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| RESEARCH ARTICLE

The Endocrine Response to Physical Therapy: Hormonal Effects on Healing and Recovery

Shivangi Chaughule
Jersey City, USA
Corresponding Author: Shivangi Chaughule, **E-mail**: shivangisawant@ymail.com

| ABSTRACT

The integration of physical therapy into patient care stimulates a cascade of physiological responses, prominently involving the endocrine system. Hormones such as cortisol, growth hormone, insulin-like growth factor-1 (IGF-1), and testosterone play pivotal roles in tissue repair, inflammation modulation, and overall recovery. This abstract explores the interplay between physical therapy interventions and endocrine responses, emphasizing their implications for optimizing healing and functional restoration. Cortisol, a glucocorticoid released during stress, exhibits dual effects, balancing anti-inflammatory benefits with potential catabolic consequences. Physical therapy techniques that incorporate stress-reduction strategies may mitigate excessive cortisol levels, fostering an anabolic environment conducive to recovery. Growth hormone and IGF-1 are integral to protein synthesis and cellular repair; exercise-induced stimulation of these hormones underscores the importance of tailored physical therapy regimens in enhancing musculoskeletal healing. Similarly, testosterone contributes to muscle hypertrophy and regeneration, with evidence suggesting that resistance-based exercises can augment its production. Furthermore, the endocrine response to physical therapy extends to metabolic hormones such as insulin and leptin, which influence energy availability and tissue remodeling. Understanding these hormonal dynamics enables physical therapists to design interventions that align with the body's natural healing processes. Future research should focus on personalized approaches, considering individual hormonal profiles and the potential for endocrine dysfunction to hinder recovery. This abstract highlights the critical role of the endocrine system in mediating the effects of physical therapy. By leveraging hormonal responses, clinicians can enhance therapeutic outcomes, accelerate recovery timelines, and improve patient quality of life.

| KEYWORDS

Cortisol, Growth Hormone, IGF-1, testosterone, tissue repair, physical therapy, rehab

| ARTICLE INFORMATION

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1. INTRODUCTION

Physical therapy is a cornerstone of rehabilitation, promoting injury recovery and improving functional capacity. Beyond its mechanical and neurological effects, the role of the endocrine system in mediating responses to physical therapy has garnered increasing attention. Hormones, the body's chemical messengers, are essential for regulating physiological processes, including tissue repair, inflammation, and energy metabolism. By understanding the hormonal changes triggered by physical therapy, practitioners can refine interventions to optimize recovery and healing. The endocrine system encompasses a network of glands that release hormones into the bloodstream, influencing distant tissues and organs. Physical stress and exercise, both integral to physical therapy, are potent stimuli for endocrine activity. Resistance training, aerobic exercises, and manual therapies each evoke specific hormonal responses. These responses vary in magnitude and duration, depending on the intensity, type, and individual's baseline hormonal status. For example, growth hormone (GH) and its downstream mediator, insulin-like growth

factor-1 (IGF-1), are integral to tissue repair and regeneration. They stimulate collagen synthesis, cell proliferation, and angiogenesis, all critical components of wound healing. Similarly, anabolic hormones such as testosterone support muscle repair and hypertrophy, enhancing functional recovery. Conversely, catabolic hormones like cortisol, while essential for modulating inflammation and mobilizing energy, can impede recovery if chronically elevated. Catecholamines, including adrenaline and noradrenaline, are another crucial component of the endocrine response. These hormones prepare the body for physical activity by increasing heart rate, blood flow, and energy availability. While their acute effects are beneficial, prolonged elevation can contribute to stress-related impairments. Emerging research also highlights the role of myokines—hormone-like molecules released by contracting muscles—in mediating systemic effects. Myokines such as interleukin-6 (IL-6) play dual roles in promoting anti-inflammatory effects and facilitating energy metabolism. This paper delves into the intricate interplay between physical therapy interventions and hormonal dynamics. It emphasizes the implications of these endocrine responses for tissue healing, inflammation control, and overall recovery. By integrating an understanding of endocrine mechanisms into treatment plans, physical therapists can harness hormonal effects to maximize therapeutic outcomes and improve patient care.

2. ENDOCRINE SYSTEM

The **hormonal or endocrine system** is a network of glands and organs that produce, release, and regulate hormones. Hormones are chemical messengers that travel through the bloodstream to target tissues and organs, influencing various physiological functions essential for maintaining homeostasis and responding to environmental changes.

