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Circulating soluble intercellular adhesion molecule-1 (sICAM-1) after exercise-induced muscular damage: Does the use of whole-body cryostimulation influence its concentration in blood?

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ABSTRACT

As soluble intercellular adhesion molecule-1 (sICAM-1) was recently hypothesized to be a key player in the mechanisms involved in exercise-induced muscular damage (EIMD), we investigated its circulating concentration changes in athletes before and after EIMD with and without the use of whole-body cryostimulation (WBC; 3 min at −110 °C) at the exercise end and repeated once a day during 4 days.

We previously characterized plasma specimens from 11 endurance athletes who performed twice (randomized crossover design) strenuous running leading to EIMD, followed by passive recovery or WBC. Muscle soreness and inflammatory response were observed in both cases but the use of WBC induced a significant reduction in these responses (PlosOne 2011; 6:e22748). We now found that sICAM-1 concentration slightly increased in both circumstances and remained elevated for 24 h ($p < 0.01$). However, no significant WBC effect was observed concerning sICAM-1 changes indicating that this compound is not a major player both in EIMD and WBC physiological impacts.

Intercellular adhesion molecule-1 (ICAM-1) and its soluble form (sICAM-1) have recently been suspected to be key components in the mechanisms involved in exercise-induced muscular damage (EIMD) [3,4]. It has been speculated that whole-body cryostimulation (WBC; 2–4 min at −110 °C or less after exercise) which lowers EIMD also impacts the expression of ICAM-1 and the amount of circulating soluble ICAM-1 (sICAM-1) [3,4].

ICAM-1 is an adhesion protein present on endothelial cells and leukocyte surfaces. This factor mediates adhesion and transmigration of leukocytes through the endothelium. In addition, ICAM-1 directly contributes to inflammatory responses within the blood vessel wall by increasing endothelial cell activation. Surface expressed ICAM-1 can be shed from the cells and then circulates as soluble ICAM-1 (sICAM-1) [3,7,10]. Initially thought to be a relevant marker of cardiovascular risk factor, sICAM-1 is nowadays more frequently considered as a biomarker of endothelial activation/dysfunction mimicking the amount of expressed ICAM on endothelial cells and leukocytes [7].

We have recently presented that in the context of EIMD sarcomeres disrupt and then leukocytes (neutrophils, monocytes, and lymphocytes) transmigrate to the injured cells/tissue via ICAM-1 [3,4]. Following this, pro-inflammatory cytokines and reactive oxygen species are produced in the muscle cells by leukocytes and amplify the initial muscle damage.

Ferreira et al. have suggested that a drop in core temperature induced by WBC would likely cause vasoconstriction of blood vessels and lower the amount of leukocytes arriving to the exercise-induced muscular inflammation site [4]. These authors propose a mechanism in which a decrease in the expression of ICAM-1 at the endothelium level would limit diapedesis through a reduction a: in the possibilities of activated leukocytes arrest, b: in a firm adherence on the endothelial cells, and c: in the initial steps of the trans-endothelial cell migration process. The level of this reduction in the expression of ICAM-1 could be followed by measuring the concentration of circulating sICAM-1.

This view may be correct if the rate of shedding (splicing) remains constant. It seems accepted that sICAM-1 is an accurate marker of inflammation reflecting the amount of ICAM-1 expressed on membranes. During inflammation and infection, membrane ICAM-1 expression on leukocytes and endothelial cells tremendously increases as well as the

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concentration of circulating sICAM-1. In this context sICAM-1 is a relevant biomarker which correctly reflects the expression of ICAM-1 on cell membranes. However, this might not always be the case. If the shedding of ICAM-1 is regulated, one can expect changes in the concentration of sICAM-1 in blood without changes in the expression of ICAM-1. The regulation of sICAM-1 in blood is definitely not clear [3]. It has previously been shown that an increase in the shedding of the ICAM-1 can be due to increased secretases activity, stimulated by catecholamines and other factors. One study showed that exercise may induce an increase in circulating sICAM-1 and such change could be blocked by the infusion of propanolol [9]. Moreover, noradrenaline is produced and released in circulation after cold stimulation [1] and can theoretically induce an extra release of sICAM-1 with or without changes in the expression of ICAM-1 [2]. In this case, the release of the soluble part of the ICAM-1 will leave a truncated form of the ICAM-1 at the membrane site which will not be able to play its role as an adhesion molecule. Therefore, the possibilities of leukocyte transmigration and the subsequent muscle inflammation will be reduced. This can be seen as a paradox, as in this case, an extra release of sICAM-1 may induce a decrease in muscle inflammation.

