Ketogenic Diet and Resistance Training

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Ketogenic diets (KDs) aim at inducing physiological ketosis (i.e., an increase in the concentration of ketone bodies in blood, usually above >0.5 mmol/L) through a marked reduction in carbohydrate intake (commonly <50 g/d or <10% of total energy intake). KDs have gained popularity in recent years among athletes. By virtue of the restriction they induce in carbohydrate availability, KDs promote the use of ketone bodies (i.e., acetoacetate, acetone and β-hydroxybutyrate (BHB)) as an alternative energy substrate for different body tissues. Owing to the low carbohydrate availability induced by this type of diet, KDs induce a metabolic switch towards a greater reliance on fatty acids, which are required for the production of ketone bodies.

low-carbohydrate power output resistance training muscle keto

1. Introduction

Ketogenic diets (KDs) aim at inducing physiological ketosis (i.e., an increase in the concentration of ketone bodies in blood, usually above >0.5 mmol/L) through a marked reduction in carbohydrate intake (commonly <50 g/d or <10% of total energy intake) [1]. KDs have gained popularity in recent years among athletes [2]. By virtue of the restriction they induce in carbohydrate availability, KDs promote the use of ketone bodies (i.e., acetoacetate, acetone and β-hydroxybutyrate (BHB)) as an alternative energy substrate for different body tissues. Ketone bodies are produced from free fatty acids mainly in the mitochondria of liver cells. Once in the bloodstream, acetoacetate and BHB (the two ketone bodies used for energy) can reach extrahepatic tissues (notably, skeletal muscles, heart, brain). BHB is converted to acetoacetate by a reaction catalyzed by BHB dehydrogenase, and acetoacetate is converted back to acetyl-CoA by the action of a beta-ketoacyl-CoA transferase. The resulting acetyl CoA enters the Krebs cycle to produce ATP through the electron transport chain. Due to the initial, non-energy demanding activation of ketone bodies into an oxidable form (in a reaction catalyzed by succinyl-CoA:3-oxoacid CoA transferase), ketone bodies represent a more efficient fuel than glucose and fatty acids [3], thereby enabling the muscle tissue to produce more work for a given energy cost [4]. Owing to the low carbohydrate availability induced by this type of diet, KDs induce a metabolic switch towards a greater reliance on fatty acids, which are required for the production of ketone bodies. Indeed, strong evidence supports the effectiveness of KDs for increasing fat oxidation rates during exercise [5][6][7].

2. Effects of Combining Ketogenic Diets with Resistance Training on Body Composition in Trained Individuals

Evidence on the effects of KD on total body and fat mass loss in strength-trained individuals is promising. A recent systematic review and meta-analysis including 13 trials concluded that KD (5-50 g/d of carbohydrate for 3 to 12 weeks) are effective for reducing total body (-3.7 kg on average) and fat mass (-2.2 kg) compared with non-KD [15]. Nonetheless, KD might also contribute to loss of muscle mass or at least impair resistance training-induced hypertrophy. Indeed, the abovementioned meta-analysis concluded that KD reduce fat-free mass (-1.3 kg) compared with non-KD [15]. A summary of relevant randomized controlled trials assessing the effects of KD on body composition in strength-trained individuals is shown in **Table 1**. Several mechanisms have been proposed to explain the potential detrimental effects of KD on muscle mass [8][9], as summarized in **Figure 1**.