3. ORGANS INVOLVED IN THE ENDOCRINE SYSTEM

The endocrine system involves several glands and organs that produce and secrete hormones into the bloodstream to regulate various bodily functions. Here is a detailed breakdown of the key organs and glands involved in the endocrine system:

3.1. Hypothalamus

- Function: The hypothalamus is located in the brain and acts as the link between the nervous system and the endocrine system. It regulates the release of hormones from the pituitary gland and controls vital functions such as temperature regulation, hunger, thirst, and sleep. It produces releasing and inhibiting hormones that control the pituitary gland.
- Key Hormones:
    - Thyrotropin-releasing hormone (TRH)
    - Gonadotropin-releasing hormone (GnRH)
    - Growth hormone-releasing hormone (GHRH)
    - Corticotropin-releasing hormone (CRH)
    - Somatostatin (inhibits growth hormone)

3.2. Pituitary Gland

- Location: The pituitary gland is a small, pea-sized gland located at the base of the brain, just below the hypothalamus.
- Function**:** Often called the "master gland" because it controls other endocrine glands, the pituitary produces hormones that regulate growth, metabolism, and reproduction. It has two parts: the anterior (front) lobe and the posterior (back) lobe.
- Key Hormones:
    - Anterior Pituitary:
        - Growth hormone (GH)
        - Prolactin (PRL)
        - Thyroid-stimulating hormone (TSH)
        - Adrenocorticotropic hormone (ACTH)
        - Luteinizing hormone (LH)
        - Follicle-stimulating hormone (FSH)
    - Posterior Pituitary:
        - Oxytocin
        - Antidiuretic hormone (ADH or vasopressin)

3.3. Thyroid Gland

- Location: The thyroid is located in the neck, just below the Adam's apple.

- Function: The thyroid produces hormones that regulate metabolism, energy production, and growth. It influences almost every tissue in the body, controlling how quickly cells use energy and make proteins.
- Key Hormones:
    - Thyroxine (T4)
    - Triiodothyronine (T3)
    - Calcitonin

3.4. Parathyroid Glands

- Location: The parathyroid glands are typically four small glands located behind the thyroid gland.
- Function: The parathyroid glands regulate calcium and phosphate balance in the blood. They release parathyroid hormone (PTH), which increases blood calcium levels when they are too low.
- Key Hormone:
    - Parathyroid hormone (PTH)

3.5. Adrenal Glands

- Location: The adrenal glands are located on top of the kidneys and consist of two parts: the adrenal cortex (outer part) and the adrenal medulla (inner part).
- Function: The adrenal glands produce hormones that help manage stress, regulate metabolism, and control salt and water balance. The adrenal medulla produces hormones involved in the "fight or flight" response.
- Key Hormones:
    - Adrenal Cortex:
        - Cortisol
        - Aldosterone
        - Androgens
    - Adrenal Medulla:
        - Epinephrine (adrenaline)
        - Norepinephrine (noradrenaline)

3.6. Pancreas

- Location: The pancreas is located behind the stomach and is both an endocrine and exocrine organ.
- Function: The endocrine part of the pancreas produces hormones that regulate blood sugar levels. The exocrine part produces digestive enzymes. The pancreas plays a key role in regulating glucose metabolism.
- Key Hormones:
    - Insulin
    - Glucagon
    - Somatostatin
    - Pancreatic polypeptide

3.7. Gonads (Ovaries and Testes)

- Location: The ovaries are located in the female pelvis, while the testes are located in the male scrotum.
- Function: The gonads produce sex hormones that are involved in the development of sexual characteristics, reproduction, and the menstrual cycle in females.
- Key Hormones:
    - Ovaries (female):
        - Estrogen
        - Progesterone
        - Inhibin
    - Testes (male):
        - Testosterone
        - Inhibin

3.8. Pineal Gland

- Location: The pineal gland is a small, pea-shaped gland located in the brain, near the center of the brain, between the two hemispheres.
- Function: The pineal gland is responsible for producing melatonin, which regulates the sleep-wake cycle (circadian rhythms).
- Key Hormone:
    - Melatonin

