TRICHOLOGY AND COSMETOLOGY

Open Journal

Openventio PUBLISHERS

Systematic Review

Hair as a Specimen to Determine the Concentration of Cortisol Levels in Individuals that have Performed Physical Activity

Alexandre Gonçalves de Meirelles, BSc[1*]; Marcia Cristina Moura-Fernandes, BSc[1,2]; Eloá Moreira-Marconi, MSc[1,2]; Tânia Regina Lemos-Santos, BSc[1]; Gefferson da Silva-Costa, BSc[1]; Sérgio Oliveira De-Carvalho, BSc[1]; Ivana de Cássia Araújo Ventura, BSc[1]; Ygor Teixeira-Silva, BSc[1,3]; Laisa Liane Paineiras-Domingos, MSc[1,3,4]; Danúbia da Cunha de Sá-Caputo, PhD[1,3,4,5]; Mario Bernardo-Filho, PhD[1]

[1]Laboratório de Vibrações Mecânicas e Práticas Integrativas – LAVIMPI Roberto Alcantara Gomes Biology Institute and Américo Piquet Carneiro Polyclinic, State University of Rio de Janeiro, RJ, Brazil
[2]Programa de Pós-Graduação em Fisiopatologia Clínica e Experimental, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
[3]Programa de Pós-Graduação em Ciências Médicas, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
[4]Faculdade Bezerra de Araújo, Rio de Janeiro, Brazil
[5]Centro Universitário Serra dos Órgãos, Teresópolis, Rio de Janeiro, Brazil

[*]***Corresponding author***
Alexandre Gonçalves de Meirelles, BSc
Departamento de Biofísica e Biometria, Instituto de Biologia Roberto Alcântara Gomes, Universidade do Estado do Rio de Janeiro, Avenida 28 de setembro, 87, fundos, 4° andar, Vila Isabel, Rio de Janeiro, RJ, 20551-030, Brazil; Tel. 55-21-28688332; Fax: 55-21-28688332; E-mail: meirelles.ale@gmail.com

Article information
Received: September 18th, 2018; **Revised:** October 3rd, 2018; **Accepted:** October 3rd, 2018; **Published:** October 8th, 2018

Cite this article
Meirelles AG, Moura-Fernandes MC, Moreira-Marconi E, et al. Hair as a specimen to determine the concentration of cortisol levels in individuals that have performed physical activity. *Trichol Cosmetol Open J.* 2018; 1(2): 1-6. doi: 10.17140/TCOJ-1-110

ABSTRACT

Introduction
The physical inactivity has been identified as the fourth leading risk factor for mortality in the world. Physical activity may exert beneficial influence on the cardiovascular system, besides to bring benefits to the lipid metabolism, the increase of the lean mass, and the increase of the basal metabolism. As a response of the physical activity, the concentration of several hormones is altered, as the cortisol. Different specimens are used to determination of concentration of the cortisol, like saliva, urine, blood samples and hair. The aim of this narrative review is to present scientific information about the use of the hair to evaluate the concentration of cortisol in individuals that have performed physical activity.

Materials and Methods
Publications were accessed in the database PubMed September 12th, 2018 using the keywords hair and "*physical activity*" and cortisol.

Results
In general, it was found that the hair can be used to determine the concentration of cortisol in different populations.

Conclusions
In conclusion, all the considerations of this review, it is possible to conclude that the hair can be used successfully, as a specimen, to determine the concentration of the cortisol in the body. This would have an importance to verify the response of the hypothalamus-pituitary-adrenocortical axis to the physical activity.

Keywords
Hair; Cortisol, Physical activity.

Openventio PUBLISHERS

INTRODUCTION

According to World Health Organization (WHO), physical activity (PA) is related to movements of the body produced by skeletal muscles with an expenditure of energy.[1] PA includes exercise as well as other activities, which involve bodily movement and are done as part of playing, working, active transportation, house chores and recreational activities.[1]

It is important to verify the difference between "*physical activity*" and "*exercise*". Exercise is a type of PA that is planned, structured, repetitive and purposeful aiming at the improvement or maintenance of one or more components of physical fitness.[2]