Nevertheless, there is for the time being no information available on the changes of sICAM-1 due to the combine effects of EIMD and whole-body cryostimulation. We have previously studied the effects of EIMD and whole-body cryostimulation in high level athletes on perceived muscle soreness, inflammation markers and pro and anti-inflammatory cytokines. We were able to show that the heavy exercise our athletes had to perform led to muscle soreness accompanied by pro-inflammatory response. The use of whole-body cryostimulation (−110 °C, 3min of exposure after the exercise and repeated once a day during 4 days) induced in our athletes both a reduction in muscle soreness and in the concentration of circulating markers of inflammation (lower blood concentration in C-reactive protein and interleukin-1beta) and an increase in the concentration of anti-inflammatory circulating markers (increase in the concentration in blood interleukin-1 receptor antagonist) [8].

The aim of the present study was to investigate whether sICAM-1 is an important regulating substance in formation of EIMD and whether cryostimulation can modulate its concentration in blood (vs. passive recovery). To conduct this analysis, we used well preserved plasma specimens [5] collected from a previous experiment [8] where we investigated the effect of two different recovery modalities (passive recovery and WBC) after a simulated trail running race that created a EIMD in our athletes.

The subjects and the methods have previously been described [8]. In summary, 11 well-trained male runners (age 31.8 ± 2.0 years; $\dot{V}O_{2max}$ 62.0 ± 1.2 ml min^{-1} kg^{-1}) participated in the study. All of them gave their informed consent and the study was approved by the local Ethics Committee (Île-de-France XI, France; Ref. 200978). The study had a crossover design. The subjects completed two simulated runs at a one-month interval on a treadmill followed in a random order by a passive recovery or with a recovery where WBC was used. The runs were organized on the same treadmill and were designed to generate fatigue. Blood specimens were collected before and after the simulated run, after the first recovery session, and before the recovery sessions after 24 h, 48 h, 72 h, 96 h following the end of the run. Hydration/nutrition before and during each session was standardized. Between trials, low intensity training was ensured.

One week before the first simulated run, subjects were familiarized with the test scheme and preliminary tests were performed to determine maximal oxygen uptake, the first and the second ventilatory thresholds, and the maximal aerobic speed as previously described [8]. Concerning the proper test, the race lasted 48 min and was divided into 5 stages. The first stage consisted of a 6 min run on treadmill on a flat surface (intensity comprised between the subject first and the second ventilatory thresholds), followed by 3 min uphill (+10% gradient; ≈80% of the subject maximal aerobic velocity) and 3 min downhill (−15% gradient; first ventilatory threshold). Stages 2–5 consisted of 3 min at 0°, followed by 3 min uphill and 3 min downhill at the gradients and velocities as previously described [8]. After the run, subjects were randomly assigned to WBC or passive recovery. WBC sessions were administered in a cryogenic chamber (Zimmer MedizinSysteme GmbH, Ulm, Germany) and the subjects were exposed to −110 °C for 3 min. The exposures occurred at the end of the exercise and repeated once a day during 4 days at the same time of the day. Before the exposure, subjects were instructed to dry any sweat, and clothe themselves in swimming trunks, a surgical mask, ear bands, gloves, dry socks and sabots. After each WBC session, subjects spent 10 min comfortably seated in an environment at 24 °C wearing a bath robe. The control recovery was a passive recovery during which each subject was comfortably seated in an armchair for 30 min at 24 °C. The subjects were not allowed to speak to anyone during the experiment.

Blood specimens were collected from a superficial forearm vein using standard venipuncture techniques and EDTA tubes (Greiner Bio-one; Frickenhausen, Germany). Plasma aliquots were prepared and stored at −80 °C. ELISA kits for the determination of sICAM-1 were purchased from R&D Systems Europe. The intra-assay imprecision (CVA) was 4.6% and 4.8% for sICAM-1 concentrations of 126 and 476 mg/L, respectively. All specimens were analyzed in duplicate using Dynex MRXe spectrophotometer (Magellan Biosciences, Chelmsford, MA, USA).