3.9. Thymus

- Location: The thymus is in the chest, just behind the sternum and between the lungs.
- Function: The thymus is important for the development of the immune system. It produces thymosin, which helps in the maturation of T-cells (a type of white blood cell critical for immune responses).
- Key Hormone:
    - Thymosin

3.10. Other Organs Involved in Hormonal Secretion:

- **Heart:** The heart secretes atrial natriuretic peptide (ANP), which helps regulate blood volume and pressure.
- **Kidneys:** The kidneys produce erythropoietin (EPO), which stimulates red blood cell production, and renin, which helps regulate blood pressure.
- **Adipose Tissue (Fat):** Adipose tissue produces hormones such as leptin, which helps regulate energy balance and appetite, and resistin, which affects insulin resistance.

4. FUNCTION OF THE HORMONES

The hormonal system, also known as the endocrine system, plays a crucial role in regulating various bodily functions through the release of hormones. Hormones are chemical messengers that are secreted into the bloodstream by glands, which then travel to target organs or tissues, where they exert their effects.

4.1. Regulation of Metabolism

- **Thyroid Hormones (T3 and T4):** The thyroid gland releases thyroid hormones, which regulate the metabolic rate of the body. They influence the rate at which cells convert nutrients into energy and thus play a key role in energy production, heat generation, and overall metabolism.
- **Insulin and Glucagon:** These hormones, released by the pancreas, are involved in regulating blood sugar levels. Insulin promotes the uptake of glucose into cells, lowering blood sugar levels, while glucagon works to raise blood sugar levels by prompting the liver to release stored glucose.

4.2. Growth and Development

- **Growth Hormone (GH):** Secreted by the pituitary gland, growth hormone stimulates the growth and development of bones, muscles, and other tissues. It influences protein synthesis and the growth of long bones in children and adolescents.
- **Thyroid Hormones:** These are also involved in regulating growth, particularly during early development. A deficiency in thyroid hormones during childhood can lead to stunted growth and developmental delays.
- **Sex Hormones (Estrogen, Progesterone, Testosterone):** These hormones regulate the development of primary and secondary sexual characteristics during puberty. They also influence reproductive health and the functioning of the reproductive organs.

4.3. Reproductive Function

- **Estrogen and Progesterone:** These are the primary female sex hormones produced by the ovaries. Estrogen is involved in the development of female secondary sexual characteristics and the regulation of the menstrual cycle, while progesterone prepares the uterus for pregnancy and supports early gestation.
- **Testosterone:** This is the primary male sex hormone produced by the testes. Testosterone is responsible for the development of male secondary sexual characteristics such as facial hair, deepening voice, and muscle mass.
- **Prolactin:** Produced by the pituitary gland, prolactin stimulates milk production in the mammary glands following childbirth.
- **Oxytocin:** This hormone, released by the pituitary gland, is involved in uterine contractions during labor and the release of milk from the mammary glands during breastfeeding.

4.4. Homeostasis and Stress Response

- **Cortisol:** Released by the adrenal glands, cortisol helps regulate the body's response to stress. It also plays a role in maintaining blood sugar levels, reducing inflammation, and modulating the immune system.
- **Adrenaline (Epinephrine) and Noradrenaline (Norepinephrine):** These hormones, released by the adrenal medulla, are part of the body's "fight or flight" response. They increase heart rate, blood pressure, and energy availability to help the body respond quickly to stressful situations.
- **Aldosterone:** This hormone is produced by the adrenal glands and regulates salt and water balance, helping to maintain blood pressure. It increases sodium reabsorption in the kidneys, which in turn promotes water retention and increases blood volume.

4.5. Water and Electrolyte Balance

- **Antidiuretic Hormone (ADH):** Also known as vasopressin, ADH is released by the posterior pituitary gland. It regulates water balance by promoting water reabsorption in the kidneys, thus preventing dehydration and maintaining blood volume and pressure.
- **Aldosterone:** As mentioned earlier, aldosterone also plays a role in electrolyte balance, especially in regulating sodium and potassium levels, which are essential for proper cell function and nerve transmission.

4.6. Immune System Regulation

- **Thymosin:** Produced by the thymus gland, thymosin promotes the development and maturation of T lymphocytes (T cells), which are critical for immune responses.
- **Cortisol:** While primarily known for its role in stress response, cortisol also has an immunosuppressive effect, reducing the activity of the immune system to prevent overreaction.

