

Review

Peri-Operative Nursing of Patients with Malignant Hyperthermia: A Narrative Literature Review

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Abstract

Background/Objectives: Malignant hyperthermia (MH) is an uncommon but potentially fatal pharmacogenetic syndrome triggered by specific anesthetic agents, including certain muscle relaxants and volatile anesthetics. The clinical presentation of MH varies widely, making timely recognition challenging but essential to patient survival. Perioperative nurses have a critical role in MH prevention, crisis recognition, and effective management. This review aimed to identify and summarize current evidence on the perioperative nursing management of MH, emphasizing preventive measures, staff education, and the adoption of innovative strategies to enhance patient outcomes. **Methods:** A narrative literature review was conducted by searching the PubMed–Medline, Scopus, and Web of Science databases. The methodological quality was ensured using the Scale for the Assessment of Narrative Review Articles (SANRA), and the review process adhered to the PICOS framework. For transparency, the protocol has been reported to the Open Science Framework (OSF). **Results:** Nineteen studies met the inclusion criteria and were analyzed. The key findings underscored the vital role of perioperative nurses in conducting thorough preoperative risk assessments to identify susceptible individuals. Simulation-based training emerged as highly beneficial, improving staff preparedness, crisis recognition, teamwork, and communication skills. The integration of cognitive aids, such as emergency checklists, and the use of activated charcoal filters to rapidly reduce anesthetic gas concentrations were also highlighted as effective management strategies. Nonetheless, significant gaps in MH

knowledge among nursing staff persist, indicating the need for ongoing education and training. **Conclusions:** Effective management of MH critically depends on comprehensive nurse-led assessments, regular simulation drills, and continuous staff education. The adoption of cognitive aids and activated charcoal filters further enhances crisis response capabilities. Future research should continue to explore innovative training methods and strategies to mitigate knowledge deficits among perioperative nursing teams.

Keywords: malignant hyperthermia; perioperative nursing; crisis management; narrative review

1. Introduction

Malignant hyperthermia (MH) is recognized worldwide as a rare but potentially fatal pharmacogenetic disorder triggered by certain anesthetic agents and muscle relaxants, representing a serious perioperative complication [1–5]. International guidelines, such as those from the World Health Organization (WHO) and the European Malignant Hyperthermia Group (EMHG), emphasize the need for early recognition, prompt treatment, and systematic perioperative protocols to improve patient safety and reduce morbidity and mortality related to MH [1,2]. Despite overall advances in anesthesia safety, MH remains a leading cause of anesthesia-related adverse events and fatalities where awareness or emergency preparedness is insufficient [3,4,6]. Although MH events are rare (estimated to be between 1 and 5000 worldwide, 1 and 100,000 anesthetics in adults and 1 and 30,000 in pediatric subjects), timely reporting and adherence to established perioperative protocols are crucial, as failure to recognize or manage these cases appropriately can lead to severe, potentially fatal outcomes [1–7]. Recent reviews highlight the importance of systematic susceptibility screening, rapid intervention, and ongoing education to mitigate the risk of catastrophic outcomes [6,7]. In addition, MH is considered one of the best models for team-based perioperative crisis management [7]. Triggers of malignant hyperthermia primarily include volatile anesthetics such as halothane, sevoflurane, and desflurane, along with the depolarizing neuromuscular blocking agent succinylcholine [8–10]. The precise mechanisms underlying these drug-induced reactions remain incompletely understood, although defective regulation of calcium ions within the sarcoplasmic reticulum of muscle cells has been widely implicated [11]. Specifically, these triggering agents induce excessive and uncontrolled calcium release, leading to prolonged muscle contraction and subsequent hypermetabolic responses. Furthermore, emerging evidence has recognized that environmental stressors, notably extreme physical exertion or heat stress, can provoke MH-like reactions, complicating clinical presentations and diagnostic accuracy [12]. Notably, recent studies have also identified associations between exertional rhabdomyolysis and underlying MH susceptibility, suggesting that certain individuals may be genetically predisposed even in the absence of anesthetic exposure [13]. Recognition of these diverse triggers is essential for preventing severe MH episodes, particularly in susceptible individuals. Epidemiologically, malignant hyperthermia presents a complex profile, varying significantly across geographical regions and ethnic populations [14,15]. Consistent epidemiological patterns indicate higher susceptibility among populations of Northern European descent, highlighting notable genetic predisposition within specific ethnic backgrounds [16]. Extensive genealogical studies have underscored the familial nature of MH susceptibility, typically transmitted through an autosomal-dominant inheritance pattern, emphasizing the importance of detailed family histories in identifying at-risk patients [17]. While the genetic prevalence of abnormalities associated with MH susceptibility may be as high as 1 in 400 individuals, the exact prevalence of Ryanodine Receptor 1 (RYR1) mutations in

