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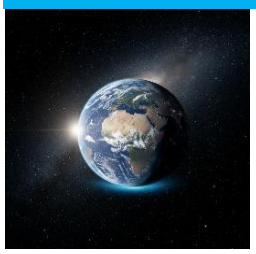

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From Molecular Mechanisms to Functional Outcomes: How Anesthesia Type Affects Postoperative Recovery and Return to Physical Activity

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Abstract:

Introduction

Anesthetic management plays a central role not only in ensuring intraoperative safety but also in shaping postoperative recovery, including the return to physical and sports activities. Surgical

procedures induce a complex neuroendocrine, metabolic, and immune stress response that may influence tissue regeneration and functional recovery. Different anesthetic and analgesic strategies can modulate this response, raising the question of whether the type of anesthesia affects both early recovery and long-term return to physical activity, particularly in physically active individuals and athletes.

Materials and Methods

This review was based exclusively on publications available in PubMed, PMC, and related scientific databases. The analyzed studies included retrospective, clinical, and comparative investigations, as well as narrative and review articles. The research focused on the impact of anesthesia type (general, regional, spinal, and combinations thereof) on postoperative functional outcomes. These outcomes assessed in the reviewed studies included isokinetic muscle strength testing, pain intensity, recovery quality scores (e.g., QoR-40), early mobilization parameters, and selected indicators of physiological stress response. Statistical analyses in the cited studies included methods such as analysis of variance (ANOVA) to compare recovery outcomes between anesthetic techniques.

Literature Review

The reviewed literature suggests that the type of anesthesia may influence early postoperative parameters, including pain control, hemodynamic stability, adverse effect profile, and early quality of recovery. However, evidence regarding its impact on long-term return to physical activity is less consistent. In patients undergoing anterior cruciate ligament (ACL) reconstruction, no significant differences in muscle strength recovery were observed six months postoperatively between different anesthetic techniques. Similarly, studies comparing regional and general anesthesia using QoR-40 scores found no significant differences in global recovery quality, despite improved analgesia with regional techniques. Comparisons between total intravenous anesthesia (TIVA) and inhalational anesthesia demonstrated differences in emergence time, postoperative nausea and vomiting, and early recovery quality, but their influence on long-term exercise capacity remains unclear. Early mobilization interventions did not consistently increase overall physical activity during the first postoperative days, underscoring the multifactorial nature of postoperative recovery.

Summary and Conclusions

The impact of anesthesia type on return to physical activity after surgery is complex and influenced by multiple interacting factors. While anesthetic technique may affect early recovery parameters such as pain intensity, adverse effects, and quality of emergence current evidence does not consistently demonstrate a direct effect on long-term physical performance or exercise

capacity. Full return to activity appears to depend on the combined influence of surgical factors, stress response modulation, effective pain management, rehabilitation strategies, and individual patient characteristics.

Keywords

General anesthesia; Regional anesthesia; Return to physical activity; TIVA; Quality of recovery; Postoperative functional assessment.

Contents:

1. Introduction

General anesthesia, regional anesthesia, and other anesthetic techniques are integral components of perioperative care in patients undergoing surgery. Medical literature emphasizes that anesthetic decisions affect not only the course of the operation itself, but also the postoperative recovery process, including the return to physical and sports activities.[1]

Additionally, growing evidence on the pharmacodynamic, pharmacokinetic, and molecular mechanisms of general anesthetics including aspects such as chirality and receptor-level interactions provides a deeper understanding of how these agents may influence early postoperative recovery processes [2,3]

Surgical procedures trigger a complex stress response in the body, involving neuroendocrine, metabolic, and immune reactions to tissue injury. These processes lead to a hypercatabolic state and metabolic changes that directly influence tissue regeneration and the return to physical activity. [4] The choice of anesthetic technique and analgesic strategy may modify this stress response by affecting the nervous and hormonal systems, as well as pain pathways.[4]

