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A REVIEW ON PHYSIOLOGICAL CHANGES ASSOCIATED WITH COLD WATER EXPOSURE

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ABSTRACT:

Hydrotherapy is an established ancient method of treatment, employing water at varying temperatures to produce different physiological effects. It is considered to be an integral part of the Natural System of Medicine which had a diverse mode of applications ranging from compress, baths, immersions, and direct applications. Cryotherapy or cold water exposure is a kind of hydrotherapic intervention where the application of water can be administered at a temperature less than 15^0 Celsius. This cold water exposure can bring a significant physiological effect that constructs the therapeutic aspects of a specified modality. More number of studies are concern about the effects of hydrotherapy, where there is a lack of temperature-specific study irrespective the mode of applications. This review is conducted with the primary aim to explore the physiological effects that are associated with cold water exposure alone irrespective of the mode on which it is administered. We carry out PubMed, Science direct and Google Scholar Boolean searches to collect the relevant articles that reported the effects of cold water exposure. Our review concluded with the suggestion that cold water exposure can be an effective treatment choice that can be administered to have varied physiological effects.

Keywords: Hydrotherapy, Balneotherapy**,** Coldwater exposure, Physiological effects, Cryotherapy.

INTRODUCTION:

Application of water (Hydrotherapy) is a common treatment modality used in Naturopathy, which employs the practice of using water at different temperatures ranging from very cold to very hot. Water can be therapeutically employed in rendering the normal physiological functions of the human body. These applications of water at different temperatures produce different physiological effects on the body.[1]

From the period of Hippocrates till now the therapeutic effect of Water has been appreciated significantly and has evolved by recent trends in Medicine, acting as a classical remedial agent to improve health. The universal availability and high capacity to produce varied physiological effects place hydrotherapy as a strong treatment modality in the Alternative Medicine System.

Coldwater can be administered through drinking internally and also through external applications like baths, packs, immersions, compresses, swimming, and direct ice applications. The effect of Coldwater applications may be reflex or mechanical due to increased activity of the sympathetic nervous. The short and intense application of cold primarily produces vasoconstriction of internal viscera and subcutaneous blood vessels followed by vasodilatation, while a prolonged moderate application of cold results in sustained contraction.[2] Based on the properties of cold water such as thermal conductivity, buoyancy, hydrostatic pressure, and resistance, it may elicit physiological reactions such as decrease local edema, cerebral blood flow, Nerve conduction velocity, changes in cardiac vasomotor variability,[3] and increase the local anesthetic effect, muscular endurance, Heart Rate (HR), Blood Pressure (BP), metabolic functions, peripheral catecholamine concentration.[1]

Many studies have explored the effect of cold water in the form of internal and external applications on cardiovascular systems, neuromuscular systems, respiratory systems, and gastrointestinal systems respectively. There is no such existence of reviews that are related only to cold water exposure on normal physiological functions, which makes us to conduct the review. Hence our primary aim is to explore the physiological changes that are associated with cold water exposure alone and also to explore the effects of cold water exposure irrespective of the mode of applications like compresses, baths, immersions, and direct applications.

This study follows with the identification of the Research Gap, Searching for articles that satisfied our criteria with data collection and analysis, and ended up with a comprehensive summary. Our search strategy includes primary research studies like Randomized controlled trials (RCT's), Randomized crossover studies, cohort studies, and clinical trials published from 1960-2021 on PubMed, Science direct, Google scholar using Boolean logic keyword search. All the relevant studies were fulfilled with the inclusion criteria (i) Temperature of the water should be <15^0 Celsius (ii) Mode of application should be cold Baths, cold immersion, cold compresses, cryotherapy, cold swimming, and cold water drinking (iii) Articles which are published as English literature in full-text form.

PHYSIOLOGICAL EFFECTS OF COLD ON CARDIOVASCULAR SYSTEM

Cold application stimulates vasomotor constrictor and accelerator nerves of blood vessels which contract small blood vessels later by active dilatation.

Depends upon the intensity and duration of cold application, Heart rate, vascular resistance, and Blood pressure may vary. The very short cold application increases the Heart rate and Blood pressure by continuous contraction of blood vessels followed by 3-10 mins of dilatation later gives rise to contraction, where prolonged cold application to the reflex areas stimulates the sympathetic nerves causes contraction later by dilatation.[2]

Local cold water exposure to a small surface area increases blood flow at the site of exposure by inducing Vasodilatation.[4] Physiological changes that occur after a systematic cold application differ from a Local cold application.[5]

