Publication date: 15.09.2025
DOI: 10.24412/2782-6570-2025_04_03_2
UDC 612.74; 796.015.54

LACTATE-PYRAMIDAL TRAINING FOR ENHANCING STRENGTH CAPABILITIES AND MUSCLE MASS

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Abstract. ***Introduction.*** This comprehensive narrative review provides a detailed investigation of lactate-pyramidal training as a hypertrophy strategy, synthesizing mechanical tension and metabolic stress. Objective: to conduct a literature analysis of lactate-pyramidal training, focusing on biochemical and neurophysiological responses, practical implementation methods, integration strategies, and recovery. ***Methods.*** The study was conducted according to the CINAR guideline for narrative reviews and the SANRA scale for narrative review quality assessment. Literature searches were performed following the PRISMA-S and PRESS literature search checklists. Literature searches were conducted in the PubMed, Scopus, RSCI, and Cochrane Library databases. No time or language restrictions were applied during the search. ***Results.*** Thirty-six studies met the inclusion criteria (randomized controlled trials (n=24), meta-analyses (n=5), systematic reviews (n=7)). The identified literature was categorized into three areas: physiological mechanisms of the lactate-pyramidal method; classic examples of pyramidal training schemes; methodological approaches of the lactate-pyramidal method. ***Conclusion.*** Currently, this methodology represents an effective, yet consciously and carefully applied tool for overcoming training stagnation and achieving new levels of muscular definition and hypertrophy in sports characterized by maximal strength demands.

Keywords: lactate-pyramidal training, muscle hypertrophy, metabolic stress, mechanical tension, lactate, hydrogen ions, acidosis, pyramidal schemes, drop-sets, rest-pause, hypoxia, periodization, strength training, recovery.

Introduction. *Origins of the lactate-pyramidal training.* Traditional approaches to teach strength capabilities and to grow muscle mass are historically reflected in two directions of athlete training. The first one is described solely as pedagogical, while the second one takes into account a number of physiological and biochemical processes in a body. Although the peak of research in this direction occurred in 1960-1980, back in 1948 Thomas L. DeLorme & Arthur L. Watkins [1] published the work titled "Progressive resistance exercise; technic and medical application" (Archives of Physical Medicine, 1948), in which they developed the DeLorme protocol, which is essentially an ascending pyramid: 3 sets with increasing weights (10 repetitions with 50% of 10RM (repetition maximum), 10 repetitions with 75% of 10RM, 10 repetitions with 100% of 10RM (maximum weight of 10 repetitions). The focus was put on rehabilitation and strength, and the principle of weight progression and the importance of heavy sets formed the basis of strength training and bodybuilding in the 60s and 90s. Their method has been cited and applied for decades.

Pedagogical research on progressing loads was conducted in the Soviet weightlifting school in 1960s, and it was based on numerous studies of L.P. Matveev [2, 3]. For example, Yurij Vlasov [4] and Rudolph Plyukfelder [5] applied ascending pyramids to manage volume and intensity of training. On the other side, as mentioned above, it is worth noting the training approach that takes into account the physiological and biochemical changes in a body. Here we highlight the concept of metabolic training, which focused on the use of lactate as an anabolic stimulus, which became possible after the revolutionary work of Brooks [6] describing the "lactate shuttle", and subsequent studies of the signaling role of lactate in Gladden's research [7]. In general, the modern understanding of lactate-pyramid training has taken shape as a methodological response to the problem of training plateaus among elite bodybuilders and other representatives of strength sports. Some clinical observations have shown that combining pyramidal progression with targeted lactate accumulation makes it possible to overcome the muscle growth stagnation in 78% of athletes with more than 5 years of experience. Currently, the search for synergetic training strategies that maximize hypertrophy through exposure to multiple mechanisms [8] remains the central task of strength training aimed at muscle tissue hypertrophy. According to the analysis of the problem situation, data from modern scientific literature and requests from sports biologists, physiologists, coaches and athletes, the objective of the study was formulated.

Objective: to conduct a literature analysis of lactate-pyramidal training (LPT), focusing on biochemical and neurophysiological responses, practical implementation methods, integration strategies, and recovery.

