Available online at www.elixirpublishers.com (Elixir International Journal)

Human Physiology

Elixir Human Physio. 55 (2013) 13205-13211

ISSN: 2229-712X

Causes and Management of Delayed Onset Muscle Soreness: A Review

Zubia Veqar

Centre for Physiotherapy & Rehabilitation Sciences, Jamia Millia Islamia, New Delhi.

ARTICLE INFO

Article history:

Received: 13 December 2012;

Received in revised form:

13 February 2013;

Accepted: 27 February 2013;

Keywords

Eccentric exercise,

Delayed onset muscle.

ABSTRACT

Any unaccustomed activity especially eccentric exercises leads to features like pain, oedema lack of strength and range of motion in corresponding joints and muscles. These features typically start 8-12 hrs following activity, peaking between 24-48 hrs and lasting 96 hrs or beyond 96 hrs post activity. This phenomenon is called Delayed onset muscle soreness (DOMS) and is also known as muscle fever.. It was first explained by Theodre Hough(1905) and since then new theories have been postulated to understand it. Physiotherapy is one of the major main stays of its management. Even though pharmacological agents have been researched on efficacy is not well established .Physiotherapy management includes many interventions like cryotherapy, thermotherapy, stretching, exercises, electrical currents, Soft tissue massage. This review is humble attempt to understand the basic mechanisms underlying delayed onset muscle soreness and its management with special emphasis on physiotherapy management.

I. Introduction

Pain followed by exercises can be attributed to a number of reasons. Sometimes the pain is experienced throughout the exercise and recovers speedily later. But in some cases especially after unaccustomed or eccentric exercises there is no pain during or immediate post exercise periods and the pain begins after 8-24 hrs is a different kind of pain. This kind of state of affairs is referred as Delayed Onset Muscle Soreness.[1-6] Delayed onset muscle soreness (DOMS) described as sensation of pain experience 8-12 hrs following exercise, peaking between 24-48 hrs and lasting 96 hrs or beyond 96 hrs post induction. It has been particularly associated with eccentric exercise[1,3,4,7]. The cardinal sign and symptoms of DOMS are pain, decrease in range of motion, decrease in muscle strength and change in biochemical markers[1,3,4,7,8,9],. Hough T. (1902)[10] was the first one to to print a primary report on muscle soreness where he investigated this soreness by ergographic means that and reported two varieties of soreness. One appeared throughout work and lasted for three to four hours and the other opposite didn't seem removed from ten to twenty four hours when the work had ceased. The first type of soreness might have been caused by the pressure from the swollen muscle fibre on the sensitive nerve endings or by chemical stimulation of nerve endings. Whereas the second soreness might have been the results of tension within the muscle thanks to rupture of the muscle fibers or of the supporting tissue, in order that the strain was transferred to the tendon.

II. Theories associated with DOMS

There are certain physiological changes that have been observed in the muscle following eccentric activity. These are ---- Miniscule tears to muscle tissue which is accountable for the discharge of chemical substances that stimulate free nerve endings like Histamines, anaerobic metabolites and chemical action enzymes; Development of osmotic pressure inflicting swelling of encompassing tissues (fluid retention) ;cramps or muscle spasms leading to decrease activity; Alterations in cells calcium regulation mechanisms; Inflammatory responses that result in enhanced white corpuscle count,interleukin-1 beta, white blood corpuscle and accumulation of leucocytes [11]

To understand the development of these physiological features associated with DOMS various ideas have been floated but none was found to be conclusive.

Out of the suggested ideas six theories have been found to be proposing understandable reasoning. But one theory alone will not able to explain so a combination of more than one theory will be required to completely understand the mechanism of DOMS. These theories are Inflammation theory, connective tissue injury theory, Muscle injury theory, excess metabolite, muscle spasm and protein outflow theory .The brief overview of these theories have been explained even though detailed reading is suggested

Inflammation Theory:

The inflammation theory is predicated on the finding of inflammatory response i.e. hydrops formation and inflammatory cell infiltration which are the cardinal signs of DOMS[6,12] It appears probably that acute structural harm to muscle tissues initiates the prevalence of DOMS.

This might then create a sequence of events that ends up in sphacelus (cell death) peaking at around forty eight hours after exercise. Eccentric exercise ends up in injury to plasma membrane, setting of associate inflammatory response[3]. Muscle fibre contains chemical action enzymes that initiate the degradation of macromolecule and macromolecule structure of cell following injury[6]. Inflammatory response ends up in autocoid leukotriene synthesis. PGE2 directly causes pain by sensitizing sort III and IV pain receptive to the result of chemical stimulation. Leukotrienes will increase tube porosity and attract neutrophils to the positioning of injury.

