- Original Article
- Published: 03 September 2021

Therapeutic and preventive effects of exercise training on metabolic regulators/markers in mouse colorectal cancer cells

- Hossein Shirvani ORCID: orcid.org/0000-0002-9465-0199[1],
- Behzad Bazgir[1],
- Mostafa Rahimi[2],
- Amin Isanejad[3],
- Mohammad Samadi[1],
- Vahid Sobhani[1],
- …
- Ali Mohammad Alizadeh[4] &
- Ehsan Arabzadeh[1]

Show authors

Sport Sciences for Health (2021)Cite this article

Abstract

Background

The enzymes and metabolic controllers of tumor cells are affecting by the regulation of physical activity and exercise training.

Aim

The aim of this study was to investigate the role of preventive and treatment of aerobic interval training in colon cancer with determining the protein values of MCT1, GLUT1, PFK-1 and expression of the p53 gene in tumor cells in the animal model.

Methods

Forty-eight male BALB/c mice (6–8 weeks old) participate in this study. Animals were equally randomized into 6 groups: I: control (C); healthy animals, II: Exercise (E), III: tumor induction (T); animals received AOM for inducing colon cancer, IV: AOM + exercise (TE); animals with colon cancer underwent 8 weeks of the exercise training protocol after tumor establishment, V: exercise + AOM (ET); animals received exercise protocol 1 week before AOM consumption, and (VI) exercise + AOM + exercise (ETE); animals received exercise protocol one week before and after AOM consumption (about 15 weeks) Groups III–VI were weekly-received AOM (as carcinogenic agent, 10 mg/kg s.c) in three consecutive weeks to induce colon cancer. Protein levels of GLUT1, MICT1 and PFK1 in solid colon tumor was measured by ELISA method. Also we used RTPcr for gene expression of P53. GAPDH were used as reference genes.

Results

The results showed that the tumor significantly increased MCT1 in the tumor group compared to the control group ($p = 0.001$), Also, exercise before and after tumor induction reduced MCT1 in the colon (respectively: $p = 0.02$ and $p = 0.01$). Levels of GLUT1 colon in the tumor group showed a significant increase compared to the control group ($p = 0.001$), that exercise after tumor induction was effective in reducing this protein ($p = 0.01$). PFK-1 had a significant decrease in ET and TE groups compare to T group ($p = 0.02$ and $p = 0.01$, respectively). While the p53 gene decreased significantly in the tumor group compared to the control group ($p = 0.01$) Exercise before tumor induction and after tumor induction increased significantly ($p = 0.01$ and $p = 0.04$, respectively) in this gene compared to the tumor group.

Conclusion

Long-term aerobic training can act as a preventive or inhibitor of tumor progression by acting as an adjunct in the treatment of colon cancer. It seems that this preventive and treatment effects exercise training can attribute to regulation of lactate and glucose transporters by up-regulation of p53 colorectal cancer cell.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Abbreviations

MCT1:

Monocarboxylate transporter 1

GLUT1:

Glucose transporter 1

PFK-1:

Phosphofructokinase-1

P53:

Protein p53

AOM:

Azoxymethane

LDHA:

Lactate dehydrogenase-A

Unc5B:

Uncoordinated gene 5B

QF-PCR:

Quantitative fluorescence PCR

AMPK:

Adenosine monophosphate-activated protein kinase

TIGAR:

Glycolysis and apoptosis regulator

References

1. 1.

   Bose S, Zhang C, Le A (2021) Glucose metabolism in cancer: the warburg effect and beyond, in the heterogeneity of cancer metabolism. Springer, Cham, pp 3–15

   Book Google Scholar

2. 2.

   Brophy S et al (2009) GLUT-1 expression and response to chemoradiotherapy in rectal cancer. Int J Cancer 125(12):2778–2782

   CAS PubMed Article Google Scholar

3. 3.

   Atsumi T et al (2002) High expression of inducible 6-phosphofructo-2-kinase/fructose-2, 6-bisphosphatase (iPFK-2; PFKFB3) in human cancers. Can Res 62(20):5881–5887

   CAS Google Scholar

4. 4.

   Miranda-Gonçalves V et al (2016) Hypoxia-mediated upregulation of MCT1 expression supports the glycolytic phenotype of glioblastomas. Oncotarget 7(29):46335

   PubMed PubMed Central Article Google Scholar

5. 5.

