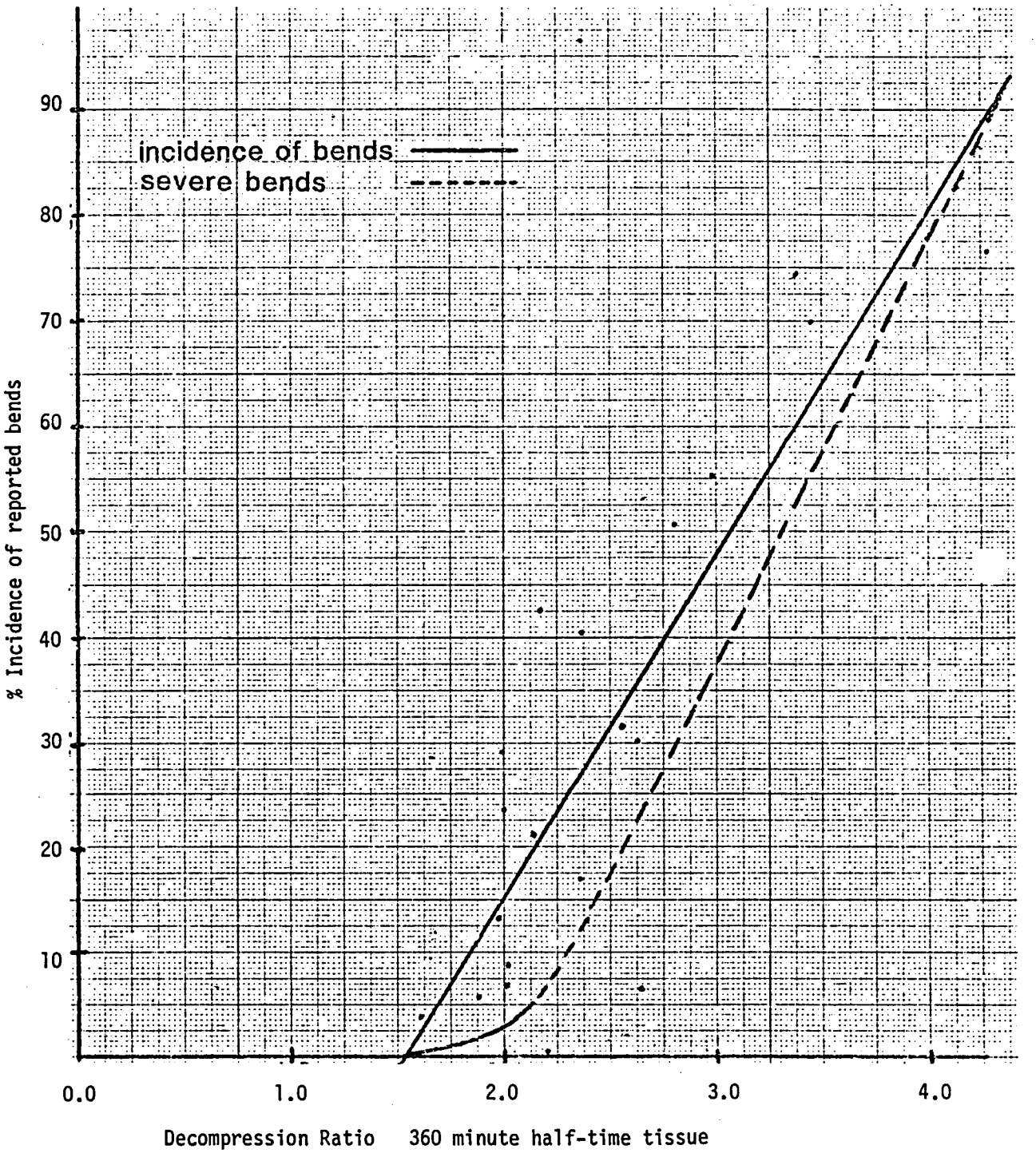

Figure 5.- Bends incidence vs. tissue N_2/final pressure (360-minute tissue).

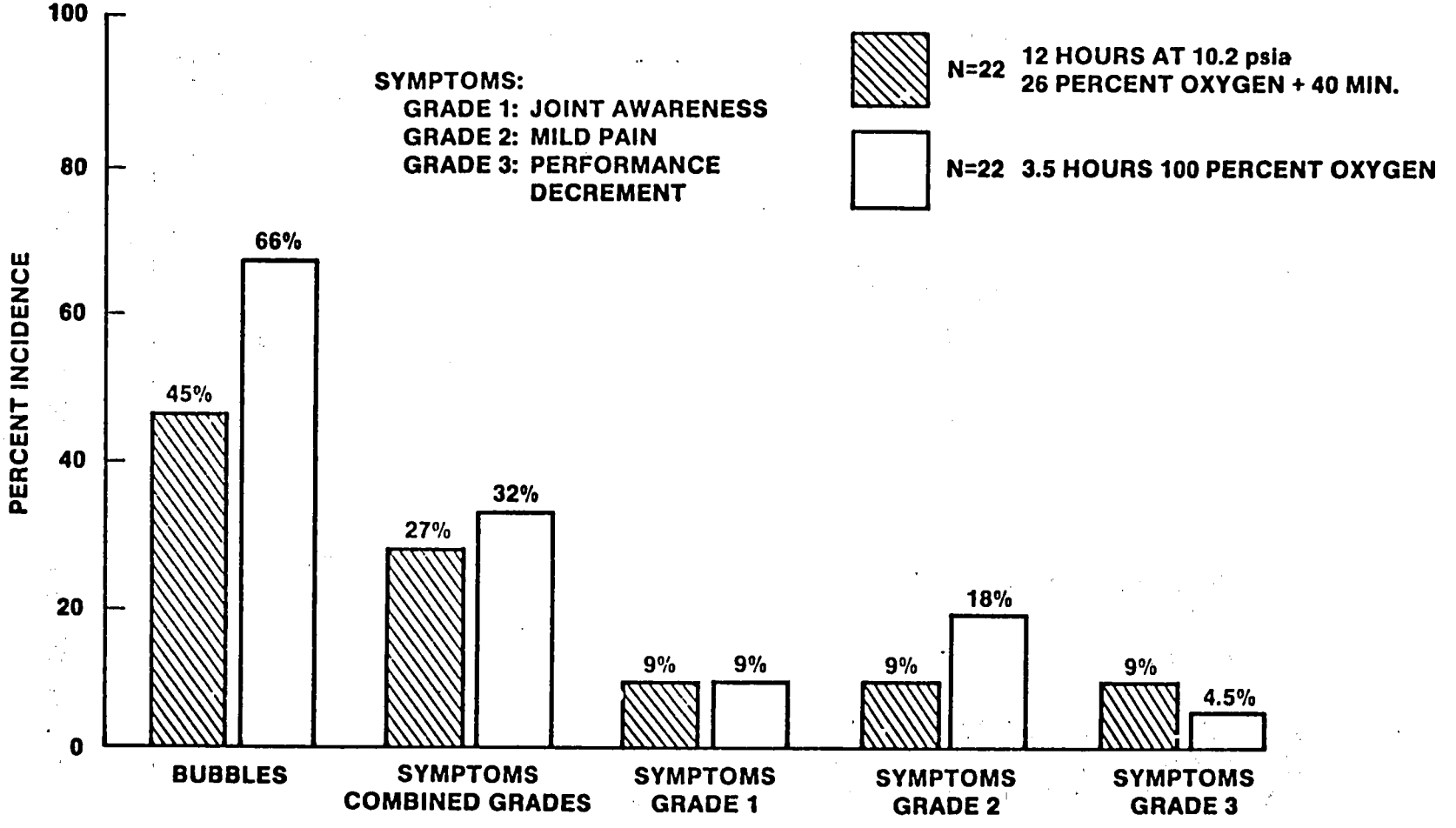

Figure 6.- Bends incidence 10.2 psi protocol vs. 3.5-hour O_2 protocol.