the general population remains unknown. Importantly, only about 50–86% of individuals with MH susceptibility are linked to RYR1 gene mutations, depending on the population, as highlighted by Galli et al. [18]. It should be evidence that RYR1 is not the only genetic factor involved in MH susceptibility; other genes, such as Calcium Voltage-Gated Channel Subunit Alpha 1 S (CACNA1S), can also contribute, highlighting the complex and polygenic nature of this condition according Beebe et al., (2020) [19]. Genetic testing for MH susceptibility is highly informative and recommended; however, in resource-limited settings, such testing may not be practical, underscoring the need for clinical vigilance and careful perioperative management [1–7,18,19]. Importantly, advances in next-generation sequencing have facilitated the identification of rare genetic variants involved in MH, increasing the accuracy of genetic counseling [14]. The intricate pathophysiological mechanisms underlying malignant hyperthermia involve a sequence of metabolic derangements initiated upon exposure to triggering agents. This exposure results in excessive calcium ion release within skeletal muscle cells, driven by dysfunctional ryanodine receptor channels on the sarcoplasmic reticulum, precipitating sustained muscular contraction [20]. Consequently, the hypermetabolic state triggers substantial increases in oxygen consumption, carbon dioxide production, metabolic acidosis, hyperthermia, and muscle breakdown, leading to elevated circulating myoglobin and creatine kinase levels, potentially precipitating severe complications, including renal failure [21]. Recent reviews also stress the importance of the perioperative monitoring of end-tidal CO₂ and temperature as early warning signs to prevent catastrophic outcomes [22]. Rapid identification and intervention remain essential, with a comprehensive understanding of these metabolic disturbances that are critical for effective anesthetic emergency management. Malignant hyperthermia typically presents during or soon after exposure to triggering anesthetics, though delayed cases have also been observed. The clinical picture is often marked by profound hyperthermia, severe muscle rigidity, tachycardia, metabolic acidosis, elevated carbon dioxide levels, and significantly increased serum creatine kinase concentrations [23]. Without timely diagnosis and intervention, these symptoms can quickly escalate to cardiovascular collapse and cardiac arrest [24]. The severity and onset of symptoms vary widely between individuals, depending on factors such as age and the specific exposure, highlighting the need for continuous vigilance and targeted education about MH susceptibility [23]. MH may present in three main forms: fulminant, moderate, or whiplash/abortive. The fulminant form is characterized by marked metabolic hyper-stimulation, acidosis, hyperthermia, generalized muscle rigidity, and a substantial rise in muscle enzyme levels. In the moderate form, metabolic stimulation is less severe and the clinical course often improves after discontinuing the triggering drugs or administering Dantrolene, a treatment that has reduced mortality from approximately 80% to 10% in recent decades [25]. MH, although rare and life-threatening like rabies, differs in that structured emergency protocols, team-based simulations, and immediate access to Dantrolene are essential, though the drug's limited shelf-life may pose logistical challenges [25]. The whiplash or abortive form is mainly distinguished by masseter muscle spasm, with or without other accompanying symptoms. Although not all patients experiencing masseter muscle spasm will develop MH, this symptom—particularly following succinylcholine administration—can serve as an early warning sign, emphasizing the importance of careful monitoring and rapid intervention according several studies [26,27]. Diagnosis is currently confirmed postoperatively by *in vitro* contracture tests on muscle tissue samples exposed to halothane and caffeine. At present, there is no validated hematochemical test to determine susceptibility to MH; however, elevated preoperative Creatine Phosphokinase (CPK) levels may indicate the need for further investigation [28]. Of note is that emerging *in vitro* diagnostic platforms and genetic screening strategies are under investigation and may further refine diagnostic protocols in the near future [14].

