

Is failure necessary for muscle growth? an updated review of resistance training to concentric failure

Abstract

Muscle hypertrophy — the increase in skeletal muscle fiber cross-sectional area — is a central goal of resistance training (RT) programs for athletic performance, aesthetics, and health. Among the variables that can be manipulated in RT, performing sets to concentric failure, the point at which a repetition cannot be completed through its full range of motion despite maximal voluntary effort, remains one of the most debated. This narrative review synthesizes current evidence on the physiological basis, comparative effectiveness, and risks of training to concentric failure for muscle hypertrophy, incorporating findings published through 2026. Mechanistically, proximity to failure is theorized to increase recruitment of high-threshold motor units and metabolic stress, both implicated in hypertrophic signaling. However, when total training volume is equated between conditions, recent systematic reviews and meta-analyses show that training to failure confers, at most, a small hypertrophic advantage over non-failure training, an effect that appears more consistent in resistance-trained individuals than in novices. Emerging dose-response meta-regressions suggest a modest, non-linear relationship between proximity to failure and hypertrophy, while strength gains do not appear to benefit from training closer to failure. Training to failure also carries physiological costs, including greater residual fatigue, slower recovery, and potential interference with volume progression, and repetitions-in-reserve estimation is less accurate when performed farther from failure. We conclude that while training to concentric failure is a valid strategy in specific contexts, particularly for advanced trainees using single-joint exercises on final sets, it is not a prerequisite for hypertrophy and should be applied selectively within a well-structured periodization plan.

Keywords: muscle hypertrophy, resistance training, concentric failure, repetitions in reserve, motor unit recruitment, training periodization

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Abbreviations: RT, resistance training; 1RM, one-repetition maximum; RIR, repetitions in reserve; RPE, rating of perceived exertion; CSA, cross-sectional area; mTORC1, mechanistic target of rapamycin complex 1; ES, effect size; CI, confidence interval.

Introduction

Muscle hypertrophy is one of the most sought-after physiological adaptations among individuals who engage in resistance training (RT), with direct relevance to athletic performance, physiotherapy and rehabilitation, body aesthetics, and healthy aging. Although progressive overload is universally recognized as the foundational principle underlying hypertrophic adaptation, the specific strategies used to maximize muscle mass gains remain a matter of ongoing debate.¹ Other manipulable training variables, such as weekly training frequency, have likewise been shown to influence hypertrophic outcomes, underscoring the multifactorial nature of program design for muscle growth.²

One such strategy is performing resistance exercise sets to concentric failure, defined as the momentary inability to complete the concentric (lifting) phase of a repetition with proper technique despite maximal voluntary effort. For consistency, this review uses the term concentric failure throughout; the terms muscular failure and momentary muscular failure, used interchangeably with concentric failure in several of the cited primary studies, are retained only when describing those studies' original terminology and should be interpreted as synonymous unless otherwise specified. Proponents argue that this approach maximizes motor unit recruitment and mechanical tension, two of the principal mechanisms implicated in hypertrophic signaling. Critics, conversely, point to the risks of excessive fatigue,

overreaching, and impaired subsequent performance, particularly when training to failure is applied indiscriminately across an entire training program.³

This narrative review critically appraises the evidence on training to concentric failure, incorporating physiological rationale, comparative efficacy data, methodological limitations, and practical implications. Relative to earlier reviews on this topic, this update incorporates systematic reviews, meta-analyses, dose-response meta-regressions, and randomized controlled trials published through 2026, reflecting a considerably more nuanced picture than was available even five years ago.

Literature Search Strategy

As a narrative review, no formal systematic protocol was registered; nonetheless, a structured search strategy was applied to identify relevant literature. The PubMed/MEDLINE, Scopus, and SPORTDiscus databases were searched from inception through 15 August 2026 (date of the final search) using combinations of the terms “resistance training,” “concentric failure,” “muscular failure,” “repetitions in reserve,” “proximity to failure,” and “muscle hypertrophy.” Priority was given to systematic reviews, meta-analyses, dose-response meta-regressions, and randomized controlled trials published from 2016 onward, supplemented by earlier mechanistic and foundational studies. Reference lists of retrieved articles were hand-searched to identify additional relevant sources.