Results are expressed in Fig. 1 as means ± SD. Two-way analysis of variance for repeated measurements was used to analyze the changes between cold and control experiments with time and treatments (WBC versus control) as factors. We used logarithm transformation as the data distribution was not Gaussian. Post hoc multiple comparisons were made by PLSD test when appropriate to single out statistical significance. Statistical significance was set at $p < 0.05$.

We observed a significant increase (data not shown) in the blood concentration of sICAM-1 and leukocytes after exhausting exercise in athletes, who experienced a significant post exercise inflammatory response, with or without the use of a 3-min cryostimulation exposure as a recovery procedure. The concentrations of sICAM-1 in blood obtained 1 h and 24 h after the end of the exercise were significantly more elevated than those obtained at rest ($p < 0.01$), whereas the sICAM-1 concentration obtained at the time point of 48, 72 and 96 h were not significantly different than those obtained at rest (Fig. 1). However, no significant interaction concerning the effect of cryostimulation was observed concerning circulating sICAM-1.

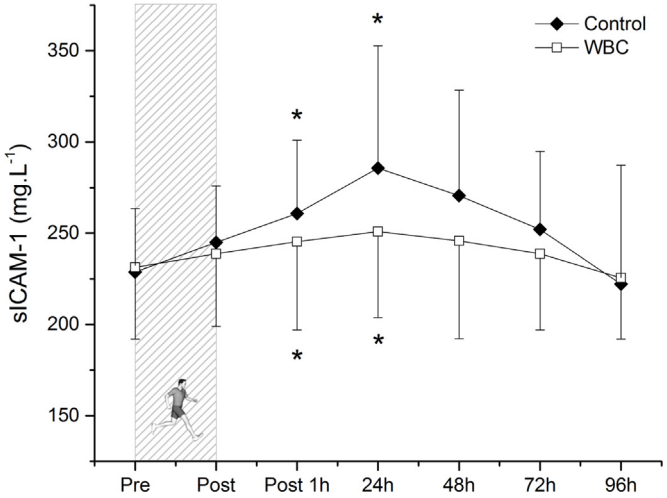

Fig. 1. Changes in circulating sICAM-1 ($ng.ml^{-1}$) from basal concentration to recovery after exhausting physical exercise without (diamond) or with (square) using a 3min cryostimulation exposure in trained athletes. Asterisk indicates a significant increase ($P < 0.01$) in comparison to basal circulating concentrations.

This work confirmed that the concentration of sICAM-1 in blood increases after a high intensity aerobic exercise [6]. In our previous analysis with the same subjects and blood specimens, we reported a reduction both in muscle soreness and in the concentration of circulating markers of inflammation (lower blood concentration in C-reactive protein and interleukin-1beta) and an increase in the concentration of anti-inflammatory circulating markers (increase in the concentration in blood interleukin-1 receptor antagonist) [8] when athletes experienced cryostimulation after exhausting exercise. Such significant physiological changes did not seem to alter the concentration of sICAM-1 in blood, though a minor reduction was observed compared with control group.

One limit of our study is the rather low number of participants (n = 11) which lowers the statistical power. Therefore, such trend might favor the hypothesis of a certain reduction in the expression of ICAM-1 on cell membranes (endothelial cells and leukocytes), a reduction in the secretase activity, or a combined effect at the expression level of the protein and in the activity of secretases.

Trans-endothelial migration is divided into at least four different steps: the attachment of circulating cells on to the enthothelium; the activation of integrins on the leukocyte cell surface; the firm adhesion of the leukocyte and transmigration of the cell through the endothelial cell barrier into the sub-endothelial space [7]. The role of ICAM-1 is to increase endothelial cell activation, to facilitate the firm arrest of leukocytes and to initiate the leukocytes' transmigratory process [7]. However, there are many other proteins (e.g. selectins, chemokines, integrins, IgSF) involved in diapedesis, and cryostimulation may influence the expression of those proteins involved in the transmigration process. If each of these proteins as well as ICAM-1 were slightly less expressed after cryostimulation, a global significant impact might appear and reduces the exercise induced inflammation. Further studies dealing with the impact of cryostimulation and the changes of proteins involved in trans-endothelial migration would still be necessary. Also, it would be of interest to investigate downstream signaling using muscle and endothelial cells in order to get a deeper insight into exercise-induced muscle damage mechanisms and to rule out sICAM-1 and ICAM-1's roles.

Conflicts of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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