Authoritative educational resources continue to provide updated clinical guidelines and support for perioperative teams in identifying and managing MH susceptibility [29]. In this context, the advancement of nursing competencies—encompassing both clinical practice and educational domains—emerges as a pivotal area for development, calling for strategic investment and scholarly attention from the scientific community [30].

The primary objective of this review was to identify and critically analyze the main barriers and knowledge gaps impacting the perioperative nursing management of MH, with particular focus on staff training, emergency preparedness, and the implementation of evidence-based protocols. The secondary objective was to explore illustrative practices and experiences from different countries and clinical contexts, and to propose future research directions aimed at strengthening the global development of effective prevention and management strategies for perioperative care teams.

2. Materials and Methods

2.1. Study Design

This study employs a narrative review methodology, conducted according to the Scale for the Assessment of Narrative Review Articles (SANRA) to ensure methodological rigor and qualitative support (Supplementary File S1: SANRA Check List) [31]. For transparency the protocol has been reported to Open Science Framework (OSF): <https://doi.org/10.17605/OSF.IO/QYDBN>.

2.2. Research Question Definition

The review was guided by the following research questions:

- What are the main barriers and knowledge gaps in perioperative nursing management of MH?
- What international practices can guide future improvements in MH prevention and management by perioperative teams?

This research was developed using the PICOS framework [32] and narrative method already established in previous studies [33,34], to ensure a structured and scientifically valid approach to the identified topic was performed in line with specific recommendations [35].

2.3. Key

P (Population): Surgical patients at risk of or affected by MH;

I (Intervention): Perioperative nursing management, prevention, and education strategies;

C (Comparison): Absence of or variation in these interventions;

O (Outcome): Effectiveness of interventions and educational strategies, team preparedness, patient safety, and crisis outcomes

S (Study type): primary or secondary studies published in English.

2.4. Inclusion Criteria and Screening

Studies were included if they addressed perioperative nursing, prevention, education, or management of MH in surgical settings. Primary or secondary studies (e.g., case reports, descriptive studies, literature reviews) published in English were included, provided they were coherent with the predefined PICOS framework. This approach allowed us to capture a broad range of evidence while maintaining methodological consistency with the review objectives. The screening process was conducted in two phases: an initial blinded review of titles and abstracts performed independently by two reviewers (F.S. and G.C.), followed by full-text screening for eligibility. In cases of disagreement, a third reviewer (M.P.) was consulted to achieve consensus. Bibliographic management was conducted using free

version EndNote 20 (©2024 Clarivate, London, UK). The detailed search strategy and Boolean operators used are reported in Supplementary File S2.

2.5. Information Sources and Search Strategy

A comprehensive search was conducted in PubMed, Scopus, and Web of Science databases for studies published in English without temporal limits. The search strategy followed the PICOS structure update to January 2025. and incorporated both free and MeSH terms relating to MH, perioperative nursing, and management strategies. Additional studies were identified by screening references of relevant articles and other source.

2.6. Data Extraction and Synthesis

Data extraction was performed independently by two reviewers (F.S. and G.C.) using a standardized electronic spreadsheet. Extracted data included bibliographic details, study design, characteristics of the population, objectives, and main outcomes. Given the heterogeneity of study designs and reported outcomes, a narrative synthesis was adopted according to SWiM (Synthesis Without Meta-analysis) recommendations [36]. This process involved categorizing the studies by key characteristics (e.g., author, year, country, intervention, and primary findings) and integrating results to provide a comprehensive overview of the literature. The synthesis highlighted common themes, research gaps, and unique aspects of each included study.

3. Results

From the search, 560 records were identified. After excluding duplicates, 140 articles were screened based on title and abstract, and 54 articles were assessed for eligibility. Of these, 35 were excluded after full text reading; 19 studies [37–55] included in the final analysis (Prisma Flow chart selection Figure 1). The selected articles were coded and analyzed using NVivo software (<https://lumivero.com/products/nvivo/> accessed on 1 September 2025). The main study characteristics are summarized in Table 1 which synthesis the specific elements for each study as First Author/Year, Type of Study, Country, Population, Outcomes/Key Points, Main Results. Narrative discussion of the studies included was performed as support.

Table 1. Descriptive Characteristics of Studies.

Publications Year	Frequency (<i>n</i> = 19)	Percentage (%)
2022	1	5.3
2020	3	15.8
2019	3	15.8
2017	1	5.3
2016	2	10.5
2015	1	5.3
2014	2	10.5
2013	1	5.3
2012	1	5.3
2011	1	5.3
2007	1	5.3
2006	1	5.3
Country		
USA	14	73.7
Others	5	26.3
Type of Study		
Case Report	10	52.6

Table 1. Cont.