   Andersen AP et al (2016) Roles of acid-extruding ion transporters in regulation of breast cancer cell growth in a 3-dimensional microenvironment. Mol Cancer 15(1):45

   PubMed PubMed Central Article CAS Google Scholar

6. 6.

   Pinheiro C et al (2012) Role of monocarboxylate transporters in human cancers: state of the art. J Bioenerg Biomembr 44(1):127–139

   CAS PubMed Article Google Scholar

7. 7.

   Boidot R et al (2012) Regulation of monocarboxylate transporter MCT1 expression by p53 mediates inward and outward lactate fluxes in tumors. Can Res 72(4):939–948

   CAS Article Google Scholar

8. 8.

Devin JL et al (2019) Acute high intensity interval exercise reduces colon cancer cell growth. J Physiol 597(8):2177–2184

CAS PubMed PubMed Central Article Google Scholar

9. 9.

Weiner LS et al (2019) Breast cancer survivors reduce accelerometer-measured sedentary time in an exercise intervention. J Cancer Surviv 13(3):468–476

PubMed PubMed Central Article Google Scholar

10. 10.

Weller S, Oliffe JL, Campbell KL (2019) Factors associated with exercise preferences, barriers and facilitators of prostate cancer survivors. Eur J Cancer Care 28:e13135

Google Scholar

11. 11.

Liu N et al (2011) Effects of treadmill exercise on the expression of netrin-1 and its receptors in rat brain after cerebral ischemia. Neuroscience 194:349–358

CAS PubMed Article Google Scholar

12. 12.

McTiernan A (2008) Mechanisms linking physical activity with cancer. Nat Rev Cancer 8(3):205

CAS PubMed Article Google Scholar

13. 13.

Aveseh M, Nikooie R, Aminaie M (2015) Exercise-induced changes in tumour LDH-B and MCT1 expression are modulated by oestrogen-related receptor alpha in breast cancer-bearing BALB/c mice. J Physiol 593(12):2635–2648

CAS PubMed PubMed Central Article Google Scholar

14. 14.

Isanejad A et al (2016) MicroRNA-206, let-7a and microRNA-21 pathways involved in the anti-angiogenesis effects of the interval exercise training and hormone therapy in breast cancer. Life Sci 151:30–40

CAS PubMed Article Google Scholar

15. 15.

Alizadeh AM et al (2012) Chemoprevention of azoxymethane-initiated colon cancer in rat by using a novel polymeric nanocarrier–curcumin. Eur J Pharmacol 689(1):226–232

CAS PubMed Article Google Scholar

16. 16.

Riggs CE Jr et al (2010) The effects of aerobic interval training on the left ventricular morphology and function of VLCAD-deficient mice. Eur J Appl Physiol 110(5):915–923

PubMed Article Google Scholar

17. 17.

Høydal MA et al (2007) Running speed and maximal oxygen uptake in rats and mice: practical implications for exercise training. Eur J Cardiovasc Prev Rehabil 14(6):753–760

PubMed Article Google Scholar

18. 18.

Khori V et al (2015) Effects of exercise training together with tamoxifen in reducing mammary tumor burden in mice: possible underlying pathway of miR-21. Eur J Pharmacol 765:179–187

CAS PubMed Article Google Scholar

19. 19.

Dhup S et al (2012) Multiple biological activities of lactic acid in cancer: influences on tumor growth, angiogenesis and metastasis. Curr Pharm Des 18(10):1319–1330

CAS PubMed Article Google Scholar

20. 20.

Wallen M et al (2018) Engage: preoperative exercise intervention for patients with prostate, colon and breast cancer, Warrnambool, Australia1(1):1–4

21. 21.

Colditz GA, Cannuscio CC, Frazier AL (1997) Physical activity and reduced risk of colon cancer: implications for prevention. Cancer Causes Control 8(4):649–667

CAS Article Google Scholar

22. 22.

Végran F et al (2011) Lactate influx through the endothelial cell monocarboxylate transporter MCT1 supports an NF-κB/IL-8 pathway that drives tumor angiogenesis. Can Res 71(7):2550–2560

Article Google Scholar

23. 23.

De Saedeleer CJ et al (2012) Lactate activates HIF-1 in oxidative but not in Warburg-phenotype human tumor cells. PLOS ONE 7(10):e46571

PubMed PubMed Central Article CAS Google Scholar

24. 24.