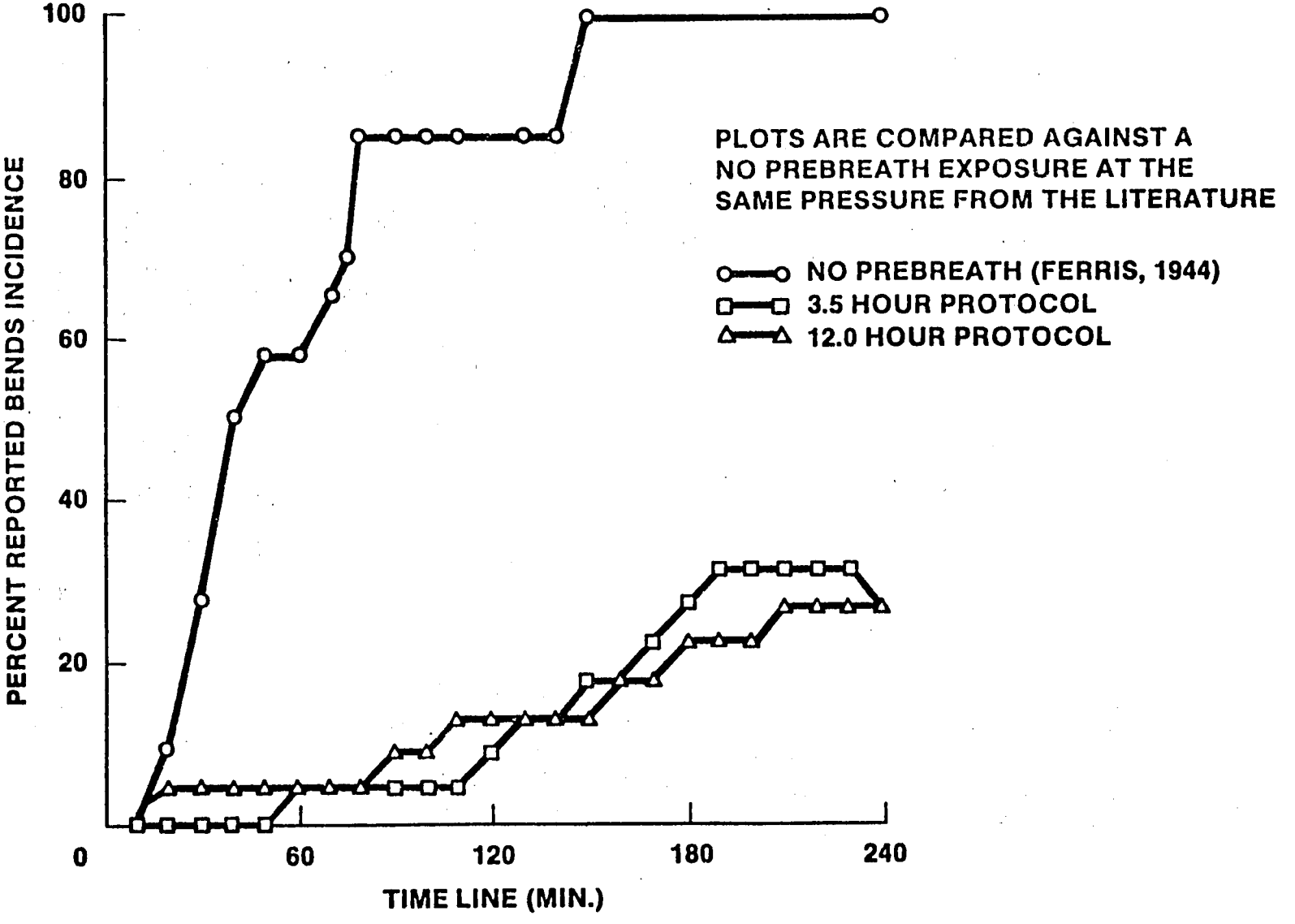

Figure 7.- Series 2 cumulative incidence of symptoms.