In specific patient populations, such as athletes, researchers also consider how different anesthetic agents and techniques influence later muscle function and the ability to resume sports. Studies examining muscle strength recovery after anterior cruciate ligament (ACL) reconstruction have shown that the type of anesthesia general or regional did not have a statistically significant impact on the ability to regain muscle strength six months after surgery. [5,6]

The literature also highlights that understanding how various anesthetic techniques influence the body's response to surgery is crucial for optimizing perioperative and rehabilitation strategies, particularly when a rapid return to physical activity is the goal.[4]

2. Materials and Methods

This review was developed exclusively on the basis of publications available in PubMed, PMC, and other scientific sources. The analyzed studies included retrospective, clinical, comparative

investigations and literature reviews examining the impact of anesthesia type on postoperative parameters related to the return to physical activity.

In clinical studies, patients were divided into groups depending on the anesthetic technique used (e.g., general anesthesia, regional anesthesia, spinal anesthesia, or combinations of these techniques). Postoperative function was assessed using standardized measurement tools, such as isokinetic muscle strength testing performed before and after surgery. Analyses also included pain assessment, functional parameters, and selected indicators of recovery.

Statistical methods, including analysis of variance (ANOVA), were used to compare outcomes between groups and to determine whether the type of anesthesia had a significant effect on parameters related to the return to physical fitness.

3. Literature Review

3.1 Pharmacodynamic and Molecular Mechanisms of General Anesthetics

Some studies have explored the deeper pharmacodynamic properties and molecular mechanisms of general anesthetics, highlighting how these properties could influence recovery processes. An emerging line of research examines the chirality, pharmacodynamics, and pharmacokinetics of anesthetic agents, noting that enantiomeric forms of inhalational and intravenous anesthetics may differ in bioactivity, toxicity, and metabolic behavior, which could potentially affect their clinical profiles and recovery trajectories. Differences in how enantiomers interact with biological targets may influence their onset, duration, and side effect profiles, although the clinical implications for return to physical activity require further investigation. [2]

At the molecular level, general anesthetics produce CNS depression by modulating key neurotransmitter systems. Mechanistic studies describe that anesthetics enhance inhibitory neurotransmission (e.g., via γ-aminobutyric acid type A (GABA (A) receptors) and suppress excitatory pathways, contributing to components of the anesthetic state such as amnesia, unconsciousness, analgesia, and immobility. These molecular actions help explain how anesthetics achieve their effects, but also why variability in pharmacodynamic responses may influence early postoperative recovery parameters such as cognitive function, emergence times, and neurophysiologic stability. Understanding these molecular mechanisms is important for appreciating how anesthetic agents interact with physiological systems that are also involved in postoperative functional recovery.[3]

3.2 Type of Anesthesia and Quality of Physical Recovery

The reviewed publications suggest that the choice of anesthetic technique may influence early recovery parameters; however, its importance for long-term return to physical activity is not always clear. [6]

In a study of 442 patients undergoing ACL reconstruction, four anesthetic techniques were compared: general anesthesia, general anesthesia with a nerve block, spinal anesthesia, and spinal anesthesia with a nerve block. Muscle strength was assessed using isokinetic testing six months after surgery. No statistically significant differences were found between groups, suggesting that the type of anesthesia did not influence long-term muscle strength recovery.[6]

In studies evaluating nerve blocks, including brachial plexus block compared with general anesthesia, quality of recovery was assessed using the QoR-40 scale. No significant differences in global QoR-40 scores were observed on postoperative days 1 and 7 between groups, despite the fact that regional techniques demonstrated favorable analgesic effects. [7]

Publications addressing the surgical stress response emphasize that regional anesthesia may modulate neuroendocrine responses and reduce pain signaling by blocking nerve conduction, thereby decreasing sympathetic activation. Effective pain control and reduced opioid consumption are considered beneficial for postoperative recovery, although this does not always translate into a faster return to full physical activity.[4]

3.3 Intravenous vs. Inhalational Anesthesia Techniques

Studies comparing total intravenous anesthesia (TIVA) using propofol and remifentanil with inhalational anesthesia have analyzed parameters such as time to awakening, early quality of recovery, and the frequency of adverse effects.[8]