Augoff K, Hryniewicz-Jankowska A, Tabola R (2015) Lactate dehydrogenase 5: an old friend and a new hope in the war on cancer. Cancer Lett 358(1):1–7

CAS PubMed Article Google Scholar

25. 25.

Doherty JR et al (2014) Blocking lactate export by inhibiting the Myc target MCT1 Disables glycolysis and glutathione synthesis. Can Res 74(3):908–920

CAS Article Google Scholar

26. 26.

Draoui N et al (2014) Antitumor activity of 7-aminocarboxycoumarin derivatives, a new class of potent inhibitors of lactate influx but not efflux. Mol Cancer Ther 13(6):1410–1418

CAS PubMed Article Google Scholar

27. 27.

Gohil K, Brooks GA (2012) Exercise tames the wild side of the Myc network: a hypothesis. Am J Physiol Endocrinol Metab 303(1):E18–E30

CAS PubMed Article Google Scholar

28. 28.

Hashimoto T, Hussien R, Brooks GA (2006) Colocalization of MCT1, CD147, and LDH in mitochondrial inner membrane of L6 muscle cells: evidence of a mitochondrial lactate oxidation complex. Am J Physiol Endocrinol Metab 290(6):E1237–E1244

CAS PubMed Article Google Scholar

29. 29.

Hojman P et al (2018) Molecular mechanisms linking exercise to cancer prevention and treatment. Cell Metab 27(1):10–21

CAS PubMed Article Google Scholar

30. 30.

Kang R, Kroemer G, Tang D (2019) The tumor suppressor protein p53 and the ferroptosis network. Free Radical Biol Med 133:162–168

CAS Article Google Scholar

31. 31.

Ramani A (2019) Effects of exercise training on the blood lactate response to acute exercise in cancer survivors. University of Northern Colorado 1(1):1–9

32. 32.

Suzuki K, Matsubara H (2011) Recent advances in p53 research and cancer treatment. BioMed Res Int 3(12):1–7

33. 33.

Kim S, An SSA (2016) An, role of p53 isoforms and aggregations in cancer. Medicine 95(26):e3993

CAS PubMed PubMed Central Article Google Scholar

34. 34.

Charrier-Savournin FB et al (2004) p21-Mediated nuclear retention of cyclin B1-Cdk1 in response to genotoxic stress. Mol Biol Cell 15(9):3965–3976

CAS PubMed PubMed Central Article Google Scholar

35. 35.

Lago CU et al (2011) p53, aerobic metabolism, and cancer. Antioxid Redox Signal 15(6):1739–1748

CAS PubMed PubMed Central Article Google Scholar

36. 36.

Kawauchi K et al (2008) p53 regulates glucose metabolism through an IKK-NF-κB pathway and inhibits cell transformation. Nat Cell Biol 10(5):611

CAS PubMed Article Google Scholar

37. 37.

Santasusagna S et al (2018) miR-328 mediates a metabolic shift in colon cancer cells by targeting SLC2A1/GLUT1. Clin Transl Oncol 20(9):1161–1167

CAS PubMed PubMed Central Article Google Scholar

38. 38.

Graziano F et al (2017) Glycolysis gene expression analysis and selective metabolic advantage in the clinical progression of colorectal cancer. Pharmacogenom J 17(3):258

CAS Article Google Scholar

39. 39.

Chan DA et al (2011) Targeting GLUT1 and the Warburg effect in renal cell carcinoma by chemical synthetic lethality. Sci Transl Med 3(94):94

Article CAS Google Scholar

40. 40.

Elf SE, Chen J (2014) Targeting glucose metabolism in patients with cancer. Cancer 120(6):774–780

PubMed Article Google Scholar

41. 41.

Cairns RA, Harris IS, Mak TW (2011) Regulation of cancer cell metabolism. Nat Rev Cancer 11(2):85

CAS PubMed Article Google Scholar

42. 42.

Ros S et al (2017) 6-Phosphofructo-2-kinase/fructose-2, 6-biphosphatase 4 is essential for p53-null cancer cells. Oncogene 36(23):3287

CAS PubMed Article Google Scholar

43. 43.

Bensaad K et al (2006) TIGAR, a p53-inducible regulator of glycolysis and apoptosis. Cell 126(1):107–120

CAS PubMed Article Google Scholar

44. 44.

Courneya KS, Friedenreich CM (2001) Framework PEACE: an organizational model for examining physical exercise across the cancer experience. Ann Behav Med 23(4):263–272

CAS PubMed Article Google Scholar

45. 45.