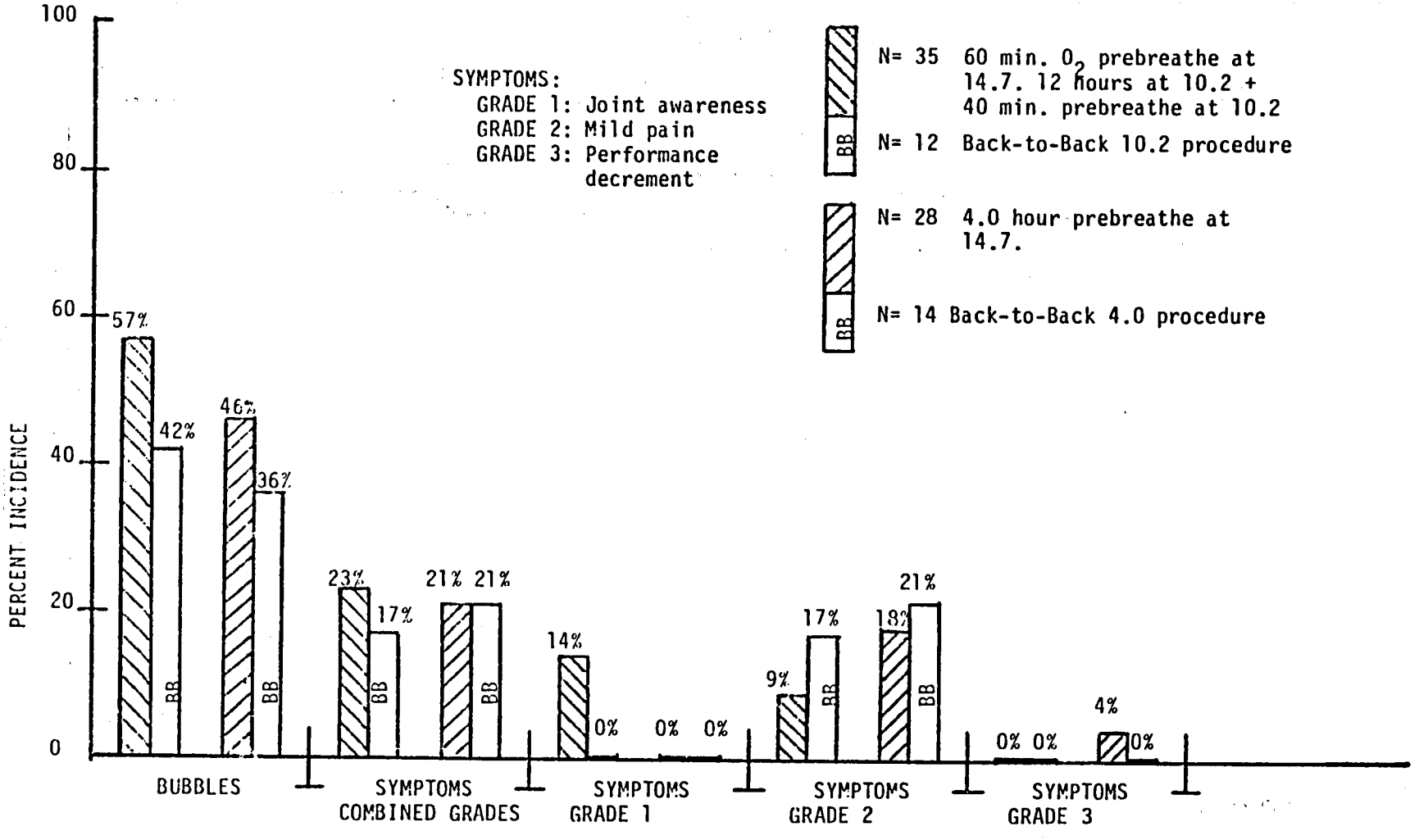

Figure 8.- Bends incidence modified 10.2 psi protocol vs. 4-hour O_2 protocol.

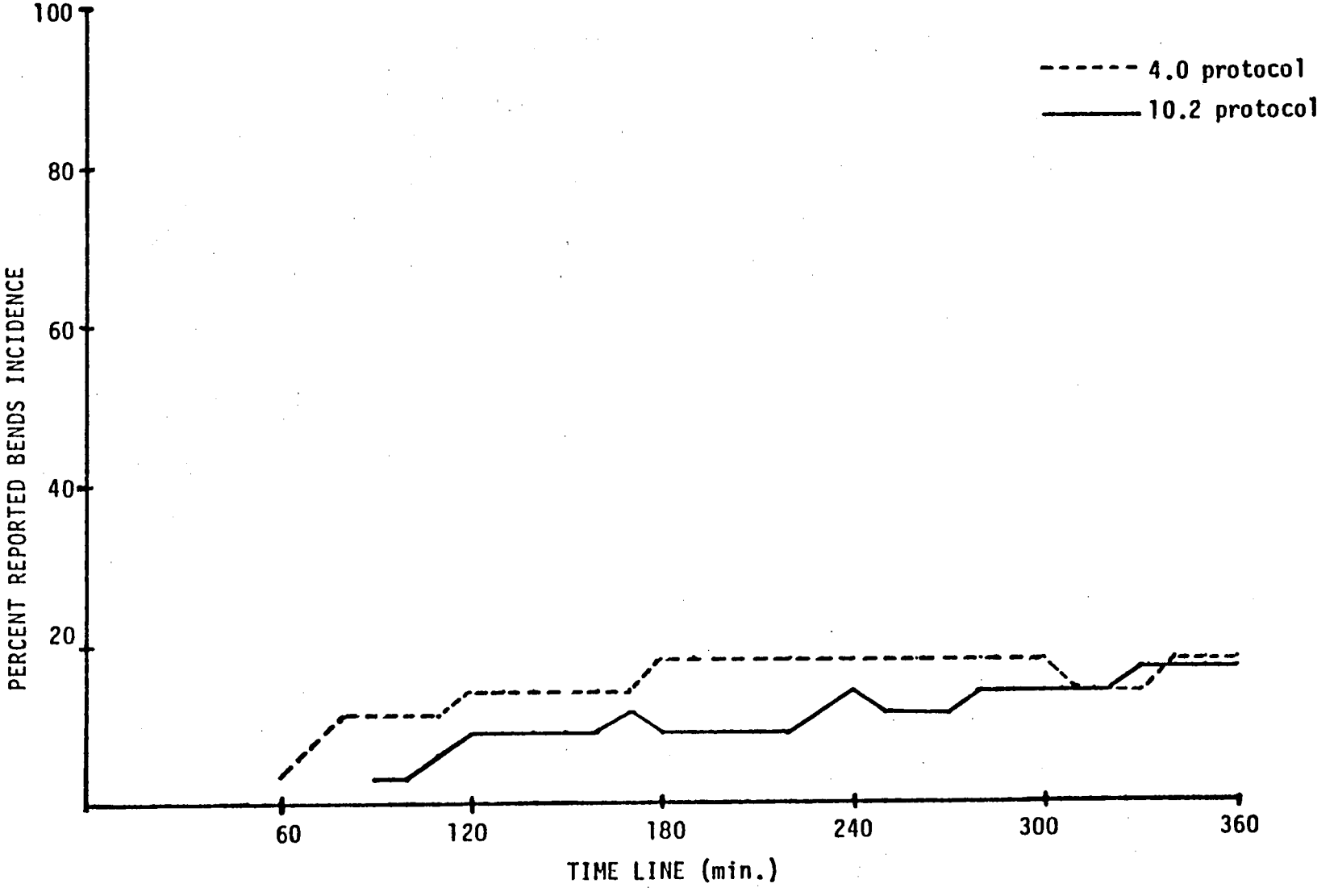

Figure 9.- Series 3 cumulative incidence of symptoms.