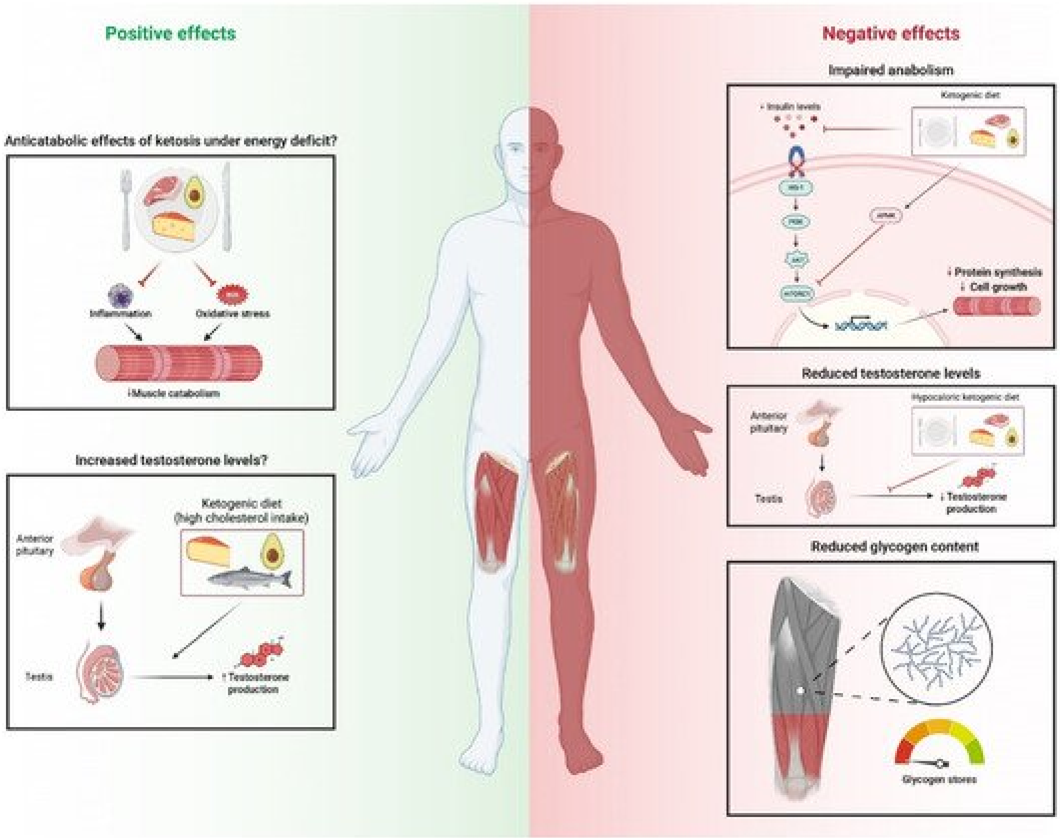

Figure 1. Summary of some potential mechanisms underlying the positive and negative effects of ketogenic diets on muscle mass.

3. Effects of Combining Ketogenic Diets with Resistance Training on Strength and Power Performance in Trained Individuals

Given the promising results of KD on body composition, further performance benefits of KD could be hypothesized at least in those sports in which body mass is a key determinant (e.g., weight-category sports or those involving actions performed with the own body mass such as jumps) [2]. In turn, the detrimental effects of KD on muscle mass could result in an impaired muscular function, especially when muscle performance is expressed in absolute values (e.g., total kg lifted, or total wattage produced) instead of relative to body mass (e.g., total kg lifted/kg or watts/kg). For this reason, it is important to explore whether muscle strength is improved or at least maintained during KD.

Conflicting results exist regarding the effects of KD on muscle strength or other related performance measures (e.g., power output). Reflecting this controversy, a recent systematic review assessed seven studies that had analyzed the effects of KD on strength or power measures on 16 performance outcomes studied (mainly muscle strength (one-repetition maximum, 1RM in different exercises, such as jump performance and sprint power output) [10]. Only two reported a significantly beneficial effect of KD, whereas 11 found no effects and 3 observed an impaired performance after a KD [10]. Nonetheless, it must be noted that the two performance measures in which benefits were observed corresponded to two cycling tests (6-s sprint and 3-min critical power test) that were implemented in the same study after a 100-km trial [11]. As such, the performance measure in question might have been more indicative of muscle endurance than of muscle power capacity. **Table 1** summarizes randomized controlled trials that have assessed the effects of KD on muscle strength- or power-related outcomes in strength-trained individuals. Overall, no effects of KD on strength or power-related performance have been reported. Indeed, except for the study by Rhyu et al., which reported greater benefits with a KD compared with a non-KD on a 2000-m running trial and on the ‘anaerobic’ fatigue index assessed by the Wingate test [12], the remainder of randomized controlled trials reported no beneficial effects of KD on performance or even detrimental effects.