Methods and organization. The study was carried out in the Educational and Methodological Laboratory of Evidence-based Development of Natural Science Education, Phystech School of Applied Mathematics and Computer Science, Moscow Institute of Physics and Technology. It was conducted according to the CINAR guidelines (Consolidation Items for NArrative Review) [9] and SANRA (Scale for the Assessment of Narrative Review Articles) [10]. The study's protocol was constructed before the search and did not alter neither during nor after the study. The literature search was conducted in accordance with the PRISMA-S [11] and PRESS (Peer Review of Electronic Search Strategies) literature search checklists [12]. Literature searches were conducted in the PubMed, Scopus, RSCI, and Cochrane Library databases according to the following keywords: lactate AND ("pyramid training" OR "metabolic stress") AND hypertrophy, "motor unit recruitment" AND fatigue. No time or language restrictions, as well as restrictions on study design were set in the search.

Results and discussion. 1750 mentions (taking into account possible article duplication between databases) have been found in the PubMed, Scopus, RSCI, and Cochrane Library databases with the keyword combination (lactate AND ("pyramid training" OR "metabolic stress") AND hypertrophy и "motor unit recruitment" AND fatigue). Thirty-six studies corresponded with the inclusion criteria (randomized controlled studies – RCTs (n=24), meta-analyses (n=5), systematic reviews (n=7)). The identified literature was categorized into three areas:

1) physiological mechanisms of LPT;

2) classic examples of pyramidal training schemes;

3) methods of LPT.

Analysis of physiological mechanisms of LPT. Classic dynamic neuromuscular adaptation is a gradual increase of weights in ascending pyramids (e.g., 12 repetitions with 60% of 1RM → 8 repetitions with 80% of 1RM), it plays the role of the "neural warm-up" [13]. Each repetition increases excitability of motor neurons, improves motor unit (MU) synchronization and facilitates the recruitment of the high-threshold (type II) [14] fibers in the key heavy set ("top of the pyramid"). It allows achieving a more effective mechanical tension in a last set, than when performing it "cold" [15]. Recruiting and activation range: a wide range of MUs is covered: highly repetitive initial sets recruit predominantly type I oxidative fibers and type IIa intermediates, creating a metabolic base. Top of the pyramid recruits type IIx/IIb glycolytic fibers maximally [16]. This provides a more complete stimulation of the muscle pool compared to monotonous schemes. Such direction in training creates a unique subsequence – the initial pyramid sets cause a pH shift in the muscle towards acidosis and create the prerequisites for hydropic dystrophy. A heavy set on the top provides peak mechanical tension and recruitment of high-threshold MUs in conditions of already increased metabolic environment. Cell swelling: metabolite accumulation increases osmolarity of sarcoplasma. It causes flow of water from the interstitium and bloodstream into the muscle fibers, stretching the sarcolemma and perimisium. Mechanosensors (integrins, PI3K) consider the stretching as anabolic signal by activating mTOR (mechanistic target of rapamycin) pathway and suppressing proteolysis through FOXO (Forkhead box O) – a family of transcription factors that regulate protein degradation and autophagy [17, 18]. LPT maximizes metabolic stress causing extreme cell hydration and hypoxia, as well as additional recruiting through reflex mechanisms. This sequence provides powerful synergetic stimulus [19]. Osmotic pressure from lactate/ions → sarcolemma stretching → mTOR activation despite mechanical tension. It is worth noting that LPT is not a substitute for the base load, but a tool for overcoming plateaus. The key is a precise dosing: if the threshold of 15 mmol/L is exceeded, myocyte apoptosis is triggered [20]. Reflex MU activation supports the metabolite accumulation (H^+, lactate, ATP) simultaneously stimulating group III/IV of afferent nerves (nociceptors) and muscle spindles. This reflexively (through the spinal tract) increases efferent impulses to alpha motor neurons, contributing to the recruitment of additional MUs, especially with developing fatigue – the phenomenon of “recurrent inhibition” or “metabolic facilitation” [21]. It is critically important for continuing the work in conditions of severe metabolic stress of LPT. The cytoplasmic swelling due to intense muscle activity, especially in conditions of limited blood flow (occlusion), leads to accelerated glycolysis. Pyruvate, having no time to oxidize in the mitochondria, restored to lactate, conjugately generating H^+ [22]. Low pH (acidosis) and accumulation of non-organic phosphate (Pi), ATP, creatine create high metabolic stress. Moreover, intensive dynamic muscle work provides pronounced hypoxia (forced lactate accumulation up to 12-15 mmol/l;), activating mTOR pathways, histone lactylation, IGF-1 (Insulin-like Growth Factor 1) secretion locally (+45%) [23]. Moreover, many studies by Pedersen show how metabolic stress stimulates myokine release from the working muscles [24]. Although their role is disputable, local paracrine/autocrine action (especially IL-6 (interleukin-6) and FGF21 (Fibroblast Growth Factor 21)) may provide proliferation of satellite cells and regeneration by indirectly supporting hypertrophy [25]. Mental aspect is also important, since increasing weights reduce a mental barrier between heavy sets, increasing preparedness to maximal effort. As Halperin et al noted [26], the progressing load reduces cognitive evaluation of threat, which alleviates effort mobilization in heavy approaches.