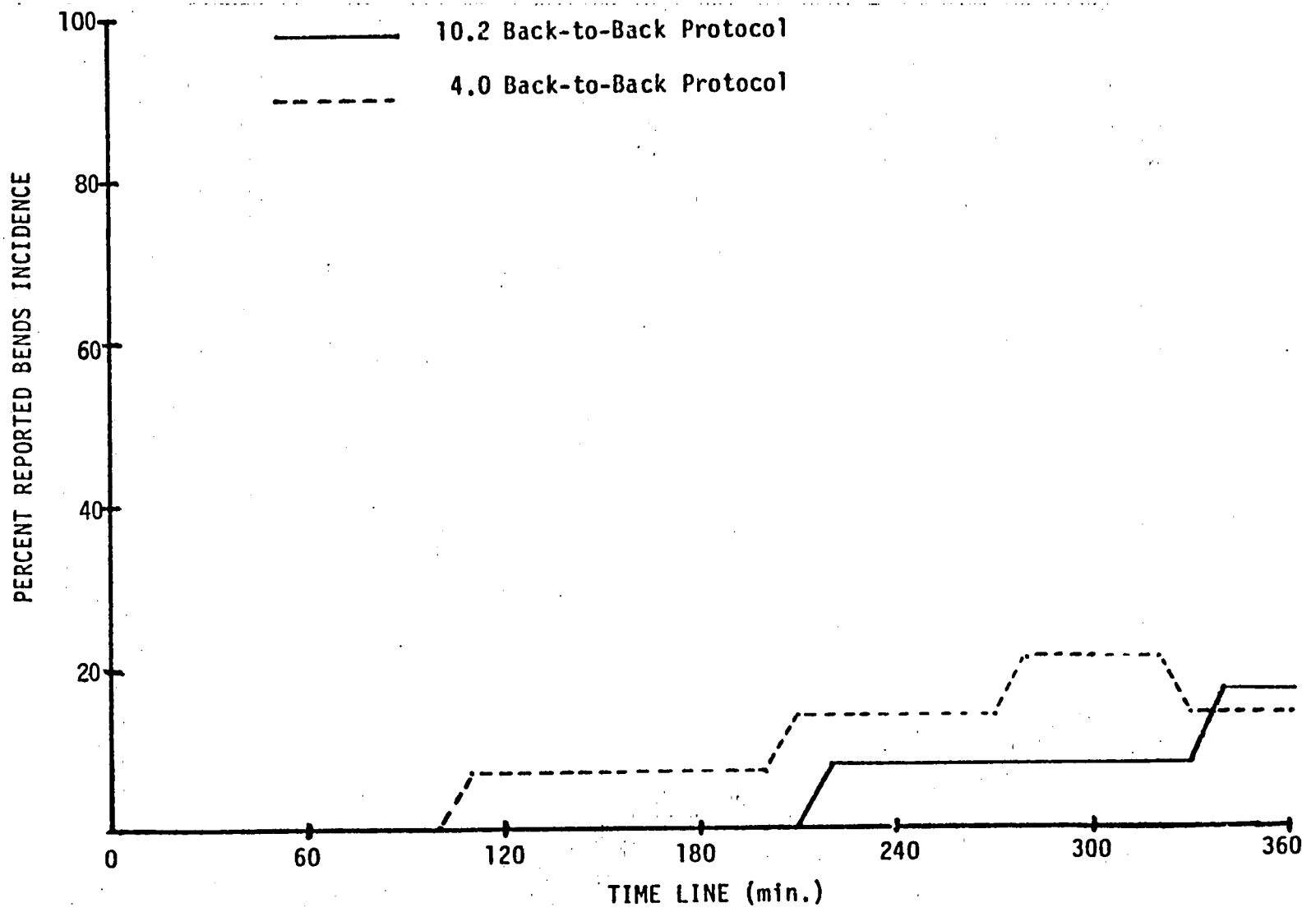

Figure 10.- Cumulative incidence of symptoms - back-to-back tests.

