

Continuous Dynamics of The Hair Follicle: Spiral Model for Understanding Follicular Activity Throughout Life

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Abstract

The hair follicle represents one of the most dynamic structures of the human organism, characterized by continuous cycles of growth, regression and rest. Hair performs functions that transcend biological protection, assuming profound psychological and cultural meanings, relating to self-esteem and personal identity. The traditional hair cycle is divided into anagen, catagen and telogen phases. The traditional annular model represents this cycle as a repetitive circular process, presenting limitations in not capturing progressive transformations that occur with aging and succession of hair cycles.

To develop a spiral conceptual model that represents physiological follicular activity from birth to aging, establishing a reference for identification of pathological deviations such as effluviums and alopecias.

An integrative review of scientific literature on follicular biology, hair cycle and its variations throughout different life phases was conducted. From this analysis, a spiral conceptual model was developed representing the continuity and temporal progression of follicular activity under physiological conditions.

The proposed Spiral Model demonstrates the continuous dynamics of the hair cycle through anagen, catagen and telogen phases, evidencing natural variations in anagen phase duration according to age and highlighting constant follicle renewal throughout life. Unlike the traditional annular model, the spiral model emphasizes temporal progression and physiological transformations inherent to follicular aging, allowing clear distinction between physiological aging and pathological processes.

The Spiral Model constitutes an innovative conceptual tool for understanding physiological follicular activity, serving as a baseline reference for early identification of pathological alterations and optimization of therapeutic strategies in trichology.

Keywords: Hair follicle, Hair cycle, Spiral model, Hair aging

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1. Introduction

The hair follicle represents one of the most fascinating and complex structures of the human organism, characterizing itself as a highly dynamic mini-organ capable of continuous

cyclic regeneration throughout life¹. This singular regenerative capacity positions the hair follicle as an exceptional biological model for studies of cell biology, tissue differentiation and organic aging. The profound understanding of follicular dynamics has direct clinical implications for the diagnosis and treatment of conditions that affect millions of people globally.

Hair performs functions that transcend its primary biological importance of thermal and mechanical protection. In contemporary society, hair assumes profound psychological and cultural meanings, intimately relating to self-esteem, personal identity and social perception^{1,2}. Studies demonstrate that hair alterations can significantly impact individuals' quality of life, affecting their interpersonal relationships, professional performance and psychological well-being³. Historically, hair has been a symbol of power, strength, sexuality and vanity in diverse cultures⁴.

The follicular structure is composed of multiple specialized cellular compartments, including the dermal papilla, germinative matrix, inner and outer root sheath, and stem cells located in the bulge region⁵. The hair cycle is traditionally divided into three main phases: anagen (active growth), catagen (regression) and telogen (rest). Some authors describe a fourth phase called exogen, corresponding to active elimination of the hair shaft^{5,6}. The anagen phase can last from two to seven years in the human scalp, a period in which the follicle is in maximum metabolic activity⁷. The catagen phase, lasting two to three weeks, represents a critical period of tissue remodeling. The telogen phase is characterized by follicular quiescence, lasting three to four months⁵.

The traditional annular model of the hair cycle represents the follicular cycle as a repetitive circular process, in which the phases succeed each other indefinitely in an identical manner. Although useful for basic understanding of follicular cyclicity, this model presents significant conceptual limitations in not adequately representing the progressive transformations that occur in the hair follicle with advancing age^{8,9}. Scientific evidence demonstrates that the hair cycle is not a static and repetitive process, but dynamic and progressive. Longitudinal studies reveal that the duration of the anagen phase gradually decreases with aging, resulting in progressively shorter and thinner strands^{10,11}. Progressive follicular miniaturization is observed in conditions such as androgenetic alopecia, in which each successive cycle results in a structurally smaller follicle^{12,13}.

Given these considerations, the need for a conceptual model that adequately represents the continuous, progressive and evolutionary nature of follicular activity throughout life becomes evident. This model should serve as a reference for physiological follicular activity, allowing early identification of pathological deviations. The present study proposes the development of a Spiral Model of the hair cycle, representing follicular activity as a continuous and progressive process, in which each successive cycle occurs in a temporal and physiological context slightly different from the previous one.