Publications Year	Frequency (n = 19)	Percentage (%)
Simulation	4	21.0
Literature Review	2	10.5
Instrumental Test	2	10.5
Guidelines	1	5.3

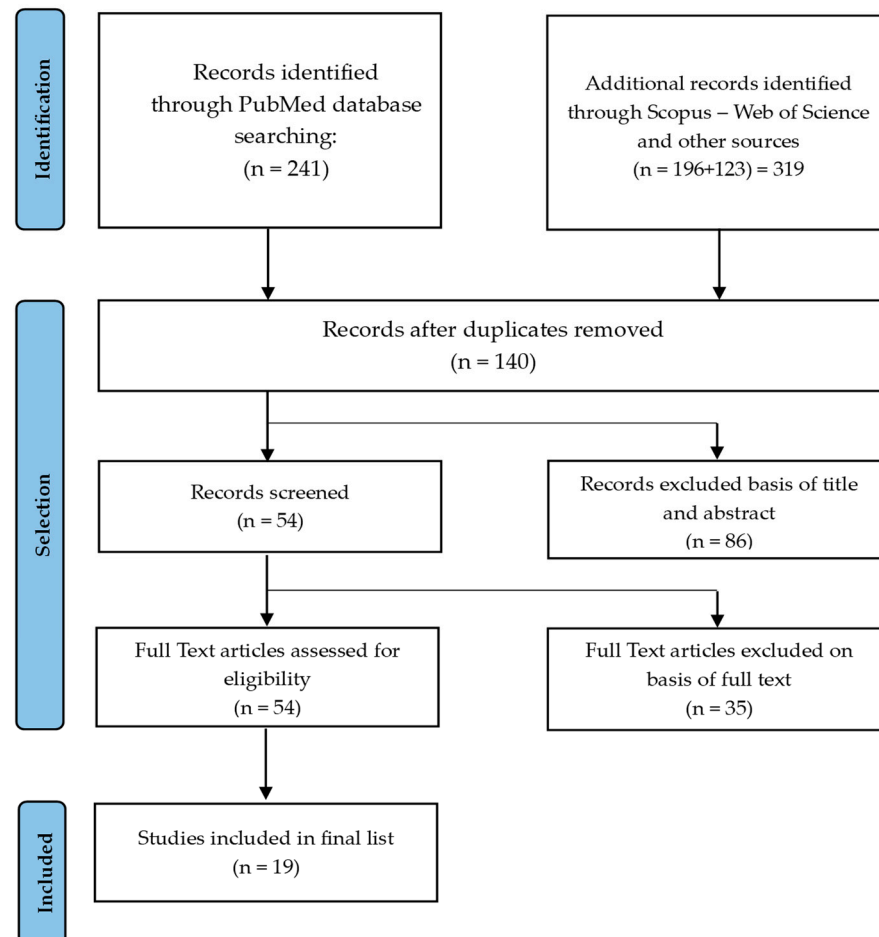


Figure 1. Prisma flow chart.

3.1. Characteristics and Emerging Themes of Included Studies

Nineteen studies published were included [37–55] (Summary in Tables 1 and 2). Over half were case reports on MH crises and management [38,39,41,42,44,46,50–52,54,55]. Simulation-based or quality improvement studies accounted for 21%, focusing on team training and preparedness [37,43,45,46]. Two studies assessed technical measures for MH prevention [40,53], and two were literature reviews on informatics and risk models [47,48]. One guideline paper addressed staff education and institutional policies [44]. Target populations included perioperative staff, nurses, and patients with MH [37–39,41–46,49,50,52,54]. Most studies evaluated improvements in knowledge, teamwork, and response to MH emergencies following training or protocol implementation [37,43,45,46]. The findings consistently highlight the importance of simulation, cognitive aids, multidisciplinary collaboration, and structured protocols in MH crisis management [37–55].

Table 2. Summary of Included Studies.