Eligible sources were limited to peer-reviewed, English-language publications reporting original data or quantitative synthesis in humans; conference abstracts, non-peer-reviewed preprints, and animal studies were excluded. Title and abstract screening, followed

by full-text assessment, was performed independently by two authors, with disagreements resolved through discussion with a third author.

Discussion

Physiological basis of concentric failure and muscle hypertrophy

The central hypothesis supporting the use of concentric failure relates to the complete recruitment of motor units, particularly type II fibers, which possess greater hypertrophic potential. According to Henneman's size principle, motor units are recruited progressively, from those with the lowest to those with the highest activation threshold. Fatigue accumulated across a set is thought to bring the activation of high-threshold motor units closer, theoretically promoting a greater hypertrophic stimulus.⁴

Mechanical tension is currently considered the most influential stimulus for muscle hypertrophy, mediated through mechanosensing mechanisms and downstream activation of the mechanistic target of rapamycin complex 1 (mTORC1) signaling pathway.⁵ In addition to mechanical tension, the accumulation of metabolites such as lactate, inorganic phosphate, and hydrogen ions during high-effort sets creates an intracellular environment that may stimulate anabolic signaling, reinforcing muscle plasticity.⁶ Training closer to failure may also increase mitochondrial and metabolic stress, which, within physiological limits, can contribute favorably to muscular adaptation.⁶ Beyond motor unit recruitment, the fatigue accumulated during low-load training to failure may itself contribute to hypertrophy through additional mechanisms, such as cellular swelling, heightened metabolite accumulation, and compensatory recruitment of larger, more fatigue-resistant motor units as smaller units become unable to sustain the required force output.⁷

It is essential, however, to distinguish between true muscular failure and technical failure. The inability to maintain correct exercise execution does not always coincide with genuine exhaustion of the contractile capacity of the target muscle, and this distinction has important implications for how "failure" is operationalized across studies, a source of substantial heterogeneity in the literature.⁸

Empirical evidence: hypertrophy with and without training to failure

Some earlier trials reported superior hypertrophic gains with training to failure, particularly among untrained individuals and in less complex exercises.⁹ However, when total training volume was carefully equated between conditions, other investigations found no significant difference in muscle mass gains between groups that trained to failure and those that terminated sets before reaching it.^{10,11} Consistent with this, a study conducted specifically in resistance-trained men found comparable strength gains between failure and non-failure protocols, although certain muscle groups exhibited greater architectural adaptations, such as fascicle length, with training to failure, illustrating that outcomes may vary by muscle and adaptation type even among experienced lifters.¹²

The most comprehensive meta-analysis on this topic to date, updated in 2022, pooled data from studies comparing RT performed to repetition failure versus non-failure and found no statistically significant overall difference between conditions for either strength (effect size [ES] = -0.09) or hypertrophy (ES = 0.22).³ Subgroup analysis, however, revealed a small but significant hypertrophic advantage for training to failure specifically in resistance-trained individuals (ES = 0.15), suggesting that training status moderates the utility of this strategy.³

A 2023 systematic review and meta-analysis that focused specifically on proximity-to-failure, rather than the binary failure/non-failure distinction, likewise found no clear advantage of training to full momentary failure over non-failure training for hypertrophy, and further showed that higher velocity-loss thresholds (theoretically closer proximities to failure) did not consistently produce greater muscle growth, pointing to a potentially non-linear dose-response relationship.⁸ This non-linearity was explored more directly in a 2024 series of meta-regressions covering 55 hypertrophy studies, which found that muscle hypertrophy improved modestly as sets were terminated closer to failure, whereas strength gains showed no comparable benefit from reduced proximity to failure.¹³ A subsequent eight-week randomized trial in resistance-trained adults, directly comparing training to momentary muscular failure against training with one to three repetitions in reserve, found statistically similar quadriceps hypertrophy between conditions, further supporting the notion that failure is not a strict requirement for muscle growth, even if a small stimulus may be forfeited by consistently stopping well short of it.¹⁴

Taken together, current evidence suggests that (i) training to failure is not necessary to elicit robust hypertrophic adaptations when volume is properly accounted for; (ii) any additional benefit of training closer to or at failure is generally small and appears more relevant for resistance-trained individuals than for novices; and (iii) the relationship between proximity to failure and hypertrophy is likely non-linear and exercise- and population-dependent, rather than following a simple "more failure equals more growth" model.