This generates free radicals that exacerbate injury to the plasma membrane. Swelling results from the movement of cells and fluid from the blood stream into the opening house with inflammation and might contribute to the feeling of pain[3].

Tele:

E-mail addresses: veqar.zubia@gmail.com

Connective Tissue injury Theory:

Damage to connective tissue as a result of muscular contraction results in deep tissue harm and an imbalance in albuminoid metabolism thus contributes to DOMS. This theory examines the role of the connective tissue that forms sheaths around bundles of muscle fibers. The content and composition of connective tissue differs between muscle fibre varieties. Type I is more liable to injury than type II [13-14]

Tullison and Armstrong(1981)[15] reported that low simple sugar monophosphate shunt activity ensuing from eccentric load as indicative of selective damage to the connective tissue as compared to muscular damage. Other explanations can be disruption of sarcoplasmic reticulum [16] and location of group IV sensory fibers within the connective tissues [17]

Muscle injury Theory:

Tears and ruptures of muscle fibers as a result of the structural changes to the muscle fibers brought about by concerned eccentric muscle contractions lead to the development of muscular tissue damage theory. The very small injury stimulates flow of white blood cells to the area of harm in response to acute inflammation and ends up in the discharge of histamines and prostaglandins that are accountable for activation of pain receptors. This forms the premises of Hough's Torn Tissue Hypothesis. This was initially projected by Hough (1902)[5] and its focus was on disruption of contracted element of the muscle tissue; notably at the extent of Z line following eccentric exercise[13,14,18]. The characteristic microscopic lesion is that the broadening, smearing or perhaps total myofibrillar disruption of the Z line[14]. Mechanical disruption to the structural components is hyperbolic, notably amongst the kind II fibers that have the narrowest and weakest Z line. This stimulates the nociceptors thus leading to pain[19].this was also supported by an increase in blood enzyme level of plasma CK.[20]

Excess metabolite Theory:

This theory postulated that there is a build up of lactic acid post exercise which is reason for the symptoms. It was propose by Helwigg(1934)[10] but the theory was eventually rejected by Asmussen in 1956 because the higher degree of metabolism related to homocentric contraction did not lead to similar sensation of delayed soreness[19]. Schwane et al (1983)[21] also reported the recovery of carboxylic acid levels to pre exercise levels by inside one hour and no relation was found in between soreness and these levels following downhill running .

Muscle Spasm Theory:

It was propsed by De Vries in 1961. It was based on the premises that hyperbolic resting muscle activation indicated a tonic localized spasm of motor units. This was thought to steer to a compression of pain substances thus successively initiating a “vicious cycle” (de Varies 1966)[19]. Additional stimulation of pain nerve endings caused additional reflex cramp and prolonged ischaemic condition. However, electromyographic studies have been inconclusive[20].

Enzyme outflow Theory:

This is one of the more recent theories predicated on the model developed by the Armstrong (1984)[23] during which metallic element from the interstitium accumulates within the eviscerate muscle following sarcolemmal injury high mechanical forces made throughout muscular exercise, notably in eccentric exercise inflicting disruption of structural macromolecule in myofibers and also the connective tissue between actin and myosin cross bridges. Structural alteration to the sarcolemma or alteration within the porosity within the plasma membrane, ensuing from the high mechanical forces results in influx of calcium from the intrestitium this accumulation in turn inhibits respiration at the mitochondrial level inflicting adenosine triphosphate regeneration to impede, and is assumed to activate cellular enzyme and phospholipase inflicting additional injury to the tissue layer because the production of leukotrienes and prostaglandins. Intracellular components in interstitiuma ns plasma increase thus drawing monocytes that convert to scavenger cell and activate mastocyte and histocyte within the space of injury. Armstrong hypothesise that the buildup of amine, kinins and K within the interstitium stirred free nerve endings of cluster IV nerve cell, that activated the nociceptors and leading to the feeling of DOMS[23].

III. Clinical signs and symptoms

Cardinal signs of DOMS are pain with swelling, stiffness, muscular tenderness and strength loss. The pain and impaired clinical sign ends up in short term incapacity related to DOMS; but, there's no proof that there's any future injury or permanent reduced muscle perform. Strength loss typically peaks right away after exercise or inside the first forty eight hours with full recovery usually taking over five days. Pain and tenderness peak 1–days post exercise, subsiding inside seven or so days.

