Photobiomodulation on delayed onset muscle soreness

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If the radiation intensity is so low that the photodynamic effects of endogenous photosensitizers can not damage membrane or cell compartments, there would be photobiomodulation on delayed onset muscle soreness (DOMS) at the radiation dose chosen according to the biological information model of photobiomodulation since the intracellular proteolysis of damaged proteins by ubiquitin-proteasome pathway should be the key process for DOMS recovery.

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Photobiomodulation (PBM) is an effect of low intensity monochromatic light or laser irradiation on biological systems, which stimulates or inhibits biological functions but does not results in irreducible damage. PBM has been widely used in athletic training as low intensity laser therapy as McLeod has reviewed[1]. Randomized, double blind clinical trials have shown the effectiveness of photobiomodulation on the rehabilitation of human digital flexor tendons[2], tennis and golfer's elbow[3], and wound healing of human body sport injuries[4]. There is photobiomodulation on cells related to delayed onset muscle soreness (DOMS), such as skeletal muscle satellite cells[5], skeletal muscle myoblasts[6] and skeletal muscle myotubes[7]. However, no photobiomodulation on DOMS has been found although the effects of light or laser irradiation on DOMS have been investigated[8−10]. In this paper, the mechanism of photobiomodulation on DOMS will be studied.

DOMS is most prevalent at the beginning of the sporting season when athletes are returning to training following a period of reduced activity. DOMS is also common when athletes are first introduced to certain types of activities regardless of the time of year. Cheung *et al.*[11] have reviewed up to six hypothesised theories proposed for the mechanism of DOMS, i.e., lactic acid, muscle spasm, connective tissue damage, muscle damage, inflammation and the enzyme efflux theories, and suggested that an integration of two or more theories is likely to explain muscle soreness. Liu *et al.*[12] have suggested three phases model of DOMS so that DOMS is from z-line disruption, proteolysis of damaged proteins to protein synthesis for myofibril remodeling.

There are two kinds of pathways mediating cellular photobiomodulation[13], one kind is specific, which is mediated by the resonant interaction of light with molecules such as cytochrome nitrosyl complexes of mitochondrial electron transfer chain, singlet oxygen or endogenous photosensitizer such as hemoglobin and porphyrines, the other kind is non-specific, which is mediated by the non-resonant interaction of light with membrane proteins. In some cases, the intensity is so high that it can induced photodynamic damage by some of specific pathways such as endogenous photosensitizers. Lavi *et al.*[14] have studied the effects of low energy visible light (400–800 nm, 40 mW/cm^2) on cardiac cells, and found picnotic damage to the nuclei and perinuclear edema at 5 minutes illumination (12 J/cm^2). In the Craig *et al.*'s research[8,9] the subjects of DOMS received 4 minutes irradiation using a GaAlAs cluster head multi-diode array (660–950 nm; 45.8 mW/cm^2). Their results clearly showed an increase in subjective pain and tenderness, together with a loss of available range of movement for the treated group; however, no consistent statistically significant differences were seen between groups. Obviously, the intensity of Craig et al.'s research[8,9] is so high that the induced photodynamic damage would worsen DOMS.

If the radiation intensity is so low that the photodynamic effects of some specific pathways can not damage membrane or cell compartments, photobiomodulation should be dominantly mediated by the non-specific pathways[13]. It has been shown that the biological information model of photobiomodulation (BIMP) holds for the non-specific pathway[13,15]. According to BIMP, the radiation from UVA (ultraviolet A 320–400 nm) to IRA (infrared A 700–1000 nm) has been classified into two kinds, the cold color (green, blue, violet or UVA) and the hot color (red, orange, yellow or IRA) , and the signal transduction pathways have been classified into two kinds, pathway 1 which is G_s protein mediated pathway: cAMP↑(cyclic adenosine 3', 5'–nophosphe), and pathway 2 which is G_i protein mediated pathway, G_q protein mediated pathway, or one of receptor-linked enzyme: cAMP↓; and the dose zone has been defined as dose n from low dose on. At dose 1, we have BIMP1:

$$\begin{aligned}&\text{hot color activates pathway 1,}\\&\text{cold color activates pathway 2.}\end{aligned}\tag{1}$$

If the dose is at dose 2 which is larger than the threshold of dose 1, we have BIMP 2 at dose 2:

$$\begin{aligned}&\text{cold color activates pathway 1,}\\&\text{hot color activates pathway 2.}\end{aligned}\tag{2}$$

Generally, we have Eq. 2 if the dose is at dose $2n$ (n = 1, 2, 3, ...) which is larger than the threshold of dose $2n$-1 if it does not damage membrane or cell compartments such as mitochondria, lysosomes, endoplasmic reticulum so that Eq. 2 is called BIMP $2n$, and we have Eq. 1 if the dose is at dose $2n$+1 (n = 1, 2, 3, ...) which is larger than the threshold of dose $2n$ if it does not damage membrane or cell compartments so that Eq. 1 is called BIMP $2n$+1. BIMP n (n = 1, 2, 3, ...) has been supported

by its successful application in the cellular level, animal model level and clinic level [13,15].

Glasgow *et al.*[10] have studied the effects of monochromatic infrared radiation at a wavelength of 840 nm (10 mW/cm^2, 3.0 J/cm^2) on DOMS. The hot color radiation at dose 2 should inhibited G_s-coupled pathways according to BIMP2, and then increase insulin level[16], which would inhibit the activation of ubiquitin-proteasome pathway (UPP)[17] although glucocorticoid has increased and glucocorticoid receptor has up-regulated for DOMS[18]. However, the intracellular proteolysis of damaged proteins by UPP should be the key process for DOMS recovery as Liu *et al.*[12] have pointed out. This is why there is no photobiomodulation in Glasgow *et al.*'s experiment[10]. Glasgow *et al.*'s experiment[10] have pointed out the order of dose 2 although it failed to show photobiomodulation on DOMS. According to BIMP, the hot color radiation at dose $(2n+1)$ or the cold color radiation at dose $2n$ should activate G_s-coupled pathways and then UPP if it does not damage membrane or cell compartments so that there would be photobiomodulation on DOMS. Of course, the further work should be done.

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