Methods

This study is characterized as an integrative review of scientific literature, a method that allows synthesis and critical analysis of knowledge produced in previous investigations, enabling elaboration of general conclusions and development of innovative conceptual models¹⁴. The bibliographic search strategy was systematically conducted in the main scientific databases of the biomedical area, including PubMed, Scopus, Web of Science and SciELO. The search used controlled descriptors and keywords related to follicular biology, hair cycle, hair aging and follicular dynamics. The established inclusion criteria were articles published in peer-reviewed scientific journals, studies addressing aspects of follicular biology and hair cycle, research investigating variations in follicular activity throughout life, and works discussing physiological and pathological aspects of hair growth. From the critical analysis and synthesis of selected studies, the conceptual development of the Spiral Model was carried out, considering representation of temporal continuity of follicular activity, incorporation of physiological variations associated with aging, distinction between physiological variations and pathological alterations, and clinical applicability for diagnosis and therapeutic planning.

Results

The Spiral Model of the hair cycle represents a significant conceptual innovation in the understanding of follicular dynamics throughout life. Unlike the traditional annular model, which represents the cycle as a closed and repetitive circular process, the Spiral Model visualizes follicular activity as continuous and evolutionary progression, in which each successive cycle occurs in a unique temporal and physiological context. This representation

simultaneously captures the inherent cyclicity of the hair follicle and the gradual transformations that occur with aging and succession of hair cycles. The fundamental structure maintains the three classical phases: anagen, catagen and telogen. Instead of representing them as circle segments that repeat indefinitely, the model positions them along a three-dimensional spiral that progresses temporally. Each complete turn represents a complete hair cycle. The progression along the longitudinal axis represents the passage of chronological time, from birth to advanced aging.

A fundamental distinctive characteristic is the capacity to represent variations in anagen phase duration throughout life. During childhood and adolescence, the anagen phase presents maximum duration, frequently extending for six to seven years on the scalp^{7,15}. This prolonged phase results in long strands with robust diameter. In the spiral model, this period is represented by wide and spaced turns, reflecting the extensive duration of the active growth phase. With advancing adult age, a gradual reduction in anagen phase duration is observed, a phenomenon that intensifies after forty years^{10,11}. This reduction manifests as a decrease in the maximum length that strands can achieve. In the Spiral Model, this transition is represented by progressive approximation of the turns, reflecting reduction in anagen phase duration and consequent shortening of hair cycles. This visual representation (Figure 1) facilitates understanding that hair aging is not a sudden event, but a gradual and continuous process., and rapid reductions in fat mass are all implicated in destabilizing follicular cycling¹¹.