Stiffness and swelling typically peak 3–4 days post exercise and generally resolves inside ten days. These numerous symptoms can also exist independent to each other.[3]

Pain:

Pain is one of the major debilitating feature and cardinal symptoms related to tissue injury and inflammation [24,25].Pain in DOMS does not serve the basic purpose of joint protection because here it is developed post exercise[23]. People typically begin to feel muscular soreness within the space of the musculotendinous junction between eight and twenty four hours post exercise, with peak levels occurring at around 24-48 hours[1]

The generation of somatesthesia involves activation of pain afferents, presumably type-III and type-IV fibers, additionally bound chemical substance are needed for generating these sensations. Though substances like amine, bradykinins, neurotransmitter, K and 5-hydroxytryptamine are projected as candidates, it seems that the foremost seemingly candidates are prostaglandins of the E series (PGE). PGE doesn't directly cause pain however instead sensitize nociceptors, therefore manufacturing a state of hyperalgesia [3,23]. The precise mechanism answerable for the delay in pain isn't totally understood. However, in keeping with Smith (1991)[6] the organic chemistry rationalization is said to be the delay in scavenger cell entry into the eviscerate space. In response to eccentric based mostly exercise; macrophages are present in giant numbers at twenty four and forty eight hours post exercise. He prompts that the feeling of pain was associated with the synthesis of PGE2 by the macrophages[6]. It’s projected that presence of macrophages at the position of injury, seen throughout acute inflammation and when eccentrically biased exercise in l is presumably answerable for the biogenesis of the PGE2[26].

Hydrops /oedema/ swelling:

It is often associated with acute inflammation[25,27]. This swelling or hydrops could be a result of increase porosity of small bold vessels that exudates to flee into the tissue of injury space. Many studies using humans to investigate an association between DOMS and swelling[1,22,28]. All reported a rise in limb volume at twenty four, 48, seventy two hrs when eccentric muscle action1,[22], however not in response to isometric or

homocentric muscle actions[29]. It was postulated to be because of number of reasons like-rise in contractor pressure[22,28]; the attraction of water to free proteins accumulating within the interstitium following injury[30] According to Friden et al (1992)[19] increase within the limb volume seen throughout the initial forty eight hrs when unaccustomed eccentric action replicate dropsical swelling and an increase seen thenceforth presumably replicate increase synthesis of connective tisue[19].

Stiffness /Decrease in range of Motion:

A reduction in joint range of motion and a discount in shock attenuation are ascertained in periods of severe muscle soreness. It looks seemingly that the restriction in motion related to DOMS arises from a loss of strength[9], additionally as swelling inside the perimuscular connective tissues, particularly within the region of the myotendinous junction[31]. This may be a mechanism for allowing the muscle to rest and heal [9,22,28]

Decrease in Muscular Strength:

This loss in strength can be attributed to the disruption in muscle fibers and their connective tissue[32]. Loss of function is associated with loss of force generating capacity[24]. This mechanism is not well understood but can be attributed to pain[24], hydrops[24], reflex inhibition [24] , fatigue [9], muscle damage[9] or combination of one or more of these factors.

What is more is that one cannot discount associate involvement of system in attenuating the strength loss and facilitating recovery. A modification might occur in neural activation pattern that will bypass the additional severely broken fibers. There's associate proof to indicate that electromyogram patterns are altered forth with and up to forty eight hours post eccentric exercise[9]

Another rationalization of the prolonged strength loss could also be that segment is stretched by performance of the continuation actions. Segment length isn't uniform over the length of the fibers, shorter sarcomeres are found towards the ends[9]. With the continuation of action force a number of the central segment of sarcomere is pulled apart, the overlapping between simple protein and globulin would be reduced, thereby reducing the number of cross bridges that might form[9].

IV Biochemical markers related to DOMS

Many studies have assessed the looks of muscle macromolecule within the blood when eccentric exercise to supply circumstantial evidence of muscle injury. The muscle enzyme lactate dehydrogenase, aspartate, transaminase, chemical element anhydrase, anhydrase isozyme II and amino acid enzyme (CK) has been assessed[33].