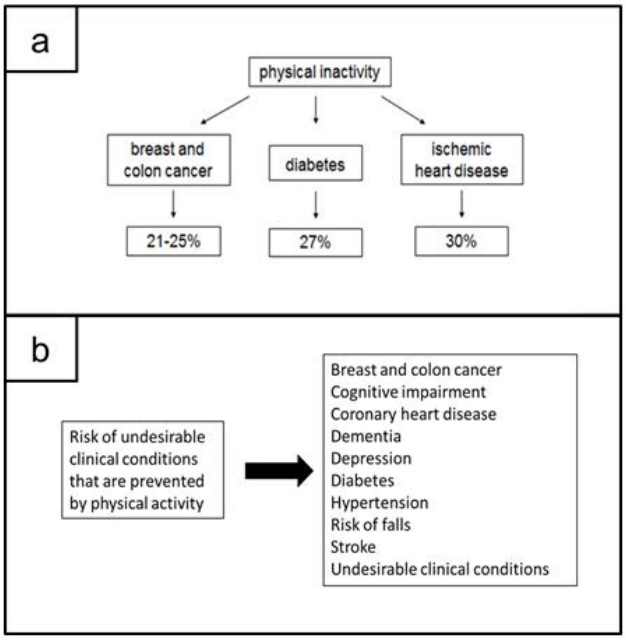
Warburton and Bredin[2] showed in a systematic review that the health benefits of exercise are evident, physical inactivity has been identified as the fourth leading risk factor for mortality in the world (6% of deaths worldwide).[1] Some diseases have been correlated with physical inactivity such as metabolic syndrome (MetS), type 2 diabetes mellitus (DM2), stroke and obesity[3] and, according to Rui et al[4] a highly prevalent and expensive disease. Increasing PA is a social problem and not just an individual problem. It therefore requires a population-based, multi-sectoral, multidisciplinary and culturally relevant approach.[1]

Regular PA leads to enhanced energy consumption and is associated with reduced risk of prevalent diseases such as obesity, T2D Mand MetS.[3] Studies indicate that combined diet and PA promotion programs can also prevent T2D Mand arterial hypertension and other conditions that can increase the risk to cardiovascular diseases.[5] Arterial hypertension is a chronic disease that affects approximately 40% of the population, with higher incidence at older ages.[6] Arterial hypertension is a risk factor for other cardiovascular diseases, such as heart failure, stroke, atherosclerosis as well as chronic renal disease.[7] It is estimated that more than 50% of deaths from coronary diseases and stroke occur in hypertensive patients.[8] In this context, the development of nonpharmacological therapies is a cost-effective strategy with few side effects, that helps in the prevention of comorbidities, that increase the cardiovascular risk of the patient. Carr et al[9] reported that in a large population-based case-control study was identified as a combination of lifestyle factors that appears to reduce risk of colorectal cancer, regardless of the patient's genetic profile. These results reinforce the importance of primary prevention of colorectal cancer. Among non-pharmacological strategies to prevent cardiovascular disease and cancer, the physical exercise deserves consideration.

In Figure Ia are estimated at approximately the main undesirable causes due to the physical inactivity to the human beings, as suggested by Warburton and Bredin.[2]

Regular and adequate levels of PA in adults (i) reduce the risk of various undesirable clinical conditions, as it is shown in Figure Ib, (ii) improve bone and functional health; and (iii) are a key determinant of energy expenditure, and thus, it would be fundamental to energy balance and weight control.[10-12]

Figure 1a. *Main Undesirable Causes Due to the Physical Inactivity to the Human Beings*
1b. *Risk of Undesirable Clinical Conditions that are Prevented by Physical Activity*



There are various types of physical exercises, that, in general, can be divided into aerobic (AeE) and anaerobic (AnE).[13] Following the American College of Sports Medicine (ACSM),[14] AeE exercise involves large muscle groups, that can be maintained continuously and is rhythmic in nature. Cycling, dancing, walking, running, swimming and walking have considered as AeE. Studies have shown that AeE improves lipid profile, particularly by increasing HDL-C, in addition to having a positive impact on cardiovascular health, and the cortisol regulation.[14] ACSM considers AnE an intense PA with short time duration. AnE has as energetic substrate, no more the oxygen, but the adenosine triphosphate *via* glycolysis and fermentation.[14] Although with particular differences, both kind of exercises, (AeE and AnE) may exert beneficial influence on the cardiovascular system, besides to bring benefits to the lipid metabolism, the increase of the lean mass, and the increase of the basal metabolism.[12]