First Author/Year	Type of Study	Country	Sample	Outcomes/Key Points	Main Results
Gallegos et al. [33], 2022	Evidence-Based Practice Project	USA	13 perioperative staff	Use of Stanford Emergency Manual in MH crisis	Cognitive aid checklists improved staff performance and reduced omission of critical treatment steps in simulation.
An et al. [34], 2020	Case Report	China	3 patients with MH during surgery	Application of MHCCGS scoring for diagnosis and management	Multidisciplinary approach, prompt recognition, risk assessment, and timely intervention led to successful rescue.
Ebbitt et al. [35], 2020	Case Report	USA	22-year-old male	Importance of multidisciplinary protocols and MH trolleys	Preoperative assessment and protocol adherence enabled prompt recognition and effective treatment, preventing complications.
Müller-Wirtz et al. [36], 2020	Instrumental Test	Germany	Not specified	MH prevention via anesthesia equipment protocols	10 min circuit flush at ≥ 10 L/min ensures safety in elective cases; activated charcoal filters for emergencies.
Soenarto et al. [37], 2019	Case Report	Indonesia	16-year-old female	Regular perioperative MH crisis simulation	Team-wide MH knowledge, written protocols, and simulation are fundamental for preparedness and safety.
Lewellen [38], 2019	Case Report	USA	Endoscopy staff	Preparation and institutional MH policies	Hospital-wide MH preparedness includes ongoing education, annual updates, MH point persons, and regular drills.
Shawn et al. [39], 2019	Quality Improvement Project	USA	16 nurses	MH simulation training for knowledge and self-confidence	Simulation improved knowledge and technical/non-technical skills required to manage MH crisis efficiently.
Normandin et al. [40], 2019	Guidelines	USA	1 emergency room case	Training in MH recognition and response for staff and administrators	Emphasizes avoidance of succinylcholine, regular MH drills, alert bracelets, adherence to guidelines.
Schaad [41], 2017	Simulation-Based Training	USA	OR and ICU staff	Annual simulation-based training on MH for staff competency	Simulation-based training enhances team performance, safety, and communication.
Bashaw [42], 2016	Case Report	USA	9 nursing students	Teamwork and simulation in management of MH	Simulation allows safe practice of critical scenarios, improving performance and teamwork.

Table 2. Cont.

First Author/Year	Type of Study	Country	Sample	Outcomes/Key Points	Main Results
Denholm [43], 2016	Literature Review	USA	Not specified	Role of nursing informatics and data management in MH	IT supports clinical decision-making; collaboration among nurses, managers, and informatics specialists enhances preparedness.
Denholm [44], 2015	Literature Review	USA	Not specified	Use of vulnerability models to assess MH risk in populations	Strategies for prevention: temperature monitoring, dantrolene, education. Advanced nurses reduce patient vulnerability.
Sousa et al. [45], 2014	Descriptive Exploratory Study	Spain	96 nurses	Assessment of nurses' knowledge regarding MH	Nurses scored > 80% on basic MH knowledge, but showed deficits (14.3–42.9%) in diagnosis/treatment competencies.
Seifert et al. [46], 2014	Case Report	USA	16-year-old male	Team training and simulation in MH emergency management	Simulation and checklists on anesthesia machines are essential for emergency preparedness.
Hirshey Dirksen et al. [47], 2013	Case Report	USA	25-year-old male	Development of assessment tools for MH risk	Regular mock drills and team preparation are essential to improve emergency response.
Hutton [48], 2012	Case Report	USA	49-year-old male	Management of perioperative emergencies and team roles	Early recognition, protocol implementation, and specific team role assignments are crucial for optimal outcomes.
Birgenheier et al. [49], 2011	Instrumental Test	USA	Not specified	Efficacy of activated charcoal filters for MH prevention	Charcoal filters reduce anesthetic concentrations < 5 ppm within 2 min, maintain safe levels for at least 60 min.
Noble [50], 2007	Case Report	USA	21-year-old male	Emphasis on preparation and education in MH management	Prognosis improved through perioperative teamwork; education and preparation are key.
Neacsu [51], 2006	Case Report	USA	Not specified	Management, nursing care, and screening for MH susceptibility	Structured nursing models and enhanced communication improve pre- and post-operative care and patient outcomes.

Legend. MH: malignant hyperthermia; MHCGS: Malignant Hyperthermia Clinical Grading Scale; OR: operating room; ICU: intensive care unit; IT: information technology.

From the review of these studies, several major themes emerged, which will be discussed in the following sections: the nurse's role in prevention, preoperative assessment, staff training, alternative approaches to prevention, and the use of activated carbon filters.