4.7. Circadian Rhythm and Sleep

- **Melatonin:** Produced by the pineal gland, melatonin helps regulate the sleep-wake cycle. It is released in response to darkness and promotes feelings of drowsiness and sleepiness, helping to synchronize the body's circadian rhythms.

4.8. Cardiovascular and Blood Pressure Regulation

- **Erythropoietin (EPO):** Produced by the kidneys, erythropoietin stimulates the production of red blood cells in the bone marrow. This is important for ensuring an adequate supply of oxygen to tissues.
- **Renin-Angiotensin-Aldosterone System (RAAS):** This system helps regulate blood pressure by controlling the volume of fluid in the body and the diameter of blood vessels. When blood pressure drops, the kidneys release renin, which activates a cascade that increases blood pressure through vasoconstriction and water retention.

4.9. Mood and Behavior Regulation

- **Serotonin:** Often considered a neurotransmitter, serotonin also acts as a hormone. It regulates mood, anxiety, and happiness, and imbalances are linked to conditions such as depression and anxiety.
- **Endorphins:** These are peptides produced by the pituitary gland and the hypothalamus, often in response to stress or pain. Endorphins help reduce pain and induce feelings of pleasure or euphoria.
- **Dopamine:** Dopamine is involved in regulating reward, motivation, and pleasure. It plays a central role in the brain's reward system, influencing behavior and emotions.

4.10. Blood Calcium Regulation

- **Parathyroid Hormone (PTH):** Released by the parathyroid glands, PTH regulates calcium and phosphate levels in the blood. It increases blood calcium levels by promoting calcium release from bones, increasing calcium absorption from the intestines, and reducing calcium excretion in urine.
- **Calcitonin:** Produced by the thyroid gland, calcitonin lowers blood calcium levels by inhibiting the release of calcium from bones and promoting its excretion in urine.

4.11. Digestion and Appetite Regulation

- **Ghrelin:** Known as the "hunger hormone," ghrelin is produced by the stomach and stimulates appetite. It also plays a role in regulating energy balance and body weight.
- **Leptin:** Produced by fat cells, leptin signals to the brain that the body has enough energy stored, helping to regulate long-term energy balance and suppress appetite.

In summary, the hormonal system regulates nearly every physiological process in the body, including metabolism, growth, reproduction, stress responses, and homeostasis. The interaction between various hormones allows the body to maintain balance and adapt to changes in the environment, ensuring proper functioning of organs and tissues.

5. HORMONES AND PHYSICAL THERAPY CORELATION: -

In physical therapy, understanding how hormones affect the body can be crucial to optimizing rehabilitation, managing pain, and supporting recovery processes. Several hormones are particularly relevant for their roles in inflammation, muscle repair, tissue healing, stress response, and overall mobility. Below are some of the most important hormones in relation to physical therapy:

5.1. Cortisol

Cortisol is a steroid hormone released by the adrenal glands in response to stress. It plays a role in regulating metabolism, reducing inflammation, and controlling the body's stress response. Cortisol has potent anti-inflammatory effects, as it inhibits the production of inflammatory cytokines and prostaglandins, which are key mediators of inflammation and pain. In the acute phase of an injury, inflammation is essential for healing, but excessive or prolonged inflammation can delay recovery, impair tissue repair, and cause pain. Cortisol helps modulate this process by reducing the duration and intensity of inflammation, thus helping to control swelling, pain, and tissue damage. Cortisol works by decreasing the production of pro-inflammatory cytokines such as interleukin-1 (IL-1), interleukin-6 (IL-6), and tumor necrosis factor-alpha (TNF-α). These cytokines are involved in the inflammatory response following injury or tissue damage. Cortisol plays a complex role in tissue repair. While it is essential for initial inflammation resolution, its effect on collagen synthesis (a key component of the extracellular matrix) is dose dependent. Cortisol plays a key role in maintaining energy balance during physical activity, particularly when the body is under stress. Cortisol helps to mobilize glucose, fatty acids, and amino acids from the liver and adipose tissue, ensuring that energy is available for muscle activity. Cortisol is released in response to stress (physical, emotional, or psychological) as part of the body's "fight-or-flight" response. It increases heart rate, blood pressure, and energy availability to help the body respond to immediate threats. Cortisol can affect bone metabolism by reducing calcium absorption in the intestines and increasing calcium excretion via the kidneys, leading to decreased bone mineral density over time. This can increase the risk of fractures and impair healing following bone injuries or fractures.