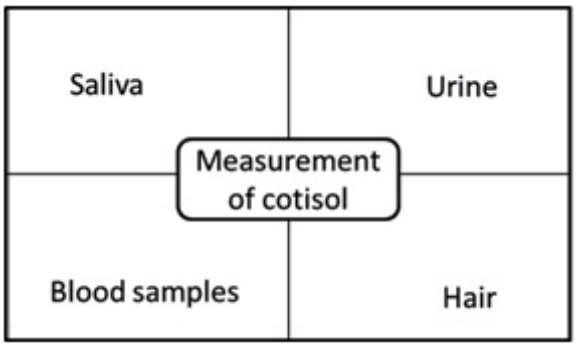
Among the wide variety of exercises, there is the whole body vibration exercise (WBVE), which is one of the types of AeE,[15] induces hormonal and immunological responses. WBVE has also been shown to be efficient for hormonal responses. Evidence suggests that the combination of WBVE and resistance work may amplify the hormonal and immune responses due to increased neuromuscular load[16] and as a response of the PA, the concentration of several hormones is altered, as the cortisol.

CORTISOL

Cortisol is a glucocorticoid hormone (a steroid hormone), produced by the upper adrenal gland secreted by the adrenal gland

cortex in response to conditions stressors. The hypothalamic-pituitary-adrenal (HPA) axis is required for adaptation to stress. Moreover, the activation of the HPA axis leads to secretion of glucocorticoids, which act on multiple organ systems to redirect energy resources to meet actual or anticipated demand once secreted, cortisol is absorbed by a variety of tissues throughout the body, such as skeletal muscle. The presence cortisol mediates physiological processes that help in exercise capacity and tissue regeneration. It is described that cortisol possesses a diurnal pattern and thus collection timing is critical. The cortisol potentially affects the metabolism of lipids and carbohydrates. The high-level of this hormone is related with the development of undesirable clinical conditions (central adiposity, insulin resistance and hyperglycemia, besides hypertension and dyslipidemia).[15,17,18] Wright et al[15] have reported different specimens used to determination of a concentration of the cortisol in the body, as it is shown in Figure 2

Figure 2. *Reported Different Specimens Used to Determination of Concentration of the Cortisol*

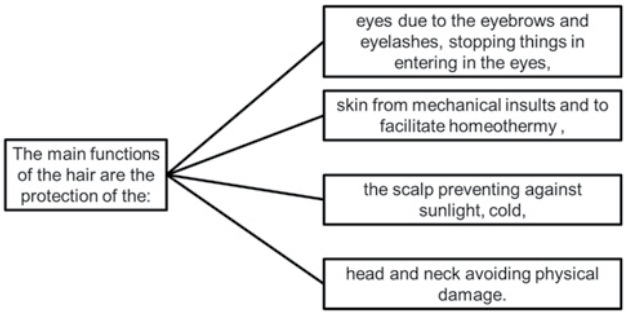


HAIR

Hair plays no vital role for humans, but its loss may be associated with several conditions (physiological, psychological, idiopathic, aging, or genetic predisposing complications).[15] As hair can have a relevant impact on the quality of life and self-esteem of individuals, its loss can generate distress and suffering of some diseases and infections. Nevertheless, the hair loss can be consequence of metabolic and hormonal dysfunctions or stress.[19] Figure 3 shows the main functions of the hair by Buffoliet al.[20] It has also a sensory function, increasing the perception of the skin surface for tactile stimuli, and sub-serves important roles in sexual and social communication. In addition, authors have reported that hair can be used as a specimen to quantify the concentration of cortisol in the body (Figure 1b).[10,11]

According to Pragst and Balikova,[21] hair grows on average one centimeter per month. Among some important hair roles are skin protection against aggressors, thermoregulation, some specialized functions such as eyebrows and eyelashes. As the hair germ extends, the epithelium of the hair bulb encapsulates the dermal condensate to form the dermal papillae. Eventually, the layers form in the outer root sheath, the inner root sheath, the cuticle of

Figure 3. *Main Functions of the Hair by Buffoli et al20*



the hair shaft, the cortex, and the medulla. Besides the hair follicle, sebaceous gland and the apocrine gland are also found.

It is relevant to point out the use of the hair at forensic studies and doping research. Considering, then, the need to develop a form of chronic stress measurement, the capillary measurement of cortisol was discovered and validated by Raul et al.[22] In addition, there is chronic exposure to the stressor, with an important effect of exposure to stressors in capillary cortisol concentrations. This reveals deregulation of the HPA axis.[23] The exposure to even a short stress can stimulate the HPA axis and can increase the level of cortisol that can persist up to 1 hour after exposure. Although adaptable in the short-term, repeated and chronic HPA axis stimulation and cortisol release may lead to allostatic loading.[23]

Putting together all the previous considerations, the aim of this narrative review is to present scientific information about the use of the hair to evaluate the concentration of cortisol in individuals that have performed PA.