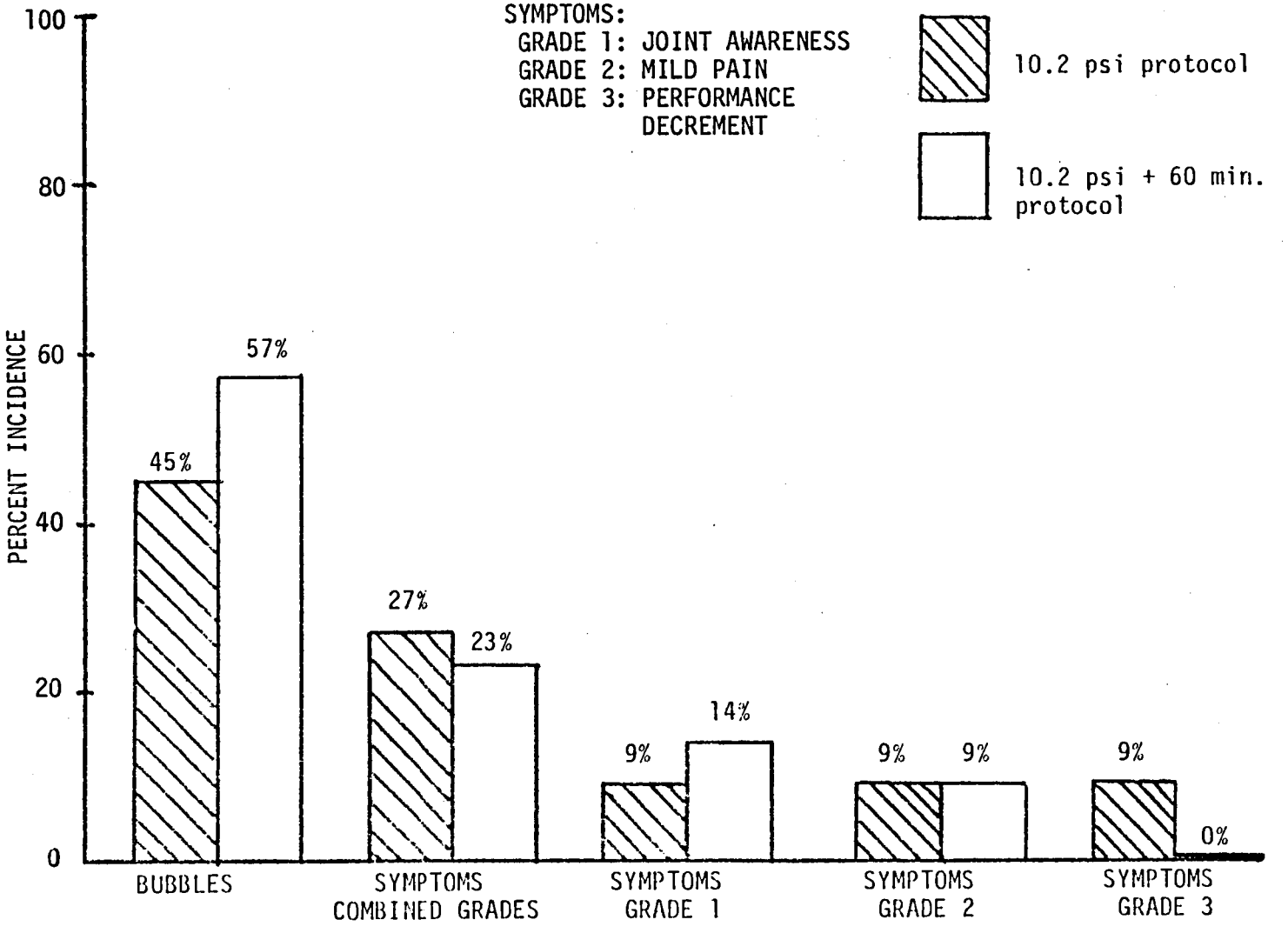

Figure 11.- 10.2 psi vs. modified 10.2 psi protocol - symptom incidence

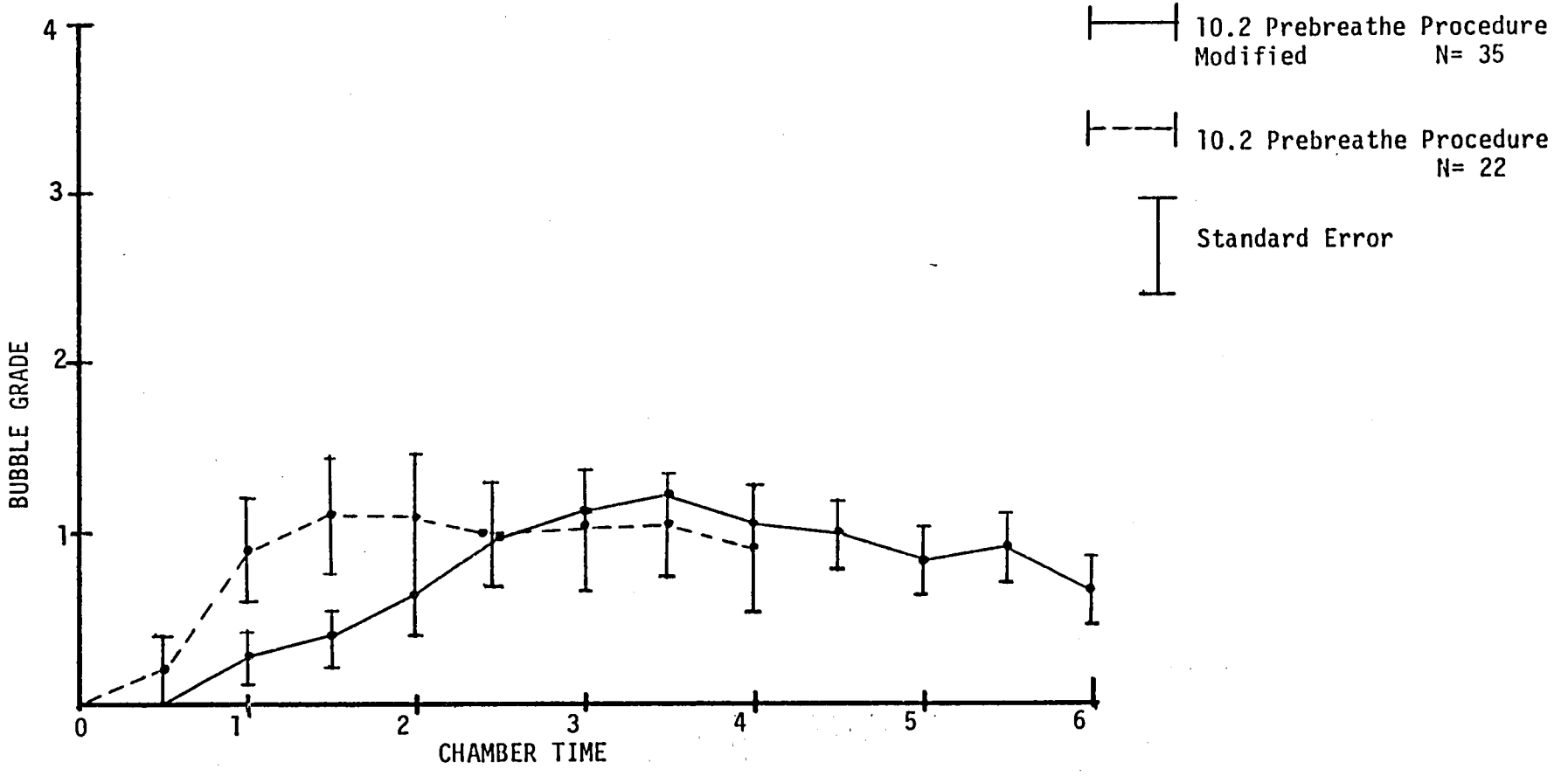

Figure 12.- $\bar{X}$ Bubble grade 10.2 psi protocol vs. modified 10.2 psi protocol.

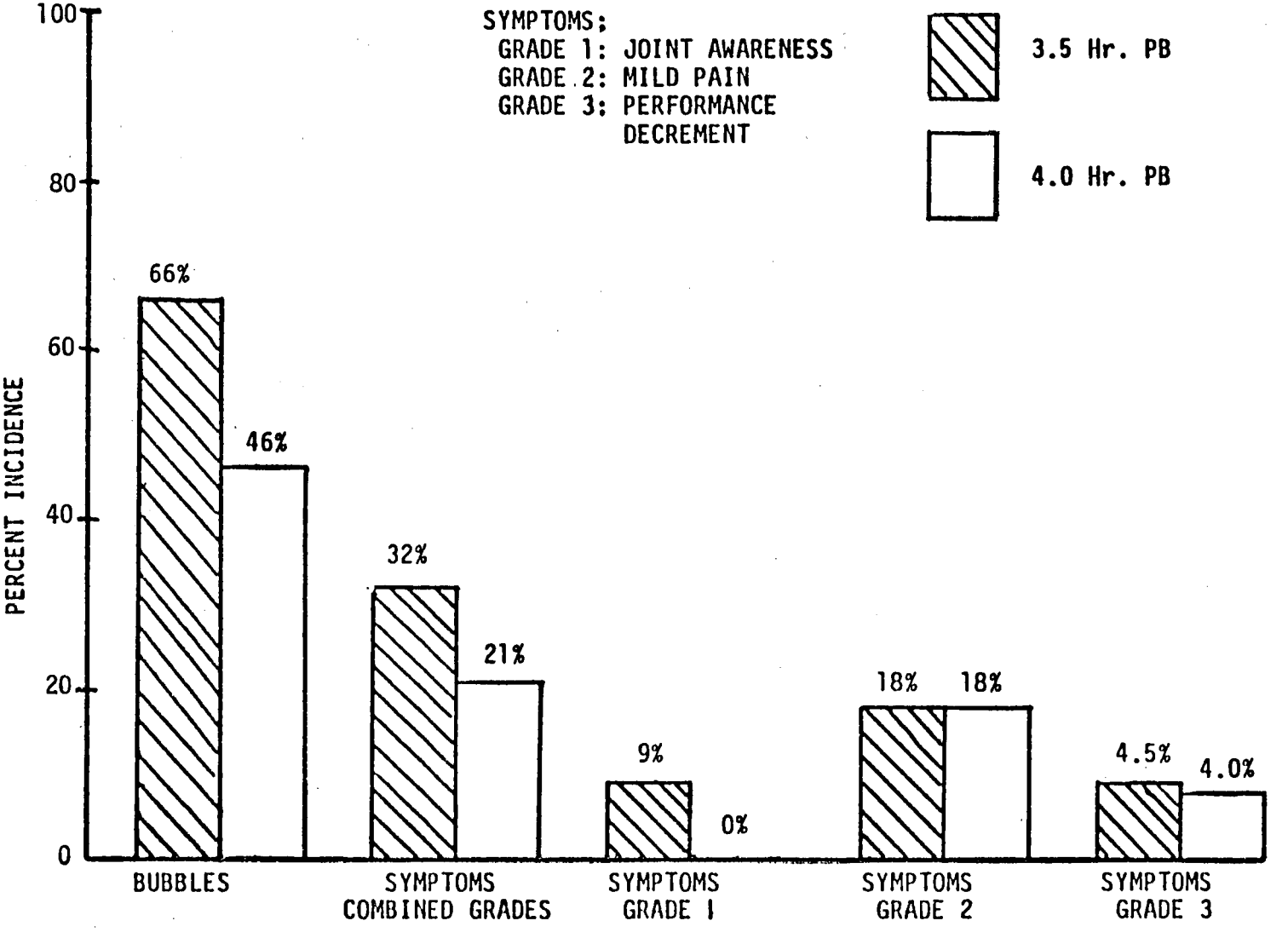

Figure 13.- 3.5-hour protocol vs. 4-hour protocol - symptom incidence.