Classic examples of pyramidal training schemes. A classic ascending pyramid implies focus on progressing weights. For example, 4 sets of 15-12-10-8 repetitions [27]. A pyramid with fixed weights and decreasing rest intervals. For example, 70-75% of 1RM decreases with decreasing rest intervals (120 s → 90 s → 60 s → 30 s). The number of repetitions usually drops. In this case, the focus is set on the metabolite accumulation.

“Reverse” pyramid (descending): begins with a heavy set (small number of repetitions), then the weights decrease while the number of repetitions increases (e.g. 6-8-10-12). It is a less common training scheme, but it can be used if the main objective is the priority of heavy loads on the initial pre-start state of the central nervous system. The “Step pyramid” / “Plato pyramid” is performed in several sets with equal weights/repetitions in the middle of the pyramid (e.g. 15 → 12 → 10 → 10 → 10 → LPT). It increases the metabolic component in the middle range. The “Truncated” pyramid: skip of the easiest sets (begins from 10 or 8 repetitions), for experienced athletes or in case of limited time. The combined methods can also be used. For example, drop-set + rest-pause on the last weights; forced repetitions + partial repetitions [28], or application of the isolating exercises on the target muscle before the basic exercise (for example, leg extension between the basic multi-joint exercise in the sagittal plane (barbell squat etc.)). Not only it increases metabolic stress and focuses on the target muscle in the basic movement, but it also can decrease weights at the top of the pyramid. Moreover, if slow (4-6 s) eccentric movements with a partner or on a training device with a lever are performed after concentric failure, it will cause severe injury and additional metabolic stress [29]. If we talk about training process periodization, we should note the following periods [30]: the microcycle will be constructed at the expense of alternating muscle work for different muscle groups with training focused on strength (small number of repetitions, long rest) or on cell swelling (great number of repetitions, short rest). The mesocycles may serve as an ideal tool for 4-8-week periods focused on hypertrophy of the underdeveloped groups.

Frequency: once in 5-7 days for a muscle group. The macrocycles will be constructed according to the objectives of micro- and mesocycles.

Lactate-pyramidal method. LPT is a strategic instrument consisting of a proper construction of a collection of sets combining hypertrophy-optimal mechanical tension on the muscle system and metabolic stress. In whole, it provides a powerful stimulus for muscle growth through the both main hypertrophy mechanisms [20, 31]. We are suggesting the following method of training strength abilities with predominant influence on muscle fiber hypertrophy. The lactate-pyramidal method includes a sequence of four approaches with different number of repetitions and rest periods. We can change the number of sequences taking into account the athlete’s fitness. However, it is important to note that rest between such sequences should be quite long (~5 minutes – active, ~10 minutes – passive), since a full recovery is needed after sets with multidirectional metabolic stress for all systems of a body. Nonetheless, it is also crucial that unlike generally accepted schemes of strength training for hypertrophy, LPT combines an optimal level of mechanical and metabolic stress that allows reaching maximal results for a shorter period and with less damage on the myofibrillar system. Meanwhile, in case of higher efficiency, it would allow to shorten terms of recovery of the target muscle group down to 7 days, while in case of classic dynamic pyramid, 14 days are required for the full resolution of inflammatory infiltration [32-34]. The main principles of LPT structure are:

1. Progressing load: implies variability of external weights depending on the set's direction.
2. Lactate/metabolic component: objective – metabolite (lactate, hydrogen ions etc.) accumulation to stimulate hypertrophy through metabolic stress, especially in the last "light" set.
3. Managing fatigue: rest regulates fatigue level of the central nervous system and muscle system allowing performance of hard sets with heavier weights and achievement of the proper level of osmotic stress in the muscles during "light" sets.

The table below shortly describes the scheme of sequences for muscle fiber hypertrophy consisting of four sets with different objectives.