HAIR CORTISOL AS A RETROSPECTIVE LEVEL OF PHYSICAL ACTIVITY

Hair cortisol is a proxy measure to the total retrospective activity of the HPA axis over the preceding months, much like hemoglobin A1c is a proxy measure of glucose control over the past 3-months.[24] It is pointed out that hair cortisol analysis advances the science of aging by permitting the characterization of chronic stress as a risk factor for chronic illness progression and as a biomarker of the effectiveness of stress reduction interventions.[15]

Cortisol obtained from scalp hair is a lipophilic substance that originates from the vascular supply which nourishes the hair shaft follicular cells. The source of cortisol within the hair shaft is from circulation to the medullary region in the core of the hair.[25] Sources of cortisol on the surface of the hair include both sweat as well as sebaceous glands which are most likely eliminated by the washing steps prior to grinding the hair for extraction. It is considered that the cortisol measured using the standard wash, grind, and extraction method most likely reflects free cortisol and not the bound steroid.[7]

Although controversial studies report that collection would be performed, it is understood that (i) the medullary region of the passive diffusion of blood, in which is the free cortisol fraction and (ii) cortisol the external cuticle of the secretions present in sebum or sweat.[22]

According to Ito et al[26] hair follicles contain a functional equivalent of the HPA axis and can synthesize cortisol after stimulation of corticotrophin releasing hormone (CRH). For this reason, it is possible that data collection can be influenced by the cortisol concentrations produced in the hair by secretion in sebum or sweat, and not by the concentration of free cortisol.[27]

Several publications were accessed in a search in the database PubMed September 12th, 2018 using the keywords "*hair*" and "*physical activity*" and "*cortisol*". They are indicated in Table 1, in which are presented the aim of the study and the findings of each study.

Table 1. *Publications Accessed in the Database Pubmed with the Keywords "Hair" and "Physical Activity" and "Cortisol"*

Studies	Aim	Findings
Teychenne et al[28]	To verify the association between common types of sedentary behavior (TV viewing, computer use, or overall sitting time) and objectively-measured stress, measured by hair cortisol concentration (HCC) amongst women living in socioeconomically disadvantaged neighbourhoods	It was shown that there was no association between any type of sedentary behaviour and HCC in either crude or adjusted models. Sedentary behaviour may not be linked to HCC (stress) in women living in socioeconomically disadvantaged neighbourhoods
Hu et al[29]	To examine possible relations between HCC as a biomarker of chronic stress and childhood overweight and obesity	HCC had a significant relation with overweight and obesity in 6-9 years old childhood especially among girls
Ullmann et al[30]	To try to identify relationships between PA, mental burden(s), subjective stress perceptions, depressiveness, anxiety, physical complaints, sense of coherence, resilience, and the long-term integrated steroid hormone levels in hair	The HCC, cortisone, and dehydroepiandrosterone were significantly correlated to mental and PA stress as well as to subjective stress perception. It was concluded that steroid concentrations in hair are decisive predictors for an increase in the long-term-HPA axis activity. Moreover, this biomarker is suitable for capturing the stress level after burdening events and PA
Gerber et al[31]	To verify if HCC was associated with perceived stress (PS) and depressive symptoms in a sample of young adults and tested if HCC could explain the variation in depressive symptoms beyond PS before and after controlling vigorous PA levels	Students with high HCC tend to report lower depressive symptoms and less PS. Increased perceived stress was associated with major depressive symptoms, and both cortisol and PS predicted depressive symptoms after vigorous PA control. Current data suggest that high HCC do not necessarily pose a health risk. The measurement of HCC can serve as a non-invasive and painless biomarker of chronic stress and mental disorders
Gerbe et al[32]	To verify relationship between moderate PA and vigorous PA levels and HCC after taking into account age, gender, and PS	Moderate PA was not correlated with HCC. A significant correlation was found between vigorous PA and HCC. A regression analysis revealed that participants with higher vigorous PA had elevated HCC even after taking into account age, gender and PS

HCC - hair cortisol concentration
PA - physical activity
HPA - hypothalamus-pituitary-adrenal
PS - perceived stress

DISCUSSION

The study of capillary cortisol presents a unique opportunity to evaluate chronic changes in cortisol concentrations in epidemiological studies. Wosu et al[33] have investigated the assessment of cortisol concentrations in hair is one of the latest innovations to measure long-term exposure to cortisol.