5.2. Growth Hormone (GH)

Growth hormone is produced by the anterior pituitary gland and stimulates growth, cell reproduction, and tissue repair. Insulin-like growth factors (IGFs) are small polypeptide hormones (70 and 67 amino acids for IGF-I and IGF-II, respectively), structurally related to insulin, and synthesized from a larger precursor peptide that is post-translationally processed into its active form (4). Patients with growth hormone deficiency often experience delayed recovery, decreased muscle mass, increased body fat, and slower tissue healing. In these cases, physical therapy can be less effective without addressing the underlying hormone deficiency. One of the most important functions of growth hormone is its ability to stimulate muscle protein synthesis. It increases the uptake of amino acids into muscle cells, which are then used to build proteins necessary for muscle growth and repair. GH promotes muscle hypertrophy (muscle growth) by stimulating the production of insulin-like growth factor-1 **(IGF-1)** in the liver and other tissues, which in turn stimulates muscle cell growth and repair. The influence of IGF-1 in mediating some of the beneficial aspects of exercise particularly with regard to postexercise recovery and remodeling mechanisms for muscle tissue has been an area of intense interest (5,6). Growth hormone supports the production of collagen, an essential protein for connective tissues such as tendons, ligaments, and cartilage. Collagen is the primary structural component that helps in the healing of soft tissues following injury. Growth hormone also stimulates the proliferation of bone-forming cells (osteoblasts) and contributes to the synthesis of bone matrix. This is especially beneficial in the recovery process following bone fractures or fractures that require rehabilitation. Growth hormone enhances fat metabolism by stimulating the breakdown of fat cells (lipolysis), releasing fatty acids into the bloodstream to be used as energy. Tendons and ligaments have relatively low blood supply, which can make healing after an injury slower. Growth hormone plays a role in improving the healing capacity of tendons and ligaments by stimulating the production of extracellular matrix components like collagen and proteoglycans. Growth hormone helps counteract the muscle breakdown (catabolism) that occurs during intense physical activity or overtraining. This is important for athletes or patients who may be engaging in vigorous rehabilitation exercises that put stress on muscles. Growth hormone can stimulate the growth and repair of cartilage, the tissue that cushions joints. This is particularly important for patients with osteoarthritis or those recovering from joint surgeries. By supporting cartilage regeneration, GH may help improve joint function, reduce pain, and increase flexibility.

5.3. Insulin

Insulin is secreted from the β-cells of the pancreatic islets of Langerhans in response to glucose and amino acids consumed during a meal. Insulin is a central regulatory hormone in the maintenance of glucose homeostasis and is also involved in anabolic processes including tissue growth and development (6).**Energy Regulation**: Insulin facilitates glucose uptake into muscles, providing energy during exercise and supporting glycogen replenishment post-therapy. **Muscle Repair**: It promotes muscle protein synthesis, aiding recovery and muscle growth after physical stress or injury. **Fat Metabolism**: Insulin helps manage body fat by promoting fat storage, which can be important for patients managing weight during rehabilitation. **Tissue Healing**: Insulin aids in tissue repair by reducing inflammation and supporting collagen synthesis, which is important for healing tendons, ligaments, and bones.

5.4. Testosterone

Testosterone is a sex hormone primarily produced by the testes in men and ovaries in women (though in much smaller amounts). Testosterone is the primary androgen and has both androgenic and anabolic effects (2). It is important for muscle growth, strength, and bone density. Testosterone plays an important role in physical therapy by promoting muscle growth, tissue repair, and overall physical recovery. **Muscle Growth**: Testosterone stimulates protein synthesis, helping repair and build muscle tissue after exercise or injury. **Bone Health**: It supports bone density and healing, which is crucial for patients recovering from fractures or bone-related injuries. **Strength and Endurance**: Testosterone enhances strength, endurance, and overall performance, which improves the effectiveness of rehabilitation exercises. **Recovery**: It reduces muscle breakdown (catabolism) and aids in faster recovery, reducing the risk of overtraining or injury. A persistent decline in testosterone is associated with reduced muscle mass and function (1). Thus, androgens are commonly used as drugs for manipulating muscle mass (1) and the supraphysiological concentration of testosterone-mimicking synthetic androgenic steroids promotes significant skeletal muscle mass increases in both males and females (3).