Risks, limitations and methodological considerations

Although concentric failure may represent one pathway to maximize muscular stimulus, it also carries measurable physiological costs. Residual fatigue and reductions in movement velocity following sets taken to or near failure can compromise the quality of subsequent sets within the same session and impair performance in later training sessions, a pattern confirmed by acute multimodal physiological assessments and by studies examining neuromuscular performance after equated volume-load protocols leading to failure.^{15,16,17} In compound, multi-joint exercises, technical failure may precede true muscular failure, increasing the likelihood of compensatory movement patterns and excessive joint loading, which may elevate injury risk. This concern is partially supported by a single crossover study reporting acute, short-term deteriorations in postural control and core endurance following high-load training to failure relative to non-failure training in collegiate weightlifters; however, this study assessed surrogate performance markers rather than injury incidence, and its findings — from one specific population — should not be generalized as direct evidence of elevated injury rates without further longitudinal confirmation.¹⁸

Frequent use of failure training can also interfere with periodization, making it more difficult to plan progressive increases in load and to precisely manipulate volume and intensity across a training cycle. Furthermore, autoregulatory approaches based on repetitions-in-reserve (RIR), often proposed as an alternative to training to absolute failure, are subject to estimation error: a scoping review and exploratory meta-analysis found that individuals tend to underpredict the number of repetitions remaining before task failure, with prediction accuracy declining meaningfully the farther a set is from failure.¹⁹ This has practical implications, as inaccurate RIR estimation, particularly common among less experienced trainees, can undermine the precision of autoregulated training prescriptions.

Part of this error can be mitigated in practice: velocity-based feedback improves RIR estimation accuracy when calibrated to an individual's own load-velocity profile, whereas fixed, population-level velocity-loss thresholds perform considerably worse; structured familiarization with the RIR scale across sessions offers a complementary, low-cost strategy to the same end.²⁰

Regarding strength outcomes specifically, a systematic review and meta-analysis pooling eight trials found that training to repetition failure did not improve strength gains relative to non-failure training and, in studies where training volume was not equated between groups,

non-failure training even showed a significant advantage for strength.²¹ This pattern has been corroborated by a more recent systematic review and meta-analysis encompassing a broader range of performance outcomes, which found that non-failure resistance training preserves, and in some outcomes enhances, exercise performance relative to training to failure, reinforcing the case for a non-failure-biased approach in performance-oriented programs.²² There is also evidence that training to failure may accentuate interindividual variability in hypertrophic responses, plausibly reflecting genetic, hormonal, and neuromuscular differences between individuals, an area that remains comparatively understudied (Figure 1).