Table

Lactate-pyramidal method

Set (repetitions)	Objective	Rest time after a set	Reason for rest
1. Light weights, high number of repetitions (12-15)	Warm-up, metabolites accumulation, onset of stress	60-90 s	Management of pulse/metabolism, light fatigue
2. Medium weights, average number of repetitions (~10)	Increasing load	90-120 s	Partial recovery for a heavy set
3. Heavy weights, near-maximum number of repetitions (6-8)	Maximum mechanical stress	150-210 s	Restoration of the creatine phosphate mechanism and the central nervous system for a heavy set involving severe metabolic stress
4. Light weights, maximum number of repetitions (~20)	Maximum oxidation, pH shift	until full recovery	Support of high metabolite content, extreme metabolic stress in a tired muscle. In case of being followed by a series, a full recovery is required.

Conclusion. The progressing muscle load is an undeniable keystone of hypertrophy [35]. LPT is one of the ways to realize it. The scheme, which combines range of repetitions, uniting small, average and high number of repetitions, demonstrates advantages for comprehensive hypertrophy compared to the classic dynamic approach [36, 37]. Moreover, some studies of Marques et al [38] show that long-term hypertrophy is closely connected with growth in strength. LPT is a specialized instrument in the arsenal of strength sports representatives aimed at maximizing metabolic stress, which is an important, though not the only, muscle hypertrophy mechanism. Its effectiveness is based on conscious usage of signaling properties of lactate in terms of structured progression of pyramidal load. LPT is able to cause muscle hypertrophy, stimulate different types of muscle fibers and potentially strengthen the anabolic response. In sports physiology, the biological purpose of LPT is reduced to a protocol of strength exercises, the biological objective of which is to stimulate hypertrophy through the synergy of two mechanisms:

1) Progressing mechanical tension achieved by diverse pyramids with external stress, which recruits high-threshold motor units (type II) and activates the myofibrillar protein synthesis (mTOR-pathway).

2) Lactate-induced metabolic stress occurred in final sets (frequently with intensificators), where a massive accumulation of lactate and H^+ (acidosis) causes osmotic stress leading to the activation of anabolic signals via cell swelling (mechanotransduction).

This process occurs during recruitment of additional MUs (through III/IV group of afferent nerves) in a state of hypoxia causing growth factor expression (HIF-1α). New studies [20] confirm that such type of training recruits and maintains high-threshold motor units under stress, creating ideal conditions for their growth. However, its extreme character requires cautious, controlled application with priority on recovery. Future studies should define long-term effectiveness of LPT more precisely compared to other methods, optimize protocols for various body types and levels of fitness, and investigate deeper individual differences in response to lactate load. Currently, this method is a progressive but demanding for a cautious and sensible application instrument to overcome the plateau and achieve new levels of muscular definition and hypertrophy in types of sports that imply the manifestation of the threshold strength abilities of a body. Another important thing to note is that in terms of theory and methods of physical education and sports LPT is an independent pedagogical method based on the principle of progressive mechanical stress, which may be used both solo and in synergy with different methods. Therefore, by taking into account the peculiarities of training, we may speak of LPT as a prospective for further study, physiologically substantiated instrument for muscle hypertrophy stimulation that skillfully combines the basic mechanisms of growth – progressive mechanical tension and extreme metabolic stress. Its effectiveness is confirmed by an understanding of biochemistry (lactate/H^+-induced swelling, hypoxia), physiology (recruitment, facilitation), and empirical success in strength sports.

Study limitations. 78% of the studies were conducted on 25-35-year-old men; there are insufficient data on athletes over 50 and women. The LPT effectiveness data are based mainly on short-term studies of young trained men in controlled conditions. There is a critical deficit of data on application of LPT in key population groups (women, the elderly), on its long-term effects and safety, as well as on the influence of deep individual differences (genetics, type of fibers, buffer capacity). This significantly limits the external validity (generalizability) of the results and requires extremely careful interpretation and application of the method in practice, especially for groups not represented in the research. Long-term RCTs with diverse cohorts and careful monitoring of long-term consequences are required.

Conflict of interest. The authors declare no conflict of interest.

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For citation: Tsybikov V.N., Miroshnikov A.B. Lactate-pyramidal training for enhancing strength capabilities and muscle mass. *Russian Journal of Sports Science: Medicine, Physiology, Training*, 2025, vol. 4, no. 3(15). DOI: 10.24412/2782-6570-2025_04_03_2