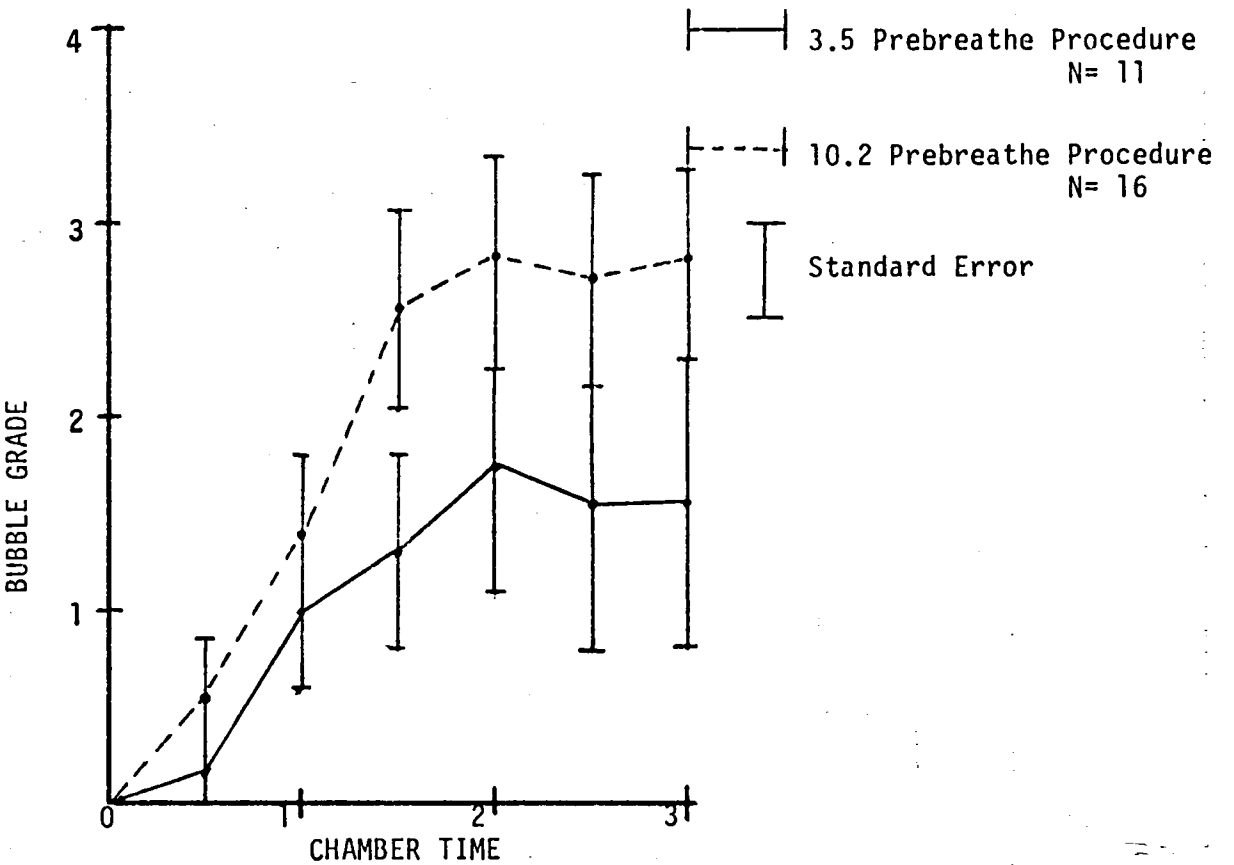

Figure 14.- $\bar{X}$ Bubble grade as a function of time - series 1 - 3.5-hour vs. 10.2 psi.

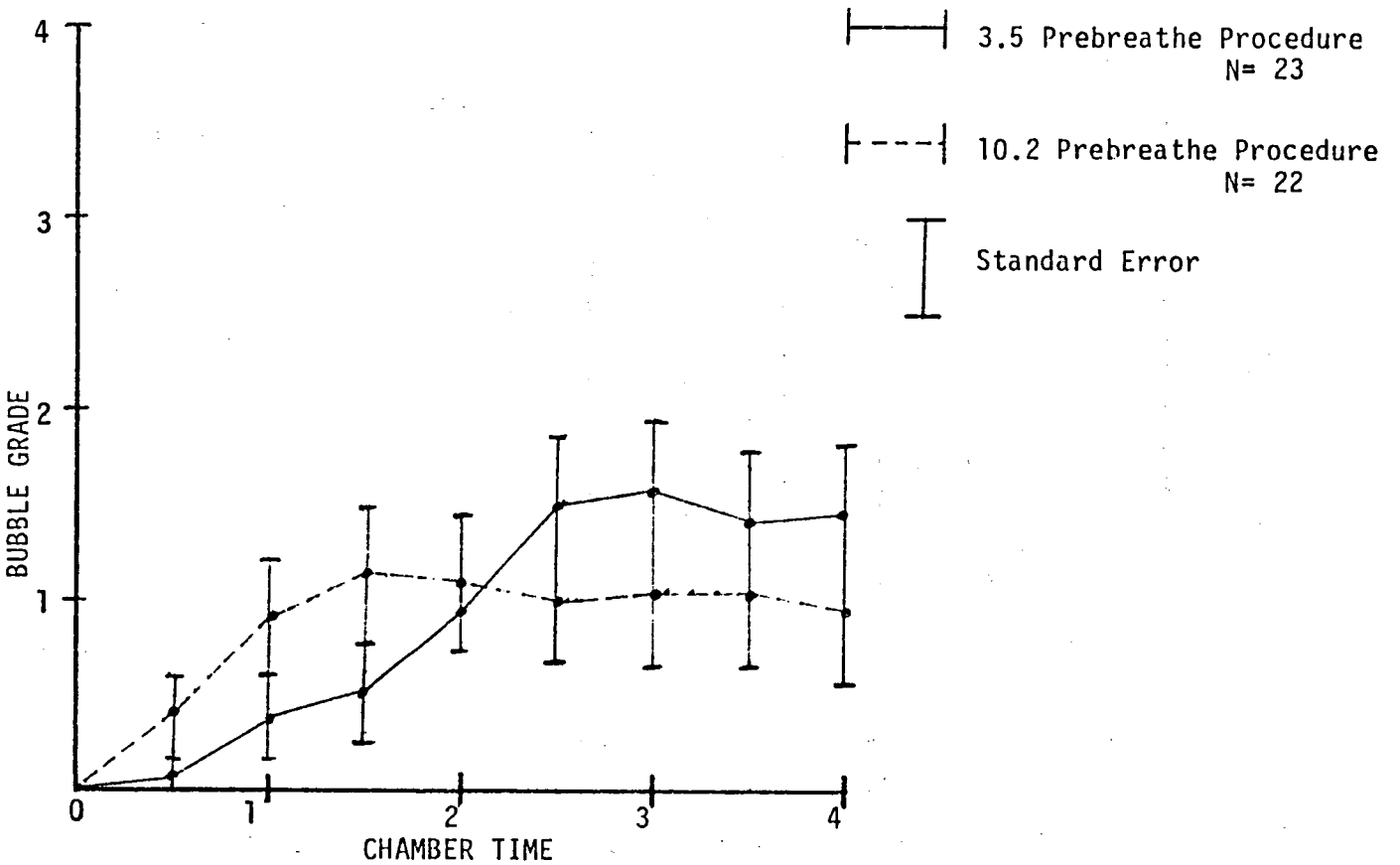

Figure 15.- $\overline{X}$ Bubble grade as a function of time - series 2 - 3.5-hour vs. 10.2 psi.