5.5. Estrogen

Estrogen is a potent steroid hormone present in high levels in females from adolescence to menopause and in low levels in men (7) influences reproductive health and has an impact on bone density, muscle function, and the cardiovascular system. Estrogen helps protect bones and prevent bone loss, which is particularly important in women as they age and during menopause. Low estrogen levels can contribute to osteoporosis, increasing the risk of fractures. Estrogen supports joint health and flexibility, which is essential for functional mobility and rehabilitation. Estrogen also plays a role in muscle recovery and strength, especially in female athletes or patients undergoing rehabilitation after injury.

5.6. Thyroid Hormones (T3 and T4)

The thyroid hormones triiodothyronine (T3) and thyroxine (T4) regulate metabolism, energy production, and overall cellular function. Hypothyroidism (low thyroid hormone levels) can lead to muscle weakness, fatigue, and joint stiffness, which can significantly impact a patient's ability to engage in physical therapy. Thyroid hormones are crucial for maintaining energy levels and supporting the body's ability to perform exercises, making them important for rehabilitation and recovery. Thyroid hormone is essential for normal development, growth, neural differentiation, and metabolic regulation in mammals (8,9,10). Abnormal thyroid hormone levels may slow down recovery from injury and surgery by impairing metabolic processes necessary for tissue healing.

5.7. Endorphins

Endorphins are neurotransmitters produced by the brain and nervous system that act as natural pain relievers and mood enhancers. Endorphins are released during exercise, which is important in physical therapy as they help reduce pain perception and improve mood during rehabilitation. They can enhance the patient's tolerance for physical activity, which is crucial when recovering from injuries or surgeries. Endorphin release can also promote feelings of well-being and help reduce the emotional stress that can be associated with injury recovery.

5.8. Adrenaline (Epinephrine)

Adrenaline is produced by the adrenal glands and plays a role in the "fight or flight" response, increasing heart rate, blood pressure, and energy availability. Adrenaline can increase physical performance by enhancing focus, strength, and endurance during rehabilitation exercises. It also helps the body respond to acute injuries by promoting the release of glucose for energy and increasing blood flow to muscles and tissues. However, excessive, or chronic adrenaline release due to stress can hinder recovery by increasing muscle tension and contributing to inflammation.

5.9. Prolactin

Prolactin is produced by the pituitary gland and primarily regulates milk production, but it also has effects on reproductive health and metabolism. Prolactin may influence muscle recovery and tissue repair, although its role in these processes is not as well defined as other hormones. Elevated prolactin levels may be associated with muscle weakness and joint pain in some individuals, which can affect rehabilitation progress.

5.10. Leptin

Leptin is a hormone produced by adipose (fat) tissue that helps regulate appetite and energy balance. Leptin levels are related to body fat stores, and fluctuations can influence appetite, weight, and energy levels during rehabilitation. In patients with obesity, leptin resistance can contribute to difficulty in achieving weight loss or maintaining an active lifestyle, which may impact physical therapy goals. Leptin may also play a role in inflammation and tissue repair during recovery.

5.11. Angiotensin II

Angiotensin II is a hormone involved in regulating blood pressure by constricting blood vessels and stimulating the release of aldosterone. Angiotensin II affects blood flow and tissue perfusion, influencing healing and recovery processes, particularly after surgery or injury. It can play a role in cardiovascular health, which is relevant for patients with cardiac conditions or those recovering from cardiovascular surgeries.

6. CONCLUSION

The endocrine system plays a vital role in physical therapy by regulating key hormones that support tissue healing, muscle recovery, and overall rehabilitation. Hormones like growth hormone**,** testosterone**,** insulin**,** and cortisol facilitate muscle repair, promote bone healing, manage energy metabolism, and control inflammation. A balanced hormonal environment optimizes recovery, accelerates healing, and enhances rehabilitation outcomes. Hormonal imbalances can hinder recovery, so recognizing and addressing these factors is essential. Physical therapists can leverage hormonal effects by incorporating appropriate exercise, nutrition, and lifestyle strategies to enhance recovery and improve patient outcomes.

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