Table 1. Summary of randomized controlled trials that have assessed the effects of ketogenic diets (KD) on body composition or performance in healthy strength-trained individuals.

Study	Participants	Duration of Intervention	KD	CD	Main Findings	
					Body Composition	Performance
Kysel et al. [13]	25 strength-trained men	8 weeks	Controlled energy intake (500 kcal of energy deficit) Fat: NS CHO: NS (<30 g) Protein: 1.6 g/kg Including 2 days of CHO re-introduction (CHO 70%) each 5 days.	Controlled energy intake (500 kcal of energy deficit) Fat: 30% CHO: 55% Protein: 15%	↓ Muscle mass and water content only with KD. Similar ↓ in body mass and fat mass with both diets.	↑ maximal muscle strength (lateral pull down and leg press) only with CD. ↑ cardiorespiratory fitness (peak oxygen uptake and peak workload) only with CD.
Paoli et al. [14]	19 competitive	8 weeks	Controlled energy intake	Controlled energy	↓ Body mass only with KD.	↑ strength (1RM in squat and

Study	Participants	Duration of Intervention	KD	CD	Main Findings	
					Body Composition	Performance
	male bodybuilders		(isocaloric) Fat: 68% CHO: 5% (44 g) Protein: 25% (216 g, 2.5 g/kg)	intake (isocaloric) Fat: 20% CHO: 55% Protein: 25% (223 g, 2.5 g/kg)	↓ Fat mass only with KD. ↑ Muscle mass only with CD.	bench press) similarly in both groups.
Rhyu et al. [12]	20 young (15–18 years) Taekwondo athletes	3 weeks	Controlled energy intake (hypocaloric, 75% of estimated energy intake) Fat: 55% CHO: 4.3% (22 g) Protein: 40.7%	Controlled energy intake (hypocaloric, 75% of estimated energy intake) Fat: 30% CHO: 40% Protein: 30%	Similar ↓ in total body mass, fat mass and muscle mass for both groups.	↑ in 2000-m running trial performance and Wingate test performance (fatigue index) with KD. Similar ↓ in peak and mean power on the Wingate test with both diets. Similar ↑ in back muscle strength and in the number of sit-ups with both diets. No changes in performance in the remaining outcomes.
Skemp et al. [15]	20 strength-trained women	4 weeks	Ad libitum Fat: 70% CHO: 10% Protein: 20%	Ad libitum (normal standard diet) Fat: NS CHO: NS Protein: NS	↓ Body and fat mass with KD vs. CD. Similar ↓ of muscle mass with both diets.	N/A
Greene et al. [16]	14 elite competitive lifting athletes (5 female)	12 weeks	Ad libitum Fat: 70% CHO: 8% (39 g) Protein: 23% (120 g, 1.6 g/kg)	Ad libitum Fat: 33% CHO: 45% (223 g) Protein: 22% (120 g, 1.5 g/kg)	↓ of both body mass and muscle mass after KD vs. CD.	No differences in performance.
Wilson et al.	25 strength-trained men	11 weeks (10 weeks	Controlled energy intake	Controlled energy	↓ Fat mass with KD vs.	Similar performance in