SPIRAL MODEL HAIR CYCLE

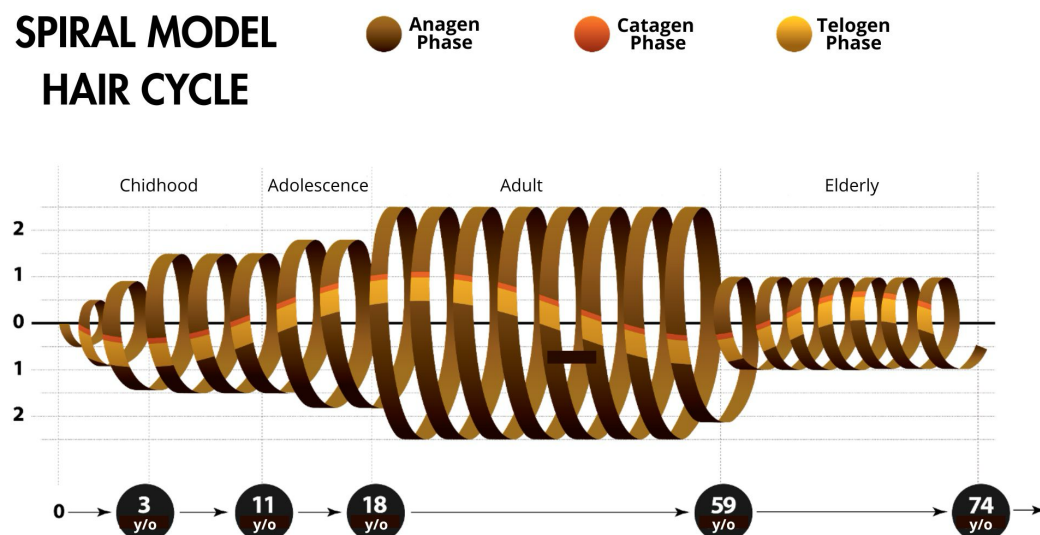


Figure 1: Spiral Model of Hair Cycle Throughout Life

Discussion

The proposed Spiral Model represents a significant conceptual advance, filling important gaps left by the traditional annular model. The main contribution resides in the capacity to simultaneously represent the inherent cyclicity of the hair follicle and the progressive transformations that occur with aging, offering a more holistic and clinically relevant vision of follicular activity. The fundamental limitation of the annular model is its representation of the cycle as a static and repetitive process. Robust scientific evidence demonstrates that the hair follicle undergoes gradual and cumulative modifications throughout its life, influenced by intrinsic factors such as hormonal alterations and oxidative stress, and by extrinsic factors such as environmental exposure^{16,17,18}. The Spiral Model incorporates this evidence, offering a representation that more faithfully reflects the dynamic and evolutionary nature of follicular activity.

The progressive reduction in anagen phase duration with aging^{10,11} constitutes a fundamental pillar of the Spiral Model. The distinction between physiological hair aging and pathological processes represents a significant clinical challenge. The Spiral Model contributes to this differentiation by establishing a reference trajectory for physiological follicular activity. Significant deviations from this trajectory signal the need for in-depth diagnostic investigation^{19,20}. The clinical applicability extends to various trichological conditions. In androgenetic alopecia, the model allows visualization of pathological acceleration of spiral compaction in

susceptible regions^{12,13}. In telogen effluvium, it allows distinction between acute and chronic forms^{21,22}. Pharmacological interventions can prolong the anagen phase and partially reverse follicular miniaturization^{23,24}, effects represented as partial decompaction of spiral turns.

The Spiral Model has multiple practical applications relevant to trichological clinical practice, professional education and patient communication. In diagnostic practice, it serves as a reference tool for evaluation of individual follicular activity. Through methods such as trichoscopy and phototrichogram, it is possible to characterize the current state of follicular activity and position the patient along the spiral trajectory. Significant deviations from the expected trajectory signal the need for in-depth investigation. The model facilitates personalized therapeutic planning. By understanding the patient's current position in the spiral trajectory and factors that influence its progression, it is possible to develop individualized strategies. Monitoring of therapeutic responses is also facilitated²⁵. In communication with patients, it offers an intuitive visual tool for explanation of complex concepts related to follicular biology and hair aging. In professional education, it can be incorporated into trichology and dermatology training curricula.

Conclusion

A The Spiral Model of the hair cycle represents a significant conceptual advance in the understanding of follicular dynamics throughout life, overcoming limitations of the traditional annular model. By representing follicular activity as a continuous and progressive process, it offers a more holistic and clinically relevant vision of follicular biology. The main contributions include adequate representation of variations in anagen phase duration, clear distinction between physiological aging and pathological processes, and establishment of a baseline reference for identification of deviations. The practical applications are extensive, encompassing clinical diagnosis, personalized therapeutic planning, response monitoring, patient communication and professional education. Future directions include empirical validation through prospective longitudinal studies, development of quantitative diagnostic tools based on the model, and investigation of genetic and epigenetic factors that influence individual trajectory. In synthesis, the Spiral Model constitutes an innovative conceptual tool that faithfully reflects the dynamic and evolutionary nature of follicular activity, serving as a reference for understanding physiological follicular functioning and identification of pathological alterations.

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