The Effect of Transcutaneous Carbon Dioxide Application on the Recovery from Muscle Fatigue.

INTRODUCTION
Carbon dioxide (CO2) therapy refers to the transcutaneous administration of CO2 for therapeutic purpose. Recently, we designed a novel transcutaneous CO2 application system using 100% CO2 gas, a transcutaneous CO2 absorption-enhancing hydrogel. We showed that our transcutaneous CO2 system could cause the absorption of CO2, and the O2 dissociation of hemoglobin by the Bohr effect in the human body [1]. In addition, we also showed that our system caused the gene expression of PGC-1α, SIRT1 and VEGF in rat muscle, increased the number of mitochondria and caused muscle fiber switching [2]. These results suggest the transcutaneous application of CO2 may have therapeutic potential for muscular recovery.

The measurement of muscle strengths, physical functions and levels of delayed-onset muscle soreness (DOMS) after exercise have been used for the evaluation standard from recovering muscle fatigue [3]. In addition, previous reports showed that adenosine triphosphate (ATP) resynthesis in muscle is one of the important factors of the recovery from muscle fatigue [4].

Thus, in this study, we investigated ATP/ADP variance during CO2 application, and measured the muscle strength, the physical function and DOMS after eccentric exercise to evaluate the effect on the recovery from muscle fatigue using our transcutaneous CO2 application systems.

METHOD
These studies were approved and permitted by the Ethical Committee of Kobe University Graduate School of Medicine and informed consent was obtained from all subjects before the start of the study.

The effect of transcutaneous CO2 application on the recovery from muscle fatigue after eccentric exercise

Subjects: Healthy fifteen male volunteers (mean 34 years, range 29-52 years) participated in the study. All subjects avoided hard exercises 1 week before the investigations.

Eccentric Exercise: Subjects were seated in a Myoret RZ-450 (Kawasaki Heavy Industries, Ltd.), Kobe, Japan). For each thigh, the quadriceps muscles performed 300 maximal eccentric contractions at an angle of 10° to 90° in the knee joint, with a velocity of 180°/s. After a few minutes of rest, the same exercise was performed on the other leg. The order of the leg to be used was randomly chosen. During the CO2 therapy, the subjects lay supine on a bench, and the entire frontal thigh was administered CO2 transcutaneously. Transcuaneous CO2 application was given directly after the exercise and once daily for 3 days after exercise.

Measurement of muscular strength: Before and after the exercise, the muscular strength of quadriceps were measured by Myoret RZ-450 (Kobe University Graduate School of Medicine, Kobe, Japan). Ten minutes after transcutaneous CO2 application, the maximal torque of quadriceps was significant recovered in the treatment group. The muscular strength was recovered 2days after exercise in the treatment group. However, it took 7days after exercise in the control group. In the functional 1-leg long jump, results patterns were similar to those of the strength testing (Fig.2).

VAS score of the levels of the DOMS: After transcutaneous CO2 application, the VAS score was significantly decreased. The VAS score in the treatment group is significantly smaller than the control group in the next day and 2days after exercise. (Fig. 3)

Measurement of ATP and ADP Concentration using 31P-MRS
Ten minutes after transcutaneous CO2 application, the concentration of ATP was significantly increased, and the concentration of ADP was significantly decreased (Fig.4A,B).

DISCUSSION
Our results showed that our transcutaneous CO2 application system accelerated the recovery of muscular strength, physical function and DOMS after excessive exercise. In addition, we also showed that transcutaneous CO2 application increased ATP synthesis in muscle, and this ATP synthesis might concern the acceleration of the muscular recovery.

SIGNIFICANCE
We suggest that transcutaneous CO2 application has a therapeutic potential for recovery on skeletal muscle damage after excessive exercise. It may be useful for physical therapy and sports training.

REFERENCE