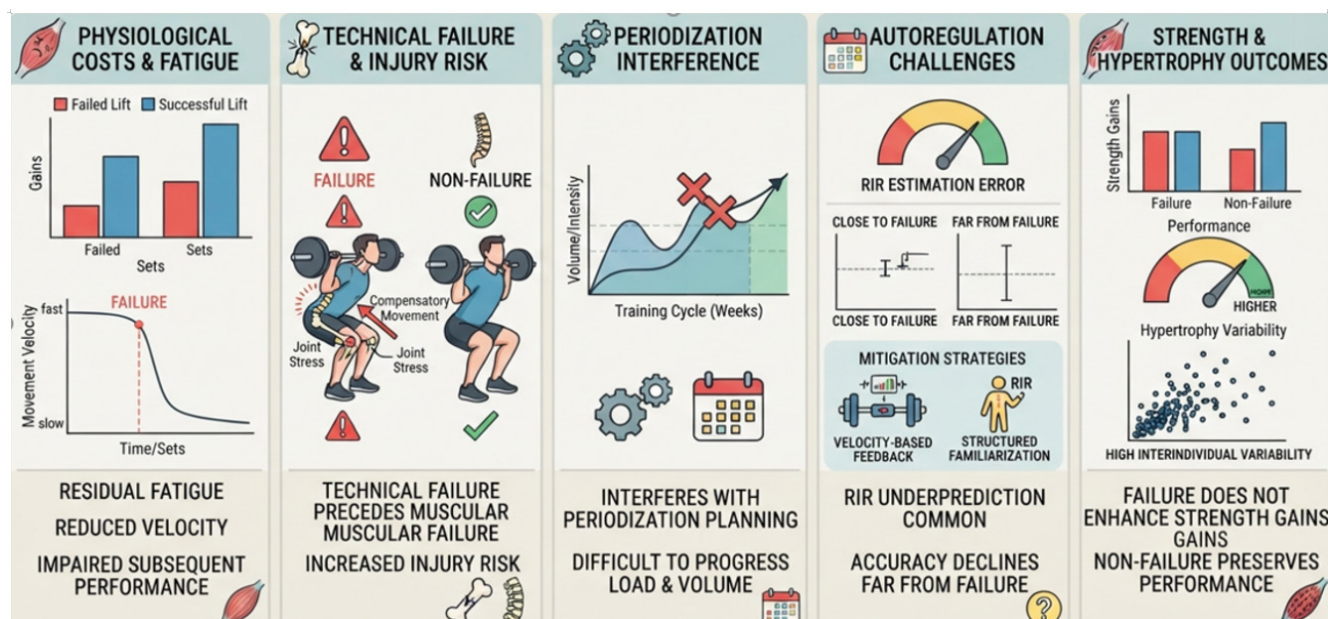


Figure 1 Schematic overview of the physiological, technical, and methodological risks associated with resistance training performed to concentric failure. (A) Residual fatigue and reduced movement velocity across sets taken close to failure. (B) Technical failure preceding true muscular failure in compound exercises, with associated compensatory movement patterns and elevated joint stress. (C) Interference of frequent failure training with planned progression of volume and intensity across a periodized training cycle. (D) Estimation error in repetitions-in-reserve (RIR)-based autoregulation, which increases with distance from failure, and candidate mitigation strategies (individualized velocity-based feedback, structured familiarization). (E) Divergent strength and hypertrophy outcomes between failure and non-failure training, and high interindividual variability in hypertrophic response. Panel content is conceptual and schematic; it does not reproduce quantitative data from any individual cited study.

Disclaimer This figure was produced with the assistance of an artificial intelligence image-generation tool (Google Gemini “Nano Banana”). All conceptual design, content selection, data framing, and final review were performed under direct human supervision, with iterative human editing and approval prior to inclusion. The figure is schematic and illustrative; it does not depict extracted or reproduced data from the studies cited in this review.

Practical applications and periodization considerations

Given this body of evidence, a strategic rather than routine application of training to failure appears most defensible. For most trainees, particularly those with health- or aesthetics-related goals, keeping the majority of working sets within approximately one to three repetitions in reserve, while reserving true concentric failure for the final set of an exercise or for lower-fatigue, single-joint movements, appears to balance hypertrophic stimulus against recovery cost.^{3,8,13}

For resistance-trained individuals seeking to maximize hypertrophy, periodic exposure to genuine failure may offer a modest additional benefit, especially later in a training cycle or mesocycle when volume can be intentionally reduced to accommodate the added fatigue.^{3,14} In novice trainees, caution is warranted given both the smaller apparent benefit of failure training and the documented inaccuracy of repetitions-in-reserve estimation in this population,

which can make autoregulation less reliable until sufficient training experience is accumulated.¹⁹

Conclusion

Performing resistance exercise to concentric failure represents a valid and potentially effective strategy for promoting hypertrophic stimuli under specific conditions of load, volume, and training status. However, critical analysis of the updated literature confirms that the additional benefits of failure training are generally small or absent when training is properly equated for volume and intensity and that any advantage appears concentrated among resistance-trained individuals rather than the general population of exercisers.

For most practitioners, routine use of concentric failure is unnecessary and, in many contexts, counterproductive given its costs in terms of fatigue, recovery, and interference with periodized

progression. A criterion-based application, informed by training status, exercise selection, and placement within the training cycle and implemented within a rational periodization framework, remains the safest and most effective approach for achieving consistent, long-term muscular gains.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

CRedit authorship contribution statement

FWK: Conceptualization, Investigation, Formal analysis, Writing – original draft, Writing – review & editing. WA: Investigation, Formal analysis, Writing – original draft, Writing – review & editing. FBS: Investigation, Formal analysis, Writing – original draft, Writing – review & editing. GSS: Investigation, Formal analysis, Writing – original draft, Writing – review & editing. VAM: Investigation, Formal analysis, Writing – original draft, Writing – review & editing. MM: Conceptualization, Investigation, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Supervision. BMR: Conceptualization, Investigation, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Supervision.

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