3.2. The Nurse's Role in Prevention

A case report by An et al. [38] described how early recognition by nurses and coordinated team intervention led to favorable outcomes in three adolescents with scoliosis. Similarly, Denholm's study [48] emphasized that preparedness, ongoing training, and educational activities among emergency nurses are essential for reducing patient vulnerability to MH and promoting evidence-based practice. The importance of education is further reinforced by Noble [54], who identified preparation and training as critical elements in the effective management of this potentially fatal genetic disorder. Hutton's study [52] showed that prompt recognition of clinical signs and the allocation of specific roles to nursing staff (preparation and administration of dantrolene and other drugs; patient cooling management) can maximize the efficiency of emergency response. There is consensus in the literature regarding the value of team-based training, as highlighted by Seifert et al. [50], who stresses the need for simulation and training to ensure optimal emergency responses during MH crises. Conversely, the study by Silva Sousa et al. [49] reveals the insufficient knowledge of MH among nurses, underscoring the need for targeted educational interventions.

3.3. Preoperative Assessment

Neacsu's study [55] emphasized the importance of nurses recognizing such factors during patient history-taking, with attention to both personal and family history of anesthesia-related issues or neuromuscular disorders. This is reinforced by the case report of Ebbitt et al. [39], which highlights the need to investigate prior surgical events in both patients and relatives. **Normandin** and Benotti study [44] further recommend avoiding the use of succinylcholine when there is a known or suspected family history of anesthesia complications, exercise- or heat-induced rhabdomyolysis, or musculoskeletal disorders.

3.4. Staff Training

Simulation-based training emerged as a key strategy for enhancing patient safety and staff competence. Schaad's study [45] demonstrated that simulation exercises are effective, well-received, and improve both performance and team communication. Hirshey et al. [51] advocate for regular practice drills to reduce errors in MH management, while Soenarto et al. [41] suggest the routine inclusion of MH crisis simulations in perioperative training. Lewellen's study [42] notes that, although rare, MH requires prompt recognition and treatment, making ongoing staff education critical. The benefits of simulation are further supported by Shawna et al. [43], who found that simulation-based training increased nurses' knowledge and confidence in crisis management. Bashaw et al. [46] also shows that simulation offers a safe environment for learners to assess and improve their skills, proving valuable for both practitioners and students.

3.5. Alternative Approaches to Prevention

Gallegos and Hennen [37] evaluated the impact of introducing the Stanford Emergency Manual Cognitive Aid in a military ambulatory surgical center. Simulation exercises showed that the use of cognitive aids improved staff perceptions and preparedness during MH crises. Similarly, Denholm's study [47] demonstrated that the integration of information technology in perioperative settings supports data collection, interpretation, and clinical decision-making, enabling improved care continuity and outcomes for MH-susceptible patients. Nurses played a pivotal role in promoting informatics-based interventions and facilitating patient management.

3.6. Activated Carbon Filters

Müller-Wirtz et al. [40] established that, in elective cases, a 10 min flush at ≥ 10 L/min with replacement of airway components achieves safe anesthetic concentrations. In emergencies, activated charcoal filters rapidly decrease volatile anesthetic concentrations. Birgenheier et al. [53] confirmed that these filters reduce anesthetic gas levels to below 5 ppm within two minutes, maintaining safe values for at least 60 min.