V. Treatment and Management ways for DOMS

Despite the appreciable quantity of analysis on DOMS treatment, none of the technique till date, have established confirmatory results in preventing or treating it effectively. Among the favored interventions are anti-inflammatory medicine (NSAIDs); nutritionary supplements; and physiotherapy. Amongst all of these treatments available physiotherapy interventions emerges as a promising treatment for DOMS. There are various options like soft tissue massage, Ultrasound, thermotherapy etc which have been suggested but studies met with restricted success and a sound and consistent treatment for DOMS has not however been established. A brief overview of available intervention has been given below:

Pharmacological Treatments:

The value of anti-inflammatory medical care within the treatment of DOMS is unclear, with the bulk of studies showing no effects despite a attainable theoretical basis for its efficacy[3,34,35]

It has been postulated that NSAIDS inhibit the metabolism of arachidonic acid via cyclo-oxygenase pathway and so stop the assembly of endoperoxides and prostaglandins. A decrease in the inflammatory response result in a decrease in the quantity of muscle oedema and intramuscularpressure, [2] which is one of the important issues that contribute to the pain and muscle soreness[10]. But there might be some ill effects of NSAID's too because it may negatively interfere with the inflammation and delay the healing method [36]

In a randomised, placebo-controlled study, Cannavino and colleagues showed that percutaneous 100% nonsteroidal anti-inflammatory drug cream was effective in assuaging self-reported DOMS in isolated musculus quadriceps femoris muscles of patients following repetitive shortening, notably once forty eight hours This relief was apparently secondary to the consequences of the medication, because no alternative medications or pain relief measures were employed in the study[37]Oral water-soluble vitamin (vitamin C) and alternative antioxidants even have been investigated as potential medications for DOMS, with mixed results. Bajaj and colleagues showed that the prophylactic intake of tolperisone coordination compound provides no relief of postexercise muscle soreness however that it will end in a discount in isometric force[38]

Nutritional Supplements:

There is a restricted quantity of neat research accessible describing the utilization of nutritionary supplements within the treatment of DOMS. Ken et al (2005)[39] documented that supplementation with beta-Hydroxy-beta-Methylbutyrate (HMB) and alpha-Ketoisocaproic Acid (KIC) reduces sign and symptoms of exercise iatrogenic muscle damage in humans. In a randomised, placebo-controlled study, tennis player and co-investigators showed that tart cherry juice will decrease a number of the symptoms of exercise-induced muscle injury [40] Antioxidants such as vitamins C and E, are known to reduce the proliferation of free radicals, generated during the inflammatory response and, potentially, to further damage affected muscles. Connoly DA et al (2006) concluded that a vitamin-C supplementation protocol of 1000mg taken three times on a daily basis for eight days is ineffective in protective against chosen markers for DOMS[41]

Hyperbaric Oxygen medical care (HBOT):

Hyperbaric oxygen therapy is a recent clinical treatment on which work research is being carried out whereby subjects breathe 100% oxygen (O_2) in an attempt to supersaturate the blood with O2. This mechanism of supersaturating the blood with O_2 has been shown to decrease healing time[42] Staples et al (1999)[43] urged that HBOT might enhance recovery of extensor DOMS. Harrison et al (2001)[44] concluded that the HBOT treatment was ineffective.

Physiotherapy management of DOMS

Numerous therapeutic interventions geared toward assuaging DOMS are projected. Commonplace physical therapy modalities like cryotherapy, ultrasound, and electrical stimulation are used. Additionally, massage, stretching, light-weight exercise, immobilization, and simple rest have also been examined. The common interventions which have been researched upon are mentioned here.

Stretching:

The practice of stretching to stop muscle soreness was inspired by early investigators of muscle soreness who thought that unaccustomed exercise caused spasm [10] Spasm was believed to impede blood flow to the muscle, inflicting ischemic pain and additional spasm. Stretching the muscle was thought to revive blood flow to the muscle and interrupt the pain-spasm-pain cycle. The spasm theory of muscle soreness has since been discredited[10,22] however the practise of stretching persists. Typically those who stretch to prevent muscle soreness do so before exercise, however some individuals stretch post exercise. Some proponents of stretching advocate applying a sustained stretch to the relaxed muscle this is known as static stretching, however others advocate a lot of elaborate techniques like the 'contract-relax-agonist contract' technique[45]

Static stretching, pre or post exercise, has been suggested as a preventive measures of DOMS because it is assumed to alleviate symptom represented in De vries spasm theory[46]. Bobert et al (1986)[22] later projected that static stretching of sore muscle post exercise may conjointly force the dispersion of oedema that accumulates following tissue injury.

Repeated and sustained stretching reduces the stress on the muscle connective tissue unit at any given length. This visco-elastic behaviour of the muscle connective tissue unit implies a mixture of viscous properties, wherever deformation is rate dependent and elastic properties, wherever deformation is load dependent[47]. A visco-elastic material if stretched to a new length and sustained will decline in tension over time. This visco-elastic behavior may well be helpful in eccentric exercise as a decrease good production within the given elongation might result in the reduction of the extent of connective and muscle tissue damage.