Studies have indicated that in hair is possible to find specific steroid hormones. Moreover, researches have analyzed exogenous steroids and androgens for doping.[31,32] Furthermore, works relating hormones, especially glucocorticoids are conducted in tests to assess the level of stress.[34] Despite the increasing use of capillary analyzes, the detection of steroid hormones in hair has received relatively minor attention. The measurement of cortisol in human hair can be also done by high-performance liquid chromatography with fluorescence detection (HPLC-FLU) along with gas chromatographic mass spectrometry (GC-MS).[35]

Hair-corrected cortisol may be a chronic stress biomarker, as it evaluates retrospective stress, and does not require repeated measures for this, reducing costs on biochemical reagents. It would be also potentially useful in clinical and sporting contexts. Physiological responses to stress are often difficult to measure, especially in relation to the measurement of cortisol levels. Cortisol concentration has only been obtained through the collection of blood, urine, or saliva, and such charges are of high financial cost.[36]

Gerber et al[32] consider that capillary cortisol has the potential to fill the long-term methodological vacuum of cortisol assessment. In addition, capillary cortisol analysis may aid to a better understanding of how long-term cortisol elevation mediates stress-related effects on health and performance of recreational practitioners and athletes.

Despite the scarce data and some inconsistencies, the researchers found that cortisol concentrations in hair are associated with stress-related symptoms and psychiatric disorders (e.g. post-traumatic stress disorder), medical conditions that indicate chronic activation of the HPA and other life situations associated with a high risk of chronic stress. It is suggested that PA, adiposity and substance abuse may correlate with cortisol concentrations in hair. In contrast to measures of a short-term release of cortisol (saliva, blood and urine), smoking and oral contraceptive use appear to be

associated with cortisol concentrations in the hair. It is indicated that in pregnant women, an increase of cortisol concentrations in hair in successive quarters is found by Wosu.[33]

Although adaptable in the short term, repetitive and chronic HPA axis stimulation and cortisol release may lead to allostatic loading. It is indicated that the hypothalamus secretes a corticotropin-releasing hormone (CRH). As a result, CRH activates the anterior pituitary gland by stimulating adrenocorticotropic hormone (ACTH). In sequence, due to stimulation of the adrenal cortex releasing cortisol.[17,37]

The advantage in relation to the use of the hair as a type of procedure to evaluate the cortisol concentration is the permission of a retrospective review of the HPA axis. This measurement is reliable in up to 6 cm of wire length, equivalent to six months of analysis. Another favorable point is the ease of storage and collection of the material, which can be stored in an envelope, kept in the environment without risk of degradation. Hair color does not interfere with cortisol levels, but there are disadvantages such as a decrease in cortisol concentration levels after 4 cm, 5 cm yarn growth due to the leaching phenomenon. Among studies there are controversies related to the quantity of material collected and still, there is not a defined protocol of the levels and values to be collected.[15,24]

Gerber et al[32] have pointed out that is crucial that scientists consider whether their research questions can be adequately addressed, since regular vigorous exercise results in substantially increased levels of cortisol in hair.

CONCLUSION

In conclusion, putting together all the considerations of this review, it possible to conclude that the hair can be used successfully, as a specimen, to determine the concentration of the cortisol. This would have an importance to verify the response of the HPA axis to the PA.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) (financecode 001), the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), the Universidade do Estado do Rio de Janeiro (UERJ), and the Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ).

REFERENCES

1. World Health Organization (WHO). WHO | Physical Activity. WHO. Website: http://www.who.int/dietphysicalactivity/pa/en/. Accessed September 15, 2018.