4. Discussion

Susceptibility to MH cannot be reliably predicted based solely on clinical presentation, making objective diagnostic investigations essential for identifying at-risk individuals [56]. While predisposing factors may sometimes be detected through careful patient history or physical examination, definitive diagnosis requires instrumental testing such as the caffeine–halothane contracture test (CHCT) or genetic analysis [57,58]. The introduction of next-generation sequencing (NGS) has markedly improved the ability to detect mutations in RYR1 and CACNA1S genes, enabling earlier identification of susceptible individuals and their families [59,60]. However, international guidelines emphasize that a negative genetic result does not entirely exclude the risk of MH, thus the CHCT remains essential in many cases [58]. MH is a rare but potentially fatal hypermetabolic syndrome triggered in genetically predisposed patients by volatile anesthetics or succinylcholine [61]. Prompt intervention is fundamental to reduce morbidity and mortality, highlighting the importance of comprehensive preparation, simulation-based training, and effective organizational protocols among perioperative teams [37,43]. Over the last decades, the implementation of standardized education programs and robust crisis frameworks has led to a significant decline in the incidence and severity of MH worldwide [43,45]. National and international guidelines—such as those from EMHG—stress the need for all perioperative professionals to be ready to rapidly recognize and manage MH, considering that preoperative identification is not always feasible [2,62]. Operating room preparedness is crucial. Essential actions include flushing anesthesia machines to remove residual volatile agents, ensuring immediate access to dantrolene, and having supportive medications and devices ready [63,64]. The literature demonstrates that delays in dantrolene administration, even as short as 10 min—increase complication rates, with such delays associated with longer ICU stays and increased costs [65,66]. The average cost per MH event can exceed \$75,000, highlighting the impact of timely response on both clinical and economic outcomes [67–69]. Nurses play a central role in MH prevention, early recognition, and multidisciplinary management [37,38,70]. Preparedness and ongoing training—particularly via simulation and crisis drills—are critical for reducing patient vulnerability and optimizing emergency response [43,45,70]. Evidence demonstrates that simulation-based team training enhances role clarity (e.g., rapid administration of dantrolene, patient cooling), strengthens communication, and improves outcomes in both simulated and real-life MH crises and clinical practice review [30,43,45,71]. Nevertheless, gaps in knowledge about MH among perioperative nurses persist, underlining the need for targeted education and routine assessment [49,72]. The preoperative assessment remains pivotal for risk identification and perioperative planning. Detailed history-taking—addressing personal and family history of anesthesia-related complications, rhabdomyolysis, or neuromuscular disorders—remains essential [38,57,73]. When relevant risk factors are present, international guidelines recommend avoidance of succinylcholine and the adoption of specific perioperative protocols [56,58]. Simulation-based training has become a foundation for maintaining preparedness and clinical competence among all perioperative staff in nursing and medical review [43,45,74,75]. Regular multidisciplinary simulation drills improve technical performance, crisis resource management, and team confidence, and provide a safe

and effective approach to rehearsing rare but critical events such as MH [43,62,76,77]. Preventive strategies have expanded to include cognitive aids (e.g., emergency manuals, digital checklists) and the use of information technology in perioperative workflows, supporting decision-making and improving care continuity for MH-susceptible patients [37,47,78]. The implementation of such cognitive and digital aids has been associated with improved preparedness and faster, more coordinated responses during MH emergencies [47]. Activated charcoal filters are increasingly recognized as a valuable preventive measure. Studies confirm that a 10 min flush of the anesthesia machine at high flow—combined with these filters—can rapidly reduce volatile anesthetic concentrations to safe levels [40,53,79]. Most international guidelines recommend their use during MH crises to ensure rapid decontamination, but there is still variability: some national guidelines do not yet include these measures in the acute phase [59,80]. From a genetic standpoint, MH is most commonly inherited as an autosomal-dominant disorder associated with RYR1 mutations (~80%) and less frequently with CACNA1S or other loci [57,61,81]. Variable penetrance and complex genotype–phenotype relationships add to the clinical heterogeneity and unpredictability of MH events [57,69,81]. The economic burden of MH is considerable: events often require prolonged ICU care, mechanical ventilation, and renal support, further underscoring the value of early recognition, prevention, and optimal multidisciplinary team training [64,65,82,83]. Targeted investment in simulation training, guideline adherence, and system-level preparedness is therefore justified both by improved patient safety and by cost-effectiveness. In conclusion, optimal management of malignant hyperthermia syndrome depends on comprehensive preparedness, early recognition, and immediate intervention. Strategic planning, robust crisis protocols, routine simulation-based training, targeted nursing education, and strict adherence to international guidelines together form the foundation for minimizing MH-associated risks [37,43,58,84–88]. Such a structured and multidisciplinary approach is essential for maximizing patient safety and clinical outcomes in modern anesthetic practice.

4.1. Perspectives for Clinical Practice

The data findings (Summarized in Figure 2) of this review highlight significant scientific and professional implications, particularly concerning the early identification of MH, and the training of professionals involved in the complex process of care and prevention review. While interventions such as simulation-based training and the use of cognitive aids have shown effectiveness, robust evidence regarding their long-term impact and economic sustainability across different healthcare systems and care settings is still lacking. In this context, perioperative nursing care plays a crucial role in