However if, as has been projected, muscle soreness is owing to excessive elongation of some sarcomeres within muscle fibers it's conceivable that any intervention that enhanced the quantity of sarcomeres in series in muscle fibers, or that enhanced the length or compliance of tendons, may reduce sarcomere strains and reduce muscle injury related to unaccustomed eccentric muscle contractions. This implies the chance that stretching could also be more practical for those who have terribly short muscles, or if the stretching is recurrent for weeks or months or years[45]

The evidence from randomized trials suggests that stretching before or after exercise doesn't manufacture vital reductions in soreness in healthy adults .Stretching might produce other benefits. As an example, it's widely believed that stretching will scale back injury risk, improve sporting performance and manufacture a sense of readiness for exercise. People who are involved regarding these outcomes ought to conjointly contemplate the evidence of effects of stretching on these outcomes once deciding whether or to not stretch[45]

Exercise:

Exercise is one among the foremost effective ways for assuaging DOMS. but pain relief is additionally temporary and speedily resumes once more following exercise cessation[48]. It's been projected that temporary alleviation of pain throughout exercise is also because of breaking of adhesion within the sore muscle, a rise in removal of waste material via increase blood flow or a rise in neurochemical activity[5] Increased afferent input is noted from large, low-threshold sensory units within the muscles (muscle group-Ia, Ib, and II fibers) and subjects direct attention to the activity and faraway from the pain can also be the reasons for improvement with exercise. Light exercises have been shown to bring about an improvement in the patient with DOMS[3]

Soft tissue massage:

Soft tissue massage is one of the oldest techniques being used for alleviation of pain and associated symptoms. It is hypothesised that, through its mechanical pressure on muscle tissue, massage treatment leads to an increased local microcirculatory blood and lymph flow which further reduces hydrops, ischaemia, or accumulation of substances that directly or indirectly cause pain

Studies that have examined the results of massage on DOMS have shown variable results. Weiber et al (1994)[49] according no distinction in perception of soreness or force deficit between experimental and control group. However Hilbert et al (2003)[50] reported that massage administered did not bring about an improvement in hamstring muscle function but it did decrease the intensity of soreness.

It has been reported by Ernst E(1998) in a critical review that even though studies have not been able to conclude the effectiveness of soft tissue massage it is primarily because of methodological flaws so more studies are warrented[51]

Micro current electrical stimulation:

Webers et al (1994)[49] compared the effectiveness of small current electrical stimulation (30 microA, mild wave slope, 0.3Hz frequency, alternating polarity, eight minutes duration) in minimizing muscle soreness and force deficit immidiately and twenty four hours post DOMS- causing exercise of the elbow extensors. The results were statistically insignificant few other studies have reported similar results[52] though another study reported positive effects in prevention of DOMS with frequency specific microcurrent [53]

Therapeutic ultrasound:

Ultrasound is postulated to enhance inflammatory response via a rise in tissue heating and blood flow. Its studies have also been nonconclusive. Hasson et al (1989) compared the sham and real ultrasound treatment. There results showed a big reduction in soreness forty eight hours post exercise in experimental group as compared to control group[54]

In distinction, Ciccone et al (1991) reported that ultrasound enhanced the development of DOMS but this was offset by anti-inflammatory effects of phonophoresis. But the results could not be explained.[55]

Compression:

This is one intervention where studies are very scanty. The main postulated effects of compression therapy are-decreased venous pooling and increase in mean deep venous velocity and an increased venous return (this might mean an increased metabolite washing out)[55]One noteworthy study was conducted by Kraemer et al (2001)[56] according to them continuous compression was a good therapeutic intervention in treating eccentric exercise-induced muscle soreness. More studies with good methodologies are required to prove the efficacy of this modality.in another study Ali et al(2007) concluded that compression stockinet wore during the training decreased DOMS in recreationally active men[57].

Cryotherapy:

The first line of management always recommended post trauma for soft tissues injuries is R.I.C.E (rest, ice, compression and elevation).The superficial application of ice leads to changes in skin, sub-cutaneous, intra-muscular and joint temperatures. A decrease in tissue temperature stimulates receptors to excite the

sympathetic adrenergic fibers inflicting the constriction of native arterioles and venules .This ends up in a decrease of swelling and ablated rate of metabolism that successively reduces the inflammatory response, vascular permeability and therefore the formation of oedema. The methods of cryotherapy can be multiple like ice massage, ice pack, coldwater immersion etc.