2. Warburton DER, Bredin SSD. Health benefits of physical activity: A systematic review of current systematic reviews. *Curr Opin Cardiol*. 2017; 32(5): 541-556. doi: 10.1097/HCO.0000000000000437

3. Gordon B, Wang Z, Luo X. Chronic disease and the link to physical activity. *J Sport Heal Sci*. 2013; 2(1): 3-11. doi: 10.1016/J.JSHS.2012.07.009

4. Li C, Feng F, Xiong X, et al. Exercise coupled with dietary restriction reduces oxidative stress in male adolescents with obesity. *J Sports Sci*. 2017; 35(7): 663-668. doi: 10.1080/02640414.2016.1183807

5. Polegato BF, Paiva SAR. Hypertension and exercise: A search for mechanisms. *Arq Bras Cardiol*. 2018; 111(2): 180-181. doi: 10.5935/abc.20180146

6. Mancia G, Fagard R, Narkiewicz K, et al. 2013 ESH/ESC Guidelines for the management of arterial hypertension: The task force for the management of arterial hypertension of the European society of hypertension (ESH) and of the European society of cardiology (ESC). *J Hypertens*. 2013; 31(7): 1281-1357. doi: 10.1097/01.hjh.0000431740.32696.cc

7. Rapsomaniki E, Timmis A, George J, et al. Blood pressure and incidence of twelve cardiovascular diseases: Lifetime risks, healthy life-years lost, and age-specific associations in 1.25 million people. *Lancet*. 2014; 383(9932): 1899-1911. doi: 10.1016/S0140-6736(14)60685-1

8. Whelton PK, Carey RM, Aronow WS, et al. 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA Guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: A report of the American college of cardiology/American heart association task force on clinical practice guidelines. *Hypertension*. 2018; 71(6). doi: 10.1161/HYP.0000000000000065

9. Carr PR, Weigl K, Jansen L, et al. Healthy lifestyle factors associated with lower risk of colorectal cancer irrespective of genetic risk. *Gastroenterology*. 2018; S0016-5085(18): 34942-34944. doi: 10.1053/J.GASTRO.2018.08.044

10. Warburton DER, Bredin SSD. Reflections on physical activity and health: What should we recommend? *Can J Cardiol*. 2016; 32(4): 495-504. doi: 10.1016/j.cjca.2016.01.024

11. Warburton D, Bredin S, Jamnik V, et al. Consensus on evidence-based preparticipation screening and risk stratification. *Annu Rev Gerontol Geriatr*. 2016; 36(1): 53-102. doi: 10.1891/0198-8794.36.53

12. Wisløff U, Loennechen JP, Currie S, et al. Aerobic exercise reduces cardiomyocyte hypertrophy and increases contractility, Ca2+ sensitivity and SERCA-2 in rat after myocardial infarction. *Cardiovasc Res*. 2002; 54(1): 162-174. doi: 10.1016/S0008-6363(01)00565-X

13. Patel H, Alkhawam H, Madanieh R, et al . Aerobic vs anaerobic exercise training effects on the cardiovascular system. *World J Cardiol*. 2017; 9(2): 134. doi: 10.4330/wjc.v9.i2.134

14. Ferguson B. ACSM's guidelines for exercise testing and prescription 9th Ed. 2014. *J Can Chiropr Assoc*. 2014; 58(3): 328.

15. Wright KD, Hickman R, Laudenslager ML. Hair cortisol analysis: A promising biomarker of HPA activation in older adults. *Gerontologist*. 2015; 55(1): S140-S145. doi: 10.1093/geront/gnu174

16. Roschel H, Barroso R, Batista M, et al. Do whole-body vibration exercise and resistance exercise modify concentrations of salivary cortisol and immunoglobulin A? *Braz J Med Biol Res*. 2011; 44(6): 592-597. doi: 10.1590/S0100-879X2011007500059

17. Hodgson N, Freedman VA, Granger DA, Erno A. Biobehavioral correlates of relocation in the frail elderly: Salivary cortisol, affect, and cognitive function. *J Am Geriatr Soc*. 2004; 52(11): 1856-1862. doi: 10.1111/j.1532-5415.2004.52505.x

18. Stachowicz M, Lebiedzińska A. The effect of diet components on the level of cortisol. *Eur Food Res Technol*. 2016; 242(12): 2001-2009. doi: 10.1007/s00217-016-2772-3

19. Sá-caputo D, Bernardo-filho M. Hair loss and chemotherapy: An overview about what you need to know. *Trichol Cosmetol Open J*. 2017; 1(2): e12-e14. doi: 10.17140/TCOJ-1-e006

20. Buffoli B, Rinaldi F, Labanca M, et al. The human hair: From anatomy to physiology. *Int J Dermatol*. 2014; 53(3): 331-341. doi: 10.1111/ijd.12362