Courneya KS (2003) Exercise in cancer survivors: an overview of research. Med Sci Sports Exerc 35(11):1846–1852

PubMed Article Google Scholar

46. 46.

Morgan T et al (1971) Effects of long-term exercise on human muscle mitochondria, in muscle metabolism during exercise. Springer, Berlin, pp 87–95

Book Google Scholar

47. 47.

Slattery ML et al (1988) Physical activity, diet, and risk of colon cancer in Utah. Am J Epidemiol 128(5):989–999

CAS PubMed Article Google Scholar

Download references

Author information

Affiliations

1. Exercise Physiology Research Center, Life Style Institute, Baqiyatallah University of Medical Sciences, Tehran, Iran

   Hossein Shirvani, Behzad Bazgir, Mohammad Samadi, Vahid Sobhani & Ehsan Arabzadeh

2. Department of Sports Science, Faculty of Humanities, Shahrekord University, Shahrekord, Iran

   Mostafa Rahimi

3. Departments of Physical Education and Sport Sciences, Shahed University, Tehran, Iran

   Amin Isanejad

4. Cancer Research Center, Tehran University of Medical Science, Tehran, Iran

   Ali Mohammad Alizadeh

Authors

1. Hossein Shirvani
   View author publications

   You can also search for this author in PubMed Google Scholar

2. Behzad Bazgir
   View author publications

You can also search for this author in PubMed Google Scholar

3. Mostafa Rahimi
View author publications

You can also search for this author in PubMed Google Scholar

4. Amin Isanejad
View author publications

You can also search for this author in PubMed Google Scholar

5. Mohammad Samadi
View author publications

You can also search for this author in PubMed Google Scholar

6. Vahid Sobhani
View author publications

You can also search for this author in PubMed Google Scholar

7. Ali Mohammad Alizadeh
View author publications

You can also search for this author in PubMed Google Scholar

8. Ehsan Arabzadeh
View author publications

You can also search for this author in PubMed Google Scholar

Corresponding author

Correspondence to Hossein Shirvani.

Ethics declarations

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. The study protocol was approved by the Institutional Animal Ethics Committe of the University.

Informed consent

Animal study.

Additional information

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Rights and permissions

Reprints and Permissions

About this article

Check for updates

Cite this article

Shirvani, H., Bazgir, B., Rahimi, M. *et al.* Therapeutic and preventive effects of exercise training on metabolic regulators/markers in mouse colorectal cancer cells. *Sport Sci Health* (2021). https://doi.org/10.1007/s11332-021-00826-8

Download citation

- Received: 05 May 2021
- Accepted: 07 August 2021
- Published: 03 September 2021
- DOI: https://doi.org/10.1007/s11332-021-00826-8

Keywords

- Aerobic interval training
- Tumor glycolysis
- Colorectal cancer
- P53

- Figures
- References

- **Fig. 1**
 extended data figure 1
- **Fig. 2**
 extended data figure 2
- **Fig. 3**
 extended data figure 3
- **Fig. 4**
 extended data figure 4
- **Fig. 5**
 extended data figure 5
- **Fig. 6**
 extended data figure 6
- **Fig. 7**
 extended data figure 7

1. Bose S, Zhang C, Le A (2021) Glucose metabolism in cancer: the warburg effect and beyond, in the heterogeneity of cancer metabolism. Springer, Cham, pp 3–15

   Book Google Scholar

2. Brophy S et al (2009) GLUT-1 expression and response to chemoradiotherapy in rectal cancer. Int J Cancer 125(12):2778–2782

   CAS PubMed Article Google Scholar

3. Atsumi T et al (2002) High expression of inducible 6-phosphofructo-2-kinase/fructose-2, 6-bisphosphatase (iPFK-2; PFKFB3) in human cancers. Can Res 62(20):5881–5887

   CAS Google Scholar

4. Miranda-Gonçalves V et al (2016) Hypoxia-mediated upregulation of MCT1 expression supports the glycolytic phenotype of glioblastomas. Oncotarget 7(29):46335

   PubMed PubMed Central Article Google Scholar

5. Andersen AP et al (2016) Roles of acid-extruding ion transporters in regulation of breast cancer cell growth in a 3-dimensional microenvironment. Mol Cancer 15(1):45