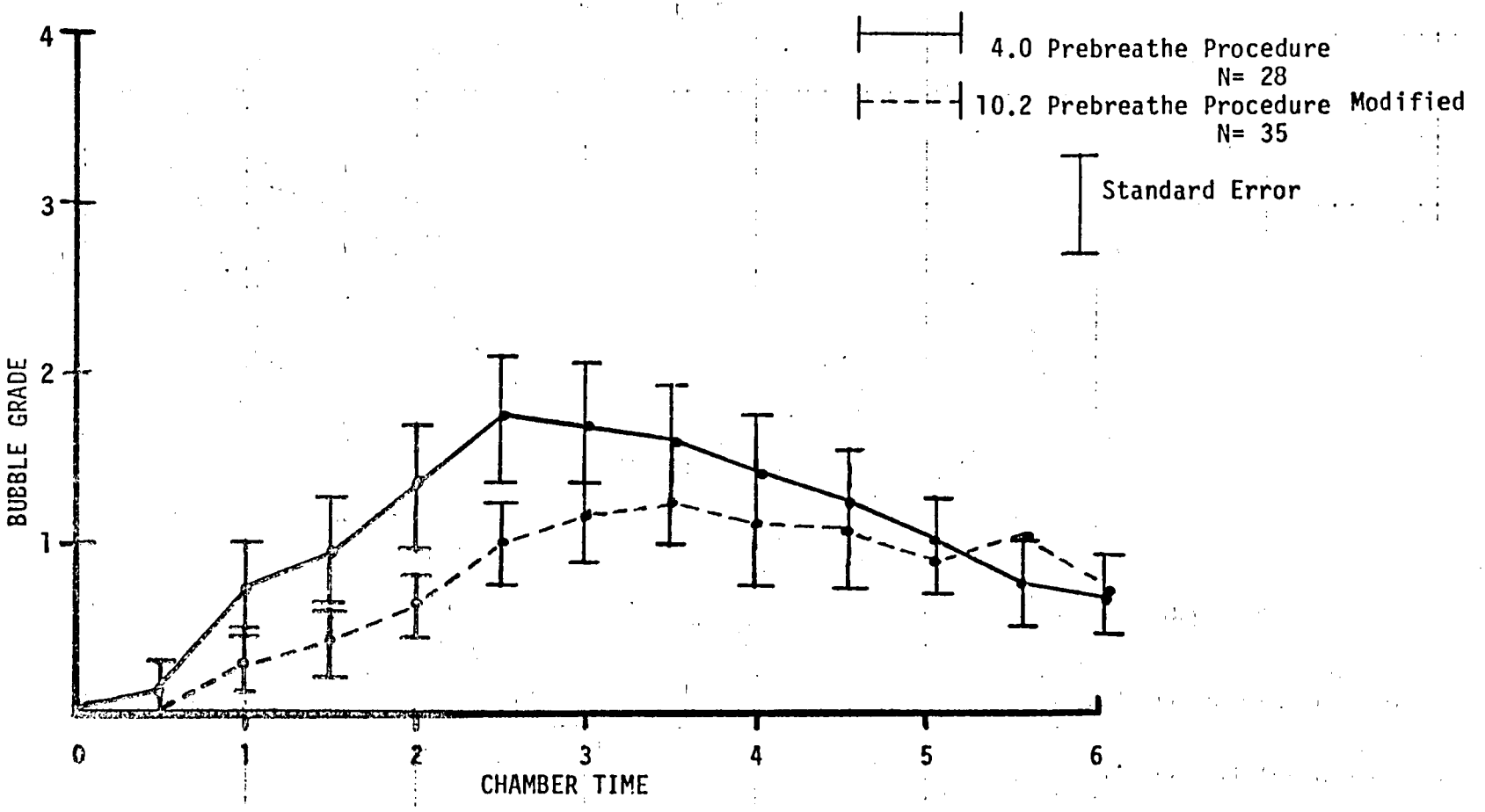

Figure 16.- $\overline{X}$ Bubble grade as a function of time - series 3 - 4-hour vs. modified 10.2 psi.

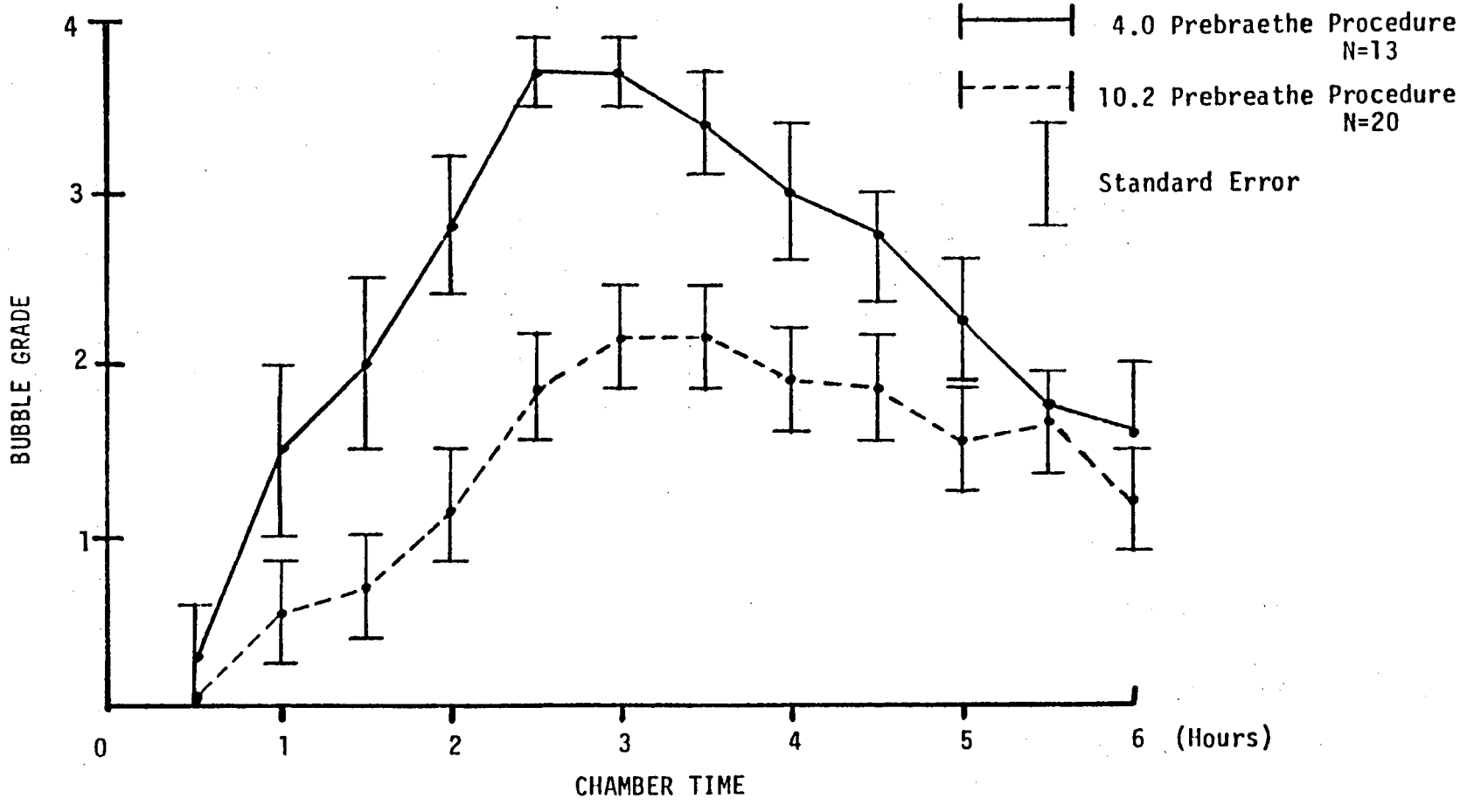

Figure 17.- $\overline{X}$ Bubble incidence of those who bubbled vs. duration of bubbling.