21. Pragst F, Balikova MA. State of the art in hair analysis for detection of drug and alcohol abuse. *Clin Chim Acta*. 2006; 370(1-2): 17-49. doi: 10.1016/j.cca.2006.02.019

22. Raul JS, Cirimele V, Ludes B, et al. Detection of physiological concentrations of cortisol and cortisone in human hair. *Clin Biochem*. 2004; 37(12): 1105-1111. doi: 10.1016/j.clinbiochem.2004.02.010

23. Staufenbiel SM, Penninx BWJH, Spijker AT, et al . Hair cortisol, stress exposure, and mental health in humans: A systematic review. *Psychoneuroendocrinology*. 2013; 38(8): 1220-1235. doi: 10.1016/j.psyneuen.2012.11.015

24. Gow R, Thomson S, Rieder M, et al. An assessment of cortisol analysis in hair and its clinical applications. *Forensic Sci Int*. 2010; 196(1-3): 32-37. doi: 10.1016/J.FORSCIINT.2009.12.040

25. Russell E, Koren G, Rieder M, et al . Hair cortisol as a biological marker of chronic stress: Current status, future directions and unanswered questions. *Psychoneuroendocrinology*. 2012; 37(5): 589-601. doi: 10.1016/j.psyneuen.2011.09.009

26. Ito N. Human hair follicles display a functional equivalent of the hypothalamic-pituitary-adrenal (HPA) axis and synthesize cortisol. *FASEB J*. 2005; 19(10): 1332-1334. doi: 10.1096/fj.04-1968fje

27. Stalder T, Kirschbaum C. Analysis of cortisol in hair: State of the art and future directions. *Brain Behav Immun*. 2012; 26(7): 1019-1029. doi: 10.1016/j.bbi.2012.02.002

28. Teychenne M, Lee Olstad D, Turner AI, et al. Sedentary behaviour and hair cortisol amongst women living in socioeconomically disadvantaged neighbourhoods: A cross-sectional study. *Int J Environ Res Public Health*. 2018; 15(4): E586. doi: 10.3390/ijerph15040586

29. Hu JJ, Duan XN, Fang J, et al. Association between hair cortisol concentration and overweight and obesity in 6-9 years old childhood. *Zhonghua Yu Fang Yi Xue Za Zhi*. 2017; 51(12): 1065-1068. doi: 10.3760/cma.j.issn.0253-9624.2017.12.003

30. Ullmann E, Barthel A, Petrowski K, et al. Pilot study of adrenal steroid hormones in hair as an indicator of chronic mental and physical stress. *Sci Rep*. 2016; 6: 25842. doi: 10.1038/srep25842

31. Gerber M, Kalak N, Elliot C, et al. Both hair cortisol levels and perceived stress predict increased symptoms of depression: An exploratory study in young adults. *Neuropsychobiology*. 2013; 68(2): 100-109. doi: 10.1159/000351735

32. Gerber M, Jonsdottir IH, Kalak N, et al. Objectively assessed physical activity is associated with increased hair cortisol content in young adults. *Stress*. 2013; 16(6): 593-599. doi: 10.3109/10253890.2013.823599

33. Wosu AC, Valdimarsdóttir U, Shields AE, et al. Correlates of cortisol in human hair: Implications for epidemiologic studies on health effects of chronic stress. *Ann Epidemiol*. 2013; 23(12): 797-811. doi: 10.1016/j.annepidem.2013.09.006

34. Cirimele V, Kintz P, Dumestre V, et al. Identification of ten corticosteroids in human hair by liquid chromatography-ions pray mass spectrometry. *Forensic Sci Int*. 2000; 107(1-3): 381-388. doi: 10.1016/S0379-0738(99)00180-2

35. Bévalot F, Gaillard Y, Lhermitte MA, et al. Analysis of corticosteroids in hair by liquid chromatography-electrospray ionization mass spectrometry. *J Chromatogr B Biomed Sci Appl*. 2000; 740(2): 227-236. doi: 10.1016/S0378-4347(00)00085-2

36. Olstad DL, Ball K, Wright C, et al. Hair cortisol levels, perceived stress and body mass index in women and children living in socioeconomically disadvantaged neighborhoods: The READI study. *Stress*. 2016; 19(2): 158-167. doi: 10.3109/10253890.2016.1160282

37. Widmaier E. Metabolic feedback in mammalian endocrine systems. *Horm Metab Res*. 1992; 24(4): 147-153. doi: 10.1055/s-2007-1003282