   PubMed PubMed Central Article CAS Google Scholar

6. Pinheiro C et al (2012) Role of monocarboxylate transporters in human cancers: state of the art. J Bioenerg Biomembr 44(1):127–139

CAS PubMed Article Google Scholar

7. Boidot R et al (2012) Regulation of monocarboxylate transporter MCT1 expression by p53 mediates inward and outward lactate fluxes in tumors. Can Res 72(4):939–948

CAS Article Google Scholar

8. Devin JL et al (2019) Acute high intensity interval exercise reduces colon cancer cell growth. J Physiol 597(8):2177–2184

CAS PubMed PubMed Central Article Google Scholar

9. Weiner LS et al (2019) Breast cancer survivors reduce accelerometer-measured sedentary time in an exercise intervention. J Cancer Surviv 13(3):468–476

PubMed PubMed Central Article Google Scholar

10. Weller S, Oliffe JL, Campbell KL (2019) Factors associated with exercise preferences, barriers and facilitators of prostate cancer survivors. Eur J Cancer Care 28:e13135

Google Scholar

11. Liu N et al (2011) Effects of treadmill exercise on the expression of netrin-1 and its receptors in rat brain after cerebral ischemia. Neuroscience 194:349–358

CAS PubMed Article Google Scholar

12. McTiernan A (2008) Mechanisms linking physical activity with cancer. Nat Rev Cancer 8(3):205

CAS PubMed Article Google Scholar

13. Aveseh M, Nikooie R, Aminaie M (2015) Exercise-induced changes in tumour LDH-B and MCT1 expression are modulated by oestrogen-related receptor alpha in breast cancer-bearing BALB/c mice. J Physiol 593(12):2635–2648

CAS PubMed PubMed Central Article Google Scholar

14. Isanejad A et al (2016) MicroRNA-206, let-7a and microRNA-21 pathways involved in the anti-angiogenesis effects of the interval exercise training and hormone therapy in breast cancer. Life Sci 151:30–40

CAS PubMed Article Google Scholar

15. Alizadeh AM et al (2012) Chemoprevention of azoxymethane-initiated colon cancer in rat by using a novel polymeric nanocarrier–curcumin. Eur J Pharmacol 689(1):226–232

CAS PubMed Article Google Scholar

16. Riggs CE Jr et al (2010) The effects of aerobic interval training on the left ventricular morphology and function of VLCAD-deficient mice. Eur J Appl Physiol 110(5):915–923

PubMed Article Google Scholar

17. Høydal MA et al (2007) Running speed and maximal oxygen uptake in rats and mice: practical implications for exercise training. Eur J Cardiovasc Prev Rehabil 14(6):753–760

PubMed Article Google Scholar

18. Khori V et al (2015) Effects of exercise training together with tamoxifen in reducing mammary tumor burden in mice: possible underlying pathway of miR-21. Eur J Pharmacol 765:179–187

CAS PubMed Article Google Scholar

19. Dhup S et al (2012) Multiple biological activities of lactic acid in cancer: influences on tumor growth, angiogenesis and metastasis. Curr Pharm Des 18(10):1319–1330

CAS PubMed Article Google Scholar

20. Wallen M et al (2018) Engage: preoperative exercise intervention for patients with prostate, colon and breast cancer, Warrnambool, Australia1(1):1–4

21. Colditz GA, Cannuscio CC, Frazier AL (1997) Physical activity and reduced risk of colon cancer: implications for prevention. Cancer Causes Control 8(4):649–667

CAS Article Google Scholar

22. Végran F et al (2011) Lactate influx through the endothelial cell monocarboxylate transporter MCT1 supports an NF-κB/IL-8 pathway that drives tumor angiogenesis. Can Res 71(7):2550–2560

Article Google Scholar

23. De Saedeleer CJ et al (2012) Lactate activates HIF-1 in oxidative but not in Warburg-phenotype human tumor cells. PLOS ONE 7(10):e46571

PubMed PubMed Central Article CAS Google Scholar

24. Augoff K, Hryniewicz-Jankowska A, Tabola R (2015) Lactate dehydrogenase 5: an old friend and a new hope in the war on cancer. Cancer Lett 358(1):1–7

CAS PubMed Article Google Scholar

25. Doherty JR et al (2014) Blocking lactate export by inhibiting the Myc target MCT1 Disables glycolysis and glutathione synthesis. Can Res 74(3):908–920