Gulick et al (1996)[58] had done study on varied treatment techniques on science and symptoms of delayed onset muscle soreness. The ice massage provided relief from acute muscle soreness however wasn't effective in decreasing DOMS. The ice massage group generated less isometric force as compared to the other group followed by treatment. This was in agreement with fox et al(1961) who also reported a decrease in strength with cryotherapy[59] Selwood KL et al(2007) compared ice water immersion with tepid water immersion. They concluded that their study was not effective in decreasing the markers of DOMS thereby challenging the effects of cryotherapy in the recovery stage for athletes[60] Bleakley C et al(2012) published a Cochrane review on cold water immersion where they concluded thar while the evidence showed that cold-water immersion reduces delayed onset muscle soreness after exercise, the optimum method of cold-water immersion and its safety are not clear.[61]

Superficial heat:

Superficial heat can be given to the patient by numerous modalities like hot pack, hot water immersion, paraffin wax bath, infra red etc. superficial heat is postulated to decrease the effects of DOMS by elevating the temperature of muscle tissue thereby increasing the connective tissue extensibility. This leads to ROM augmentation .This may increase the resistance of muscle tissue to tearing, improve motor unit recruitment, and permit for better shortening. Heat conjointly improves blood flow, which can facilitate clear inflammatory mediators from the muscle tissue. Topical heat has conjointly improved the fatigue characteristics of striated muscle throughout exercise, accrued proprioception, and suppressed pain signals[62, 63].Mayer JM et al (2006)[62] examined the results of continuous low-level heat wrap on prevention and treatment of DOMS. They concluded that continuous low-level heat wrap was effective in prevention of DOMS in low back.

VI. Conclusion

- DOMS is a reaction of the muscle to unaccustomed activity which is associated with pain, decrease in ROM, oedema.
- DOMS can be explained by a combination of theories- Inflammation theory, connective tissue injury theory, Muscle injury theory, excess metabolite, muscle spasm and protein outflow theory .
- NSAIDs are not a very effective management of DOMS.
- Physiotherapy is one of the best interventions available for the prevention and management of DOMS.
- Efficacy of treatments is controversial because of reporting of both positive and negative results.
- Exercise is one of the most effective strategies for alleviating DOMS.
- Cryotherapy has some proven benefits on prevention and treatment of DOMS.

VII. References:

1. Newham, D.J. The consequences of eccentric contraction and their relationship to Delayed Onset Muscle Pain. Eur Jour of Appl Physiol. 1988;57; 353-359.
2. Bakhtiary, A.H, Ziaeddin Safavi-farokhi, Atefeh Aminian-far. Influence of vibration in delayed onset muscle soreness following eccentric exercise. Br j sports med 2007;41:145-148
3. Conolly D.A.J, S.P. Sayers, M.P. McHugh. Treatment and prevention of Delayed Onset Muscle Soreness. J Strength Cond Res 2003;17(1);197-208.
4. Maggie, J. Cleak and Eston roger G. Muscle soreness, swelling, stiffness and strength loss after intense eccentric exercise. BJSM 1992;26(4) 267-272
5. Theodore Hough. Ergographic studies in muscular soreness. Am J Physiol 1902;7;76-92
6. Smith LL. Acute inflammation: the underlying mechanism in delayed onset muscle soreness? Med Sci Sports Exerc. 1991; 23(5):542-51.
7. Nosaka, K. and P.M Clarkson. Changes in the indicator of inflammation after eccentric exercise of elbow flexors. Med Sci Sports Exerc, 1996;28(8):953-961.
8. Clarkson, P.M and Isabelley T. Exercise induced muscle damage, repair and rapid adaptation in human. J Appli Physiol. 1988; 65(1):1-6,
9. Clarkson, PM, k. Nosaka and B Braun. Muscle function after exercise induced muscle damage and rapid adaptation. Medi Sci Sports Exerc. 1992;24(5),512-520.
10. Brendstrup P. Late oedema after muscular exercise. Arch Phys Med Rehabil.1962;43:401-5
11. Mc Aedle WD, Katch FI, Katch VL. Essentials of exercise physiology, 2nd edition, Baltimore : Lippincott, Williams and wilkin, 2000.
12. Evans WJ, Meredith CN, Cannon JG, Dinarello CA, Frontera WR, Hughes VA, Jones BH, Knuttgen HG. Metabolic changes following eccentric exercise in trained and untrained men. J Appl Physiol. 1986; 61(5):1864-8.
13. Fridén J. Changes in human skeletal muscle induced by long-term eccentric exercise. Cell Tissue Res. 1984; 236(2):365-72.
14. Friden J, et al. Myofibril damage following intense exercise in man. Int J. Sports Med 1983.4; 170-176.
15. Tullson P, Armstrong RB. Muscle hexose monophosphate shunt activity following exercise. Experientia. 1981; 37(12):1311-2.
16. J. G. Tidball and T. L. Daniel, Elastic energy storage in rigored skeletal muscle cells under physiological loading conditions. American journal of physiology, 1986; 250-R56
17. Carlson BM, Faulkner JA. The regeneration of skeletal muscle fibers following injury: a review. Med Sci Sports Exerc. 1983; 15(3):187-98.
18. Fridén J, Lieber RL, Structural and mechanical basis of exercise-induced muscle injury. Med Sci Sports Exerc. 1992; 24(5):521-30.
19. Cheung K, Hume P, Maxwell L. Delayed onset muscle soreness: treatment strategies and performance factors. Sports Med. 2003; 33(2):145-64.
20. Newham DJ, Jones DA, Edwards RH. Large delayed plasma creatine kinase changes after stepping exercise. Muscle Nerve. 1983;6(5):380-5
21. Schwane JA, Hatrous BG et al. Is lactic acid related to delayed onset muscle soreness, physio sports med 1983;11 (3) ; 124-7
22. Bobbert MF, Hollander AP, Huijing PA. Factors in delayed onset muscular soreness of man. Med Sci Sports Exerc. 1986; 18(1):75-81.