Study	Participants	Duration of Intervention	KD	CD	Main Findings	
					Body Composition	Performance
[17]		of KD + 1 week of CHO re-introduction)	(isocaloric) Fat: 75% CHO: 5% (31 g) Protein: 20% (134 g, 1.7 g/kg) Followed by a week of CHO reintroduction (increasing from 1 to 3 g/kg of CHO during the last week)	intake (isocaloric) Fat: 25% CHO: 55% (318 g) Protein: 20% (132 g, 1.7 g/kg)	CD Similar ↑ in muscle mass and thickness, but greater ↑ with KD after CHO reintroduction.	1RM with CD and KD, although only the former increased peak power in the Wingate test.
Vargas et al. [18]	24 strength-trained men	8 weeks	Controlled energy intake (moderate energy surplus, 39 kcal/kg) Fat: 70% CHO: <10% (42 g) Protein: 20% (2.0 g/kg)	Controlled energy intake (moderate energy surplus, 39 kcal/kg) Fat: 25% CHO: 55% Protein: 20% (2.0 g/kg)	↓ Fat mass with KD (no significant interaction effect) ↑ Muscle mass and body mass only with CD.	N/A
Vargas et al. [19]	21 strength-trained women	8 weeks	Controlled energy intake (moderate energy surplus, 40–45 kcal/kg FFM) Fat: 64% CHO: 9% (30–40 g) Protein: 27% (115 g, >1.7 g/kg)	Controlled energy intake (moderate energy surplus, 40–45 kcal/kg FFM). Significantly higher energy intake than KD. Fat: 23% CHO: 57% (282 g) Protein: 20% (>1.7 g/kg)	↓ Body mass and fat mass with KD vs. KD. ↑ Muscle mass with CD vs. KD.	↑ Bench press and squat performance (1RM) with CD vs. KD. Similar improvements in CMJ performance.
Vidic et al. [20]	20 strength-trained men	8 weeks	Controlled energy intake	Controlled energy	Similar ↓ in body mass,	No changes in performance

Study	Participants	Duration of Intervention	KD	CD	Main Findings	
					Body Composition	Performance
			(hypocaloric) Fat: 75% CHO: 5% (27 g) Protein: 20% (108 g, 1.2 g/kg)	intake (hypocaloric, non-ketogenic) Fat: 65% CHO: 15% (82 g) Protein: 20% (110 g, 1.2 g/kg)	fat mass and muscle mass with KD and CD.	(1RM) with any of the diets.

↑ and ↓ indicate significant increases and reductions, respectively. Abbreviations: 1RM, one-repetition maximum; CD, control diet; CHO, carbohydrate; CMJ, countermovement jump; FFM, fat-free mass; KD, ketogenic diet; NS, not specified.

In summary, although some studies support the effectiveness of KD for reducing total body mass and particularly fat mass in strength-trained individuals without harming sports performance, there is also evidence for some performance decrements compared to non-KD western diets.

References

1. Aragon, A.A.; Schoenfeld, B.J.; Wildman, R.; Kleiner, S.; VanDusseldorp, T.; Taylor, L.; Earnest, C.P.; Arciero, P.J.; Wilborn, C.; Kalman, D.S.; et al. International society of sports nutrition position stand: Diets and body composition. J. Int. Soc. Sports Nutr. 2017, 14, 1–19.
2. Paoli, A.; Bianco, A.; Grimaldi, K.A. The ketogenic diet and sport: A possible marriage? Exerc. Sport Sci. Rev. 2015, 43, 153–162.
3. Puchalska, P.; Crawford, P.A. Multi-dimensional roles of ketone bodies in fuel metabolism, signaling, and therapeutics. Cell Metab. 2017, 25, 262–284.
4. Egan, B.; D'Agostino, D.P. Fueling performance: Ketones enter the mix. Cell Metab. 2016, 24, 373–375.
5. Burke, L.M.; Ross, M.L.; Garvican-Lewis, L.A.; Welvaert, M.; Heikura, I.A.; Forbes, S.G.; Mirtschin, J.G.; Cato, L.E.; Strobel, N.; Sharma, A.P.; et al. Low carbohydrate, high fat diet impairs exercise economy and negates the performance benefit from intensified training in elite race walkers. J. Physiol. 2017, 595, 2785–2807.
6. Burke, L.M.; Whitfield, J.; Heikura, I.A.; Ross, M.L.R.; Tee, N.; Forbes, S.F.; Hall, R.; McKay, A.K.A.; Wallett, A.M.; Sharma, A.P. Adaptation to a low carbohydrate high fat diet is rapid but

impairs endurance exercise metabolism and performance despite enhanced glycogen availability. J. Physiol. 2020.