Some reports indicate that TIVA may offer advantages, including shorter emergence times, lower incidence of postoperative nausea and vomiting, and improved early recovery quality. Comparisons between different inhalational anesthetics (e.g., desflurane) and propofol-based techniques demonstrated differences in the speed of regaining consciousness and postoperative comfort. [9,10]

Researchers have noted that the pharmacokinetic and pharmacodynamic properties of anesthetic agents may influence early mobilization parameters. However, data regarding their impact on long-term return to physical activity remain inconclusive. [11]

3.4 Assessing Return to Activity After Anesthesia

The literature emphasizes the importance of standardized tools for assessing postoperative recovery quality. Scales such as the Functional Recovery Index and the Postoperative Quality of Recovery Scale evaluate mobility, cognitive function, physical comfort, and the ability to perform daily activities. [12,13]

Recovery quality is considered multidimensional, encompassing both physical and psychological aspects. In day-surgery settings, rapid restoration of functions enabling safe discharge and independence in basic activities is particularly important. These assessments serve as indirect indicators of readiness to gradually resume physical activity.[14,15]

3.5 Early Mobilization After Anesthesia

Studies investigating early mobilization in the postoperative unit have analyzed the effects of additional mobilization interventions compared with standard care. Findings suggest that immediate mobilization after surgery does not always lead to increased overall physical activity during the first postoperative days. [16]

This indicates that the return to physical activity after surgery is multifactorial and depends not only on the type of anesthesia but also on surgical factors, effective pain management, rehabilitation processes, and individual patient characteristics. [4]

3.6 Physiological Response to Anesthesia and Exercise Capacity

The reviewed publications highlight the importance of the body’s physiological response to anesthesia and surgery in relation to later exercise capacity. Surgical procedures activate the hypothalamic–pituitary–adrenal axis, increase catecholamine and cortisol levels, and induce metabolic changes leading to a hypercatabolic state. [17,18]

Anesthetic techniques may modulate this response by influencing nerve conduction and sympathetic nervous system activity. In discussions of anesthesia in athletes, authors note that

training-related adaptations such as changes in body composition, metabolism, and cardiovascular function may alter the effects of anesthetic agents and the course of postoperative recovery. [5]

Studies analyzing recovery quality indicate that early parameters such as hemodynamic stability, effective pain control, reduced adverse effects, and preserved cognitive function may influence the speed of regaining independence. However, the direct translation of these early benefits into long-term exercise capacity is not always clearly demonstrated. Full return to activity depends on the interaction of surgical factors, rehabilitation, and individual patient characteristics. [12,20]

4. Summary

The analysis of the reviewed publications indicates that the impact of anesthesia type on the return to physical activity is complex and influenced by multiple clinical factors, including the type of surgery, analgesic strategy, and the timing of outcome assessment.

In patients undergoing ACL reconstruction, no significant differences in muscle strength recovery were observed six months postoperatively between different anesthetic techniques, suggesting that anesthesia type did not determine long-term functional outcomes.

While regional anesthesia may effectively reduce postoperative pain and opioid consumption, it does not consistently improve global recovery scores compared with general anesthesia. Similarly, TIVA may provide advantages in early recovery parameters and adverse effect profiles, but its influence on long-term return to physical activity remains unclear.

Overall, although anesthesia type can influence selected early recovery parameters such as pain control, side-effect profile, and emergence quality its direct effect on long-term return to physical activity appears limited compared with other factors related to surgery and rehabilitation.

Disclosure

Author's contribution

Conceptualization: [MP], [KP]

Methodology: [DS], [MC], [KK]

Check: [EC], [AC], [JB]

Investigation: [JBa], [KP], [AB]

Data curation: [AC], [MP], [EC], [MC]

Writing - rough preparation: [KK], [JBa], [KP]

Writing - review and editing: [AB], [EC]

Visualization: [DS], [JB], [AC]

Project administration: [MP], [DS], [MC]

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Conflict Of Interest

The authors declare no conflict of interest.

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