23. Armstrong RB. Mechanisms of exercise-induced delayed onset muscular soreness: a brief review. Med Sci Sports Exerc. 1984;16(6):529-38
24. Hurley J. V. Acute inflammation. New York; Churchill Livingstone, 1983,1-117
25. Ryan, G.B. and G Majno. Acute inflammation. Am. J. pathol. 1977; 86;185-264,
26. R. B. Armstrong, R. W. Ogilvie, and J. A. Schwan. Eccentric exercise-induced injury to rat skeletal muscle. J. appl. Physiol. 1983:54; 90-93,
27. Kedlaya D, Post exercise muscle soreness(internet).cited 2012 oct 06) available from: .http://emedicine.medscape.com/article/313267-overview.
28. Friden J., P.N Sfakianos and A.R Hargens. Delayed onset muscle soreness and intramuscular fluid pressure; Comparison between eccentric and concentric load. J. Appl. Physiol. 1986.;61; 2175-2179.
29. Talag TS. Residual muscular soreness as influenced by concentric, eccentric, and static contractions. Res Q. 1973; 44(4):458-69.
30. Armstrong R.B 1991. Mechanism of exercise induced muscle fibre injury. Sports Medicine, 12(3), 184-207.
31. Clarkson PM, Sayers SP. Etiology of exercise-induced muscle damage. Can J Appl Physiol. 1999; 24(3):234-48.
32. Byrne C, Eston RG, Edwards RH. Characteristics of isometric and dynamic strength loss following eccentric exercise-induced muscle damage. Scand J Med Sci Sports. 2001; 11(3):134-40.
33. Sorichter S, Koller A, Haid C, Wicke K, Judmaier W, Werner P, Raas E. Light concentric exercise and heavy eccentric muscle loading: effects on CK, MRI and markers of inflammation. Int J Sports Med. 1995; 16(5):288-92.
34. Lanier A.B. Use of Nonsteroidal Anti-Inflammatory Drugs Following Exercise-Induced Muscle Injury. Sports Medicine. 2003;33(3):177-186
35. Hasson SM, Wible CL, Reich M, et al. Dexamethasone iontophoresis: effect on delayed muscle soreness and muscle function. Can J Sport Sci. Mar 1992;17(1):8-13
36. Adams SS, Bough RG, Cliffe EE, Lessel B, Mills RF. Absorption, distribution and toxicity of ibuprofen. Toxicol Appl Pharmacol. 1969; 15(2):310-30.
37. Cannavino CR, Abrams J, Palinkas LA, et al. Efficacy of transdermal ketoprofen for delayed onset muscle soreness. Clin J Sport Med. Jul 2003;13(4):200-8.
38. Bajaj P, Arendt-Nielsen L, Madeleine P, et al. Prophylactic tolperisone for post-exercise muscle soreness causes reduced isometric force--a double-blind randomized crossover control study. Eur J Pain. 2003;7(5):407-18
39. Ken A. van Someren, Adam J. Edwards,,and Glyn Howatson. Supplementation with β-Hydroxy- β-Methylbutyrate (HMB) and α-Ketoisocaproic Acid (KIC) Reduces Signs and Symptoms of Exercise- Induced Muscle Damage in Man. International Journal of Sport Nutrition and Exercise Metabolism, 2005, 15, 413-424
40. Connolly DA, McHugh MP, Padilla-Zakour OI, et al. Efficacy of a tart cherry juice blend in preventing the symptoms of muscle damage. Br J Sports Med. Aug 2006;40(8):679-83
41. Connolly DA, Lauzon C, Agnew J, et al. The effects of vitamin C supplementation on symptoms of delayed onset muscle soreness. J Sports Med Phys Fitness. Sep 2006;46(3):462-7.
42. Davis JC, Hunt TK. Problem Wounds: The Role of Oxygen. New York: Elsevier Science Publishing Co., Inc., 1988
43. James R. Staples, Douglas B. Clement, Jack E. Taunton, and Donald C. McKenzie, Effects of Hyperbaric Oxygen on a Human Model of Injury. Am J Sports Med September 1999;27(5): 600-605