CAS Article Google Scholar

26. Draoui N et al (2014) Antitumor activity of 7-aminocarboxycoumarin derivatives, a new class of potent inhibitors of lactate influx but not efflux. Mol Cancer Ther 13(6):1410–1418

CAS PubMed Article Google Scholar

27. Gohil K, Brooks GA (2012) Exercise tames the wild side of the Myc network: a hypothesis. Am J Physiol Endocrinol Metab 303(1):E18–E30

CAS PubMed Article Google Scholar

28. Hashimoto T, Hussien R, Brooks GA (2006) Colocalization of MCT1, CD147, and LDH in mitochondrial inner membrane of L6 muscle cells: evidence of a mitochondrial lactate oxidation complex. Am J Physiol Endocrinol Metab 290(6):E1237–E1244

CAS PubMed Article Google Scholar

29. Hojman P et al (2018) Molecular mechanisms linking exercise to cancer prevention and treatment. Cell Metab 27(1):10–21

CAS PubMed Article Google Scholar

30. Kang R, Kroemer G, Tang D (2019) The tumor suppressor protein p53 and the ferroptosis network. Free Radical Biol Med 133:162–168

CAS Article Google Scholar

31. Ramani A (2019) Effects of exercise training on the blood lactate response to acute exercise in cancer survivors. University of Northern Colorado 1(1):1–9

32. Suzuki K, Matsubara H (2011) Recent advances in p53 research and cancer treatment. BioMed Res Int 3(12):1–7

33. Kim S, An SSA (2016) An, role of p53 isoforms and aggregations in cancer. Medicine 95(26):e3993

CAS PubMed PubMed Central Article Google Scholar

34. Charrier-Savournin FB et al (2004) p21-Mediated nuclear retention of cyclin B1-Cdk1 in response to genotoxic stress. Mol Biol Cell 15(9):3965–3976

CAS PubMed PubMed Central Article Google Scholar

35. Lago CU et al (2011) p53, aerobic metabolism, and cancer. Antioxid Redox Signal 15(6):1739–1748

CAS PubMed PubMed Central Article Google Scholar

36. Kawauchi K et al (2008) p53 regulates glucose metabolism through an IKK-NF-κB pathway and inhibits cell transformation. Nat Cell Biol 10(5):611

CAS PubMed Article Google Scholar

37. Santasusagna S et al (2018) miR-328 mediates a metabolic shift in colon cancer cells by targeting SLC2A1/GLUT1. Clin Transl Oncol 20(9):1161–1167

CAS PubMed PubMed Central Article Google Scholar

38. Graziano F et al (2017) Glycolysis gene expression analysis and selective metabolic advantage in the clinical progression of colorectal cancer. Pharmacogenom J 17(3):258

CAS Article Google Scholar

39. Chan DA et al (2011) Targeting GLUT1 and the Warburg effect in renal cell carcinoma by chemical synthetic lethality. Sci Transl Med 3(94):94

Article CAS Google Scholar

40. Elf SE, Chen J (2014) Targeting glucose metabolism in patients with cancer. Cancer 120(6):774–780

PubMed Article Google Scholar

41. Cairns RA, Harris IS, Mak TW (2011) Regulation of cancer cell metabolism. Nat Rev Cancer 11(2):85

CAS PubMed Article Google Scholar

42. Ros S et al (2017) 6-Phosphofructo-2-kinase/fructose-2, 6-biphosphatase 4 is essential for p53-null cancer cells. Oncogene 36(23):3287

CAS PubMed Article Google Scholar

43. Bensaad K et al (2006) TIGAR, a p53-inducible regulator of glycolysis and apoptosis. Cell 126(1):107–120

CAS PubMed Article Google Scholar

44. Courneya KS, Friedenreich CM (2001) Framework PEACE: an organizational model for examining physical exercise across the cancer experience. Ann Behav Med 23(4):263–272

CAS PubMed Article Google Scholar

45. Courneya KS (2003) Exercise in cancer survivors: an overview of research. Med Sci Sports Exerc 35(11):1846–1852

PubMed Article Google Scholar

46. Morgan T et al (1971) Effects of long-term exercise on human muscle mitochondria, in muscle metabolism during exercise. Springer, Berlin, pp 87–95

Book Google Scholar

47. Slattery ML et al (1988) Physical activity, diet, and risk of colon cancer in Utah. Am J Epidemiol 128(5):989–999

CAS PubMed Article Google Scholar