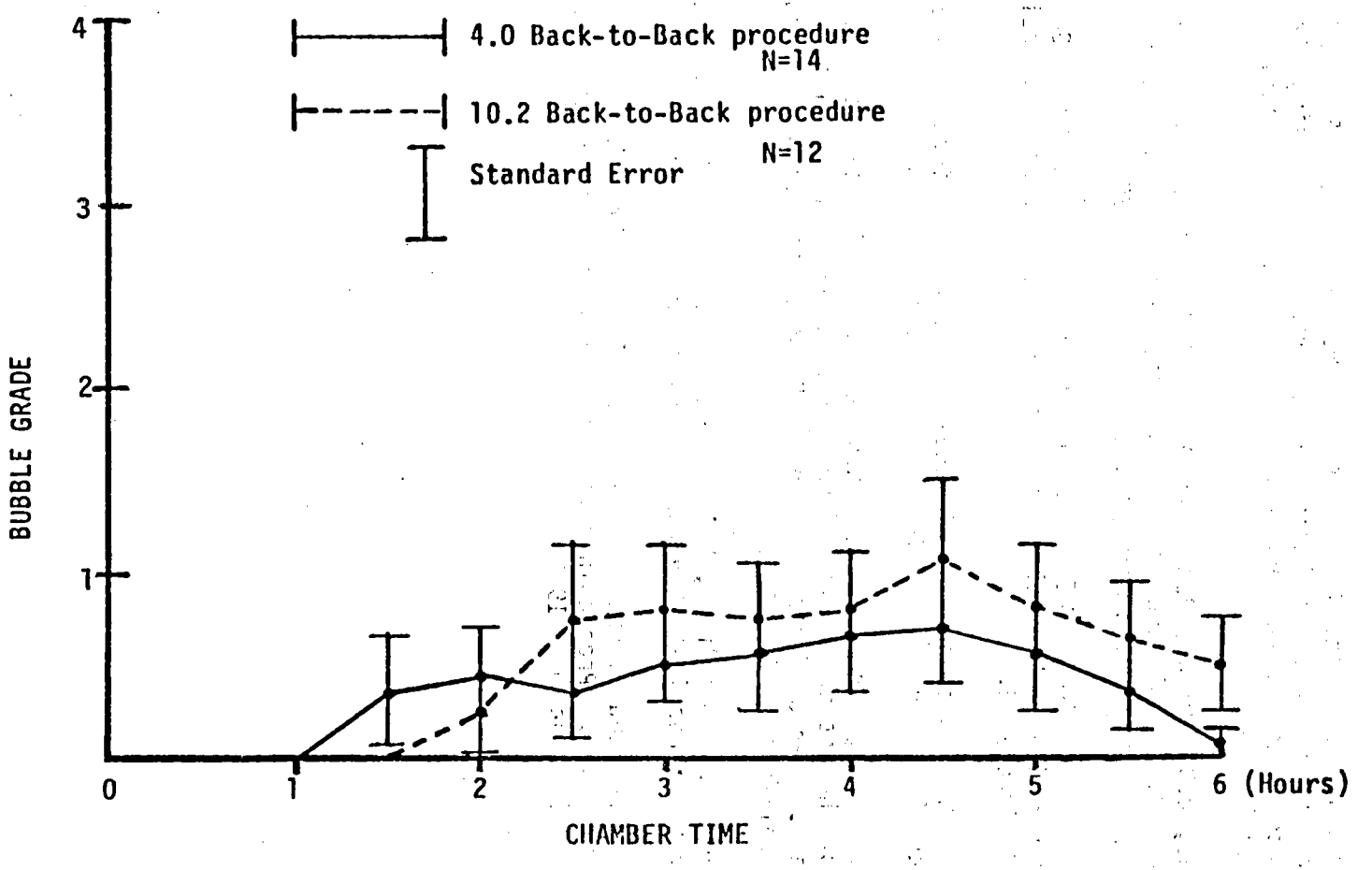

Figure 18.- $\overline{X}$ Bubble incidence as a function of time - back-to-back runs.

REFERENCES

1. Adams, J.D., Dixon, G.A., Olson, R.M., Bassett, B.E., and Fitzpatrick, E.L. Preventing of Bends During Space Shuttle EVA's Using Stage Decompression. Proceedings of the 1981 Aerospace Medical Assoc. Meeting, San Antonio, Texas, May 7, 1981.

2. Adams, J.D., Olson, R.M., and Dixon, G.A. Use of the Doppler Precordial Bubble Detector in Altitude Decompressions. Proceedings of the 1979 Aerospace Medical Assoc. Meeting, Washington, D.C., May 14, 1979.

3. Neuman, T.S., Hall, D.D., and Linaweaver, P.G. Gas Phase Separation During Decompression in Man: Ultrasound Monitoring. Undersea Biomedical Research 3:121-130, June 1976.

4. Hills, B.A. Decompression Sickness, Vol. 1, The Biophysical Basis of Prevention and Treatment. John Wiley & Sons, New York, 1977.

5. Adams, J.D., Olson, R.M., Dixon, G.A., and Fitzpatrick, E.L. Advanced Warning of the Potential Risk of Developing Bends and Screening of Bends Prone Individuals. Proceedings of the 1980 Aerospace Medical Assoc. Meeting, Anaheim, California, May 1980.

6. Butler, B.D. and Hills, B.A. The Lung as a Filter for Microbubbles. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 47:537-543, 1979.

7. Adams, J.D. and Olson, R.M. Altitude Chamber Training Regimen with Lower Bends Provocation. Proceedings of the 1982 Aerospace Medical Assoc. Meeting, Bal Harbor, Florida, May 1982.

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15. Supplementary Notes

16. Abstract

Three test series involving 173 man tests were conducted in the process of defining and verifying a pre-extravehicular activity (EVA) denitrogenation procedure that would provide acceptable protection against altitude decompression sickness while minimizing the required duration of oxygen (O_2) prebreathe in the suit prior to EVA. The tests also addressed the safety, in terms of incidence of decompression sickness, of conducting EVA's on consecutive days rather than on alternate days.

The tests were conducted in an altitude chamber, subjects were selected as representative of the astronaut population, and EVA periods were simulated by reducing the chamber pressure to suit pressure while the subjects breathed O_2 with masks and worked at EVA representative work rates.

A higher than anticipated incidence of both venous bubbles (55%) and symptoms (26%) was measured following all denitrogenation protocols in this test. For the most part, symptoms were very minor and stabilized, diminished, or disappeared in the 6-hour Series 3 Tests. Instances of clear, possible, or potential systemic symptoms were encountered only after use of the unmodified 10.2 psi protocol and not after the modified 10.2 psi protocol, the 3.5-hour O_2 prebreathe protocol, or the 4.0-hour O_2 prebreathe protocol. The high incidence of symptoms is ascribed to the type and duration of exercise and the sensitivity of the reporting technique to minor symptoms. Repeated EVA exposures after only 17 hours did not increase symptom or bubble incidence.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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