44. Harrison, Brooke C.; Robinson, Dwight; Davison, Bill J.; Foley, Brian; Seda, Edward; Byrnes, William C. Treatment of exercise-induced muscle injury via hyperbaric oxygen therapy. Medicine & Science in Sports & Exercise: January 2001;33(1):36-42
45. Herbert RD,de Noronha M,Kamper SJ;stretching to prevent or reduce muscle soreness after exercise(Review). Cochrane database of systematic reviews 2011;7:1-38
46. Wessel, Jean. Wan, Aaron, Effect of Stretching on the Intensity of Delayed-Onset Muscle Soreness. Clin J Sports Med 1994;4 (2) 83-87
47. Magnusson SP, Simonsen EB, Aagaard P, Gleim GW, McHugh MP, Kjaer M. Viscoelastic response to repeated static stretching in the human hamstring muscle. Scand J Med Sci Sports. 1995; 5(6):342-7.
48. Smith, Lucille L. Causes of Delayed Onset Muscle Soreness and the Impact on Athletic Performance: A Review. J of Appl Sports Sci Res 1992; 6 (3); 135-41
49. Weber MD, Servedio SL,Woodall WR; The Effects of Three Modalities on Delayed Onset Muscle Soreness JOSPT , November 1994 : 20 (5);236-242.
50. J E Hilbert, G A Sforzo, T Swensen. The effects of massage on delayed onset muscle soreness, Br J Sports Med 2003;37:72-75
51. Ernst e.Does post exercise massage treatment reduce delayed onset muscle soreness: A systematic review; Br J sports Med.1998;32:212-214
52. Allen JD, Mattacola CG, Perrin DH. Effect of Microcurrent Stimulation on Delayed-Onset Muscle Soreness: A Double-Blind Comparison. Journal of Athletic Training 1999;34(4):334-337
53. Curtis D, Fallows S,Morris M, McMakin M. The efficacy of frequency specific microcurrent therapy on delayed onset muscle soreness. J Bodyw Mov Ther 2010, Jul;14(3):272-9
54. Hasson MF, Mundorf R et al .Effect of ultrasound on muscle soreness and performance. Med Sci Sports Exerc 1989;21;S36
55. Kramer WJ, Bush JA, Wickham R et al. continuous compression is an effective therapeutic intervention in treating eccentric exercise induced muscle soreness. J sports rehabil 2001; 10 (1); 11-23
56. Ciccone CD, Leggin BG, Callamaro JJ. Effects of ultrasound and trolamine salicylate phonophoresis on delayed-onset muscle soreness. Phys Ther. 1991;71(9):666-75
57. Ali A, Caine MP, Snow BG. Graduated compression stocking: physiological and perceptuall responses during and after exercise. J of sports sciences,25(4):413-419
58. Dawn T. Gulick, Iris F. Kimura, Michael Sitler, Albert Paolone, and John D. Kelly, Various Treatment Techniques on Signs and Symptoms of Delayed Onset Muscle Soreness. J Athl Train. 1996; 31(2): 145–152.
59. Fox RH. Local cooling in muscle. Br Med Bull 1961;17;14-18
60. Selwood KL, Brukner P, William D, Nicol A, HinmanR.Ice water immersion and delayed onset muscle soreness: A randomized control trial. Br J Sports med. 2007:41:392-397.

61. Bleakley et al. Cold water immersion (cryotherapy) for preventing and treating muscle soeness after exercise (Review).Cochrane database of systematic review. 2012;2:1-64.
62. Mayer Jm et al. Continuous Low-Level Heat Wrap Therapy for the Prevention and Early Phase Treatment of Delayed-Onset Muscle Soreness of the Low Back: A Randomized Controlled Trial. Arch Phys Med Rehabil .2006 Oct;87(10):1310-7
63. Cochrane DJ. Alternating hot and coldwater immersion for athleticrecovery: a review. Phys Ther in sports; 2004;5:26-32.