7. Burke, L.M.; Sharma, A.P.; Heikura, I.A.; Forbes, S.F.; Holloway, M.; McKay, A.K.A.; Bone, J.; Leckey, J.J.; Welvaert, M.; Ross, M.L.R. Crisis of confidence averted: Impairment of exercise economy and performance in elite race walkers by ketogenic low carbohydrate, high fat (LCHF) diet is reproducible. PLoS ONE 2020, 15, e0234027.
8. Paoli, A.; Cancellara, P.; Pompei, P.; Moro, T. Ketogenic diet and skeletal muscle hypertrophy: A Frenemy relationship? J. Hum. Kinet. 2019, 68, 233–247.
9. Tinsley, G.M.; Willoughby, D.S. Fat-free mass changes during ketogenic diets and the potential role of resistance training. Int. J. Sport Nutr. Exerc. Metab. 2016, 26, 78–92.
10. Murphy, N.E.; Carrigan, C.T.; Margolis, L.M. High-fat ketogenic diets and physical performance: A systematic review. Adv. Nutr. 2020, 12, 1–11.
11. McSwiney, F.T.; Wardrop, B.; Hyde, P.N.; Lafountain, R.A.; Volek, J.S.; Doyle, L. Keto-adaptation enhances exercise performance and body composition responses to training in endurance athletes. Metabolism 2018, 81, 25–34.
12. Rhyu, H.; Cho, S.-Y. The effect of weight loss by ketogenic diet on the body composition, performance-related physical fitness factors and cytokines of Taekwondo athletes. J. Exerc. Rehabil. 2014, 10, 326–331.
13. Kysel, P.; Haluzíková, D.; Doležalová, R.P.; Laňková, I.; Lacinová, Z.; Kasperová, B.J.; Trnovská, J.; Hrádková, V.; Mráz, M.; Vilikus, Z.; et al. The influence of cyclical ketogenic reduction diet vs. Nutritionally balanced reduction diet on body composition, strength, and endurance performance in healthy young males: A randomized controlled trial. Nutrients 2020, 12, 2832.
14. Paoli, A.; Cenci, L.; Pompei, P.L.; Sahin, N.; Bianco, A.; Neri, M.; Caprio, M.; Moro, T. Effects of two months of very low carbohydrate ketogenic diet on body composition, muscle strength, muscle area, and blood parameters in competitive natural body builders. Nutrients 2021, 13, 374.
15. Skemp, K.; Stehly, M.; Baumann, D. The Effects of a Ketogenic Diet on Body Composition in resistance training females. Ann. Sport. Med. Res. 2021, 8, 1176.
16. Greene, D.; Varley, B.; Hartwig, T.; Chapman, P.; Rigney, M. A low-carbohydrate ketogenic diet reduces body mass without compromising performance in powerlifting and Olympic weightlifting athletes. J. Strength Cond. Res. 2018, 32, 3373–3382.
17. Wilson, J.M.; Lowery, R.P.; Roberts, M.D.; Sharp, M.H.; Joy, J.M.; Shields, K.A.; Partl, J.M.; Volek, J.S.; D’Agostino, D.P. Effects of ketogenic dieting on body composition, strength, power, and hormonal profiles in resistance training men. J. Strength Cond. Res. 2020, 34, 3463–3474.

18. Vargas, S.; Romance, R.; Petro, J.L.; Bonilla, D.A.; Galancho, I.; Espinar, S.; Kreider, R.B.; Benítez-Porres, J. Efficacy of ketogenic diet on body composition during resistance training in trained men: A randomized controlled trial. J. Int. Soc. Sports Nutr. 2018, 15, 1–9.
19. Vargas-Molina, S.; Petro, J.L.; Romance, R.; Kreider, R.B.; Schoenfeld, B.J.; Bonilla, D.A.; Benítez-Porres, J. Effects of a ketogenic diet on body composition and strength in trained women. J. Int. Soc. Sports Nutr. 2020, 17, 1–10.
20. Vidić, V.; Ilić, V.; Toskić, L.; Janković, N.; Ugarković, D. Effects of calorie restricted low carbohydrate high fat ketogenic vs. non-ketogenic diet on strength, body-composition, hormonal and lipid profile in trained middle-aged men. Clin. Nutr. 2021, 40, 1495–1502.