A single cold-water immersion at 14^0c produces a primary excitant effect which induces peripheral vasoconstriction, stimulating thermogenesis and sympathetic nervous activity by increasing metabolic rate (350%), heart rate, and 10% of systolic and diastolic blood pressure,[6,7] where immersion at 20°C and 32^0C reduces heart rate(15%), Systolic and diastolic blood pressure(11% or 12%).[7]

Diastolic blood pressure decreases after repeated cold water immersions for 6 weeks. Single short cold application induces a change in the sympathetic nervous system effectively when compared to repeated applications.[6] Repeated cold water immersion may lead to habituation which decreases the heart rate.[8]

Increased level of Heart rate variability(HRV) suggests the parasympathetic activation after a single whole body cryotherapy session at -110^0C and it lowers after the 5^{th} session due to habituation.[9,10]

Facial cooling elicits cardiac vagal activation by a trigeminal stimulation which results in increased stroke volume ($P<0.001$) and pre-ejection period levels (PEP), where a mild increase in Heart rate, Systolic, and Diastolic Blood pressure. In this study, Procedural usage of Icebag to the forehead may lead to discrepancy changes in BP.[11] In another study LBNP + Facial cooling increases mean arterial Blood pressure and skin vascular resistance.[12] Hence, Facial cooling will be effective in mitigating central hypovolemia.

Immersing various parts of the Upper limb in cold water shows significant changes in cardiovascular response. Hand cooling induces Cold-induced vasodilatation (CIVD) which increases BP ($P<0.01$) and HR ($P<0.01$) followed by progressive decrease up to baseline values within 10 minutes. Index finger cooling shows earlier CIVD without any cardiovascular changes.[13] Hand cooling coupled with α adrenergic activity and peripheral Vasoconstriction results in increased BP, TPR($P<0.001$), and a decrease in stroke volume.[11]

Immersion of legs at knee level in cold water increases the HR, systolic, and diastolic blood pressure ($P<0.05$) which declines to baseline values later. Repeated local cooling increases the sympathetic tone which shows changes in CV responses.[5]

Ice cold water drinking increases the vagal activity by stimulating thermo vagal receptors in the esophagus make changes in heart rate variability than normal RT water drinking.[14,15]

Ice bag application to head and spine shows marked changes in variables of DBP and MP (P<0.01) than Tap water bag application.[16] IBA stimulates parasympathetic activity by decreasing peripheral resistance and Vasodilatation.

Follow up measurement at 10 mins interval of Coldwater immersion induces vasoconstriction instantly, later followed by vasodilatation by decreasing Skin perfusion(P=0.01) & Skin temperature (P=0.04) where Partial body Cryotherapy mildly increases the skin perfusion & Skin temperature(P=0.01).[17]

A study shows that the Thermic effect of cold water chest pack increases parasympathetic activity by decreasing Mean Heart rate (P=0.0144) than the sham chest pack group.[18]

PHYSIOLOGICAL EFFECTS OF COLD ON BLOOD VARIABLES

Single cold water immersion at 14^{0}C for 1 hour increases the count of Red blood cells(RBC) and White blood cells(WBC).[19]

Coldwater exposure increases the number of corpuscles in circulation especially white blood cells in greater proportion than Red blood cells.[2] A study proves that Short term swimming of 150m in 6^{0}C cold water induces changes in hematological parameters by increasing counts of Erythrocyte(4.7%), thrombocytes(25.0%), Neutrophils(42.6%), Lymphocytes(40.6%), Monocytes(27.5%) but no variations observed in blood indices such as MCH, MCV, and MCHC.[20]

In another study, cold water immersion at 14^{0}C for 10 mins increases the Neutrophil count and decreases the lymphocyte count (P<0.01) after exposure, and no changes were found in leukocyte and monocyte count.[21]

Repeated cold water immersion increases the count of lymphocytes (CD3, CD4, CD8) and monocytes where no changes are found in erythrocytes, granulocytes, and neutrophils in peripheral blood.[19]

Winter swimming increases Hb concentration, hematocrit level, erythrocyte, thrombocyte, and leukocyte count(P<0.01)[22,23] comparatively with cryogenic exposure.

Regular cold water swimming produces adaptive changes in the blood variables by increasing RBC(P<0.01), Hb(P<0.001), MCH (P=0.03), MCHC(P<0.01), Serum erythropoietin(P=0.001), and decrease in platelet counts(P=0.005), serum folate(P<0.001).[24]

PHYSIOLOGICAL EFFECTS OF COLD ON NERVOUS SYSTEM

The application of cold to a nerve may diminish the rate of transmission of nervous impulses over it to $1/6^{th}$ of the normal rate. Nearly all the phenomena arising from applications of cold water are illustrations of the effects of cold upon the nervous system.[2]

There was an increased plasma norepinephrine level after the first Whole Body Cryotherapy (WBC) session at -110^{0} but lost its significance on the 5^{th} day, indicates that a single WBC at -110^{0}C will stimulate the ANS. A regular 5 days exposure to WBC shows the lowered autonomic responses, indicates the development of Physiological Habituation to WBC.[10] A larger stimulation of ANS can be achieved through WBC than Partial Body Cryotherapy.[9]

The application of ice massage, ice pack, and cold water immersion decreases the sensory nerve conduction velocity and induces the Hypoalgesic effect. The alteration in parameters of nerve conduction is effectively achieved through Coldwater immersion.[25] The reduction in nerve conduction results in increased Pain Threshold (PTH) and Pain Tolerance (PTO) making the application clinically significant.[26]

The ice water immersion of single-hand will increase the sympathetic nerve activity in non-immersed hands by reducing the temperature of the skin in non-immersed palms.

There is no significant difference between the reduction of skin temperature in both males & females, denying the gender difference in contralateral vasoconstriction response.[27] The responses resulted from cold water immersion is due to increased activity of the sympathetic nervous system where the humoral control mechanism will mediate the physiological changes that happen in the cold water immersions.[7]

PHYSIOLOGICAL EFFECTS OF COLD ON MUSCULOSKELETAL SYSTEM

Muscle Oxygen Saturation is significantly reduced in Cold Water Immersion (CWI) in comparison with Partial Body Cryotherapy (PBC). No significant difference is found between the CWI and PBC of Cutaneous Vascular Conductance but said to be increased in the Control Group. Both CWI and PBC were effective in reducing the Delayed Onset of Muscle Soreness in Females than the Control Group.[28]

The Coldwater Immersion at 15 degrees Celsius was an effective strategy to improve the handgrip performance of Males (44%) than females (26%). It also significantly increases the time to failure for second and third trials of intermittent handgrip contraction in comparison with cold immersion at 8 degrees Celsius and passive recovery.[29]

The effect of cold application has a direct relation with subcutaneous tissue thickness and required an altered duration to produce similar Intermuscular temperature changes which a clinician should be aware of.[30,31]

There was an increased Energy Expenditure (16.7%) and Fat oxidation (72.6%) from the Warm period to 31% of cold exposure in young lean men indicating the Brown Adipose Tissue and muscle might act as a non-shivering thermogenesis effector during mild cold exposure.[32]

The administration of multiple cold water immersions was not effective to increase the recovery of muscle function followed by muscle-damaging exercise. But it attenuates the muscle damage.[33]

The application of Cold Water Immersion may enhance the remodeling of muscle fiber and restore the blood supply after exercise by increasing the PGC-1α and VEGF mRNA expression in human skeletal muscle.[34]

The cold water immersion shows better post-training recovery measures by having higher muscle power and perceived recovery and less muscle soreness by reducing circulating Lactate Dehydrogenase (LDH) in jiu-jitsu athletes.[35]

PHYSIOLOGICAL EFFECTS OF COLD ON RESPIRATORY SYSTEM

Initial response to cold water exposure triggers thermoreceptors of skin which induces reflex bronchoconstriction mediated by afferent nerves.[8,36]

Short cold application to the reflex areas may produce vasoconstriction to the parts reflexively connected.[2] Facial cooling stimulates the receptors innervated by the trigeminal nerve to promote vagal activity by mildly reducing the skin conductance(sGaw) and FEV_1($P<0.001$).[36–38]

Prolonged cold application to the upper dorsal and the lower cervical area produces contraction of pulmonary vessels.[2]

Coldwater shower causes hyperventilation by increasing the Airway resistance($P<0.01$) and End- expiratory lung volume($P<0.05$) in the control group.[39] Repeated submaximal stimulation reduces the respiratory rate, inspiratory volume, and heart rate($P<0.01$) in the habituation group.[8]

FEV_1 and FVC reduce at 3 mins ($P=0.005$) in cold endurance swimmers (10 ± 0.9◦C) but returned to baseline values within 10 mins. CO diffusing capacity, alveolar volume, SpO_2 were reduced till 2.5 hours of post swimming. Mean core temperature dropped from 36.6 ± 0.1 ◦C to 35.7 ± 1.1 ◦C ($p < 0.001$) and skin temperature dropped from 33.3 ± 0.3 ◦C to 19.2 ± 1.6 ◦C ($p < 0.001$),[40] where no significant changes observed in pulmonary compliance.[39,40]

The parasympathetic activity of cold chest pack reduces Mean RR($P=0.0309$) comparatively with sham chest pack.[18]

PHYSIOLOGICAL EFFECTS OF COLD ON ENDOCRINE SYSTEM

Cold exposure stimulates non-shivering thermogenesis which activates sympathetic-adrenomedullary and hypothalamic-pituitary-adrenocortical system.[41–43]

Single cold water immersion ($P<0.05$) at 14^0C increases plasma adrenaline and dopamine concentration by 530% and 250% respectively. Plasma renin activity($P=0.015$) was reduced at high temperatures.[6,7]

A rise in plasma norepinephrine($P<0.01$) and reduced level of plasma ACTH & cortisol($P<0.05$) were found after 1st session of whole-body cryotherapy,[10,43–45] where the values remain decreased[46] or equal changes observed till 12th week of exposure infers Habituation by stimulating the pituitary-adrenal cortex axis.[43]

A study shows that plasma concentration of cortisol, epinephrine & aldosterone increased ($P<0.001$) in both SC and FC groups,[47] where other studies mention it has no significant changes in values.[6,7] Repeated cold water exposure does not affect the changes in hormonal production.

The serum level of thyroid hormones or TSH does not changes when exposes to 5-10^{0}C.[48,49] T_3 and TSH levels ($P<0.001$) were increased in hunters of the arctic region.[50] In other similar study T_4 tends to decreases and TSH increases.[51] Repeated cold water exposure increases TSH level($P<0.05$) and decreased serum prolactin level at 4th week in cold swimming group.[42] Short-term exposure to cold does not make any changes in thyroid hormone secretion.

Appetite regulating hormones such as ghrelin and leptin was higher at cold water exposure(2^{0}C),[52] where post-exercise immersion have a lowered concentration of leptin.[53]

PHYSIOLOGICAL EFFECTS OF COLD ON IMMUNE SYSTEM

Regular exposure to cold increases the resistance and defense mechanism which indicates the adaptive changes in the anti-oxidant levels.[23] β-adrenergic receptors in human leukocytes infer the activity of the immune system which can be modulated by catecholamines where cold exposure stimulates sympathetic activity by adrenergic signaling.[41,54]

Cold exposure at 4^{0}C shows a mild increase in NK cell activity but a regular increase in IFN in the blood($P<0.05$).[55]

Changes in leukocytes($P<0.01$), neutrophils($P<0.001$), lymphocytes($P<0.001$), and monocytes($P<0.001$) was significant in the SC group than in the FC group where no changes were observed in specific immunity(IL-6 and TNF-α) in both the groups.[47]

Single cold water immersion increases IgG,[19] IL α and decreases TNF-α($P<0.01$) where no changes were found in IL-1β.[21] Repeated cold water immersion increases plasma concentration IL6 and TNF, no significant changes found in IL-1β, Immunoglobins($P<0.05$).[19] Thus, Coldwater Exposure stimulates monocytes to secrete proinflammatory cytokines such as IL-1, TNF-α, and IL-6.

Serum levels of TNF-α, IL-6, IL-1β decreases($P<0.05$) and NK activity, $T_H{}^1$ cells($P<0.05$) increases in Japanese volunteers who were exposed to Antarctic winter, it returned to baseline values during inland transverse.[56]

Regular cold water swimming makes changes in innate immunity,[56]decreases the Ig concentration($P<0.001$).[24] Five months of regular cold water swimming increases the level of antioxidant enzymes SOD, CAT, and glutathione reductase($P\leq0.05$) and decreases the Oxidant enzymes 8-ISOP in plasma and oxidized glutathione($P\leq0.001$) where a mild increase is observed after whole-body cryotherapy($P\leq0.05$).[23]

PHYSIOLOGICAL EFFECTS OF COLD ON SKIN

There is a significantly decreased perfusion of microcirculation compared to baseline values between 10 minutes ($P = 0.003$) and 30 minutes ($P = 0.01$) post-treatment in Coldwater immersion. It also decreases the local skin temperature significantly up to 30 minutes ($P = 0.04$) post-treatment. [17]

The Mean skin temperature is significantly reduced in CWI compared with PBC, while it is increased in the Control group over a while.[28]

The skin temperature is said to be significantly reduced ($P<0.05$) immediately after the Whole Body Cryotherapy (WBC) in comparison with Coldwater immersion (CWI). A single WBC will reduce the muscle and core temperature similar to CWI.[57]

The decrease in skin temperature after exposure to a cold environment will decrease the Thermal Pain.[58]

CONCLUSION:

From our knowledge, our review is considered to be the first article that explored the physiological effects brought in association with cold water exposure alone, irrespective of the mode on which the modality is applied. From the obtained articles it is cleared that the application of cold water can be administered to preserve a healthy state of living in terms of treatment and as a preventive tool as well. This review also suggests that cold-based treatment modalities can be the right choice of Physician's Prescription that needs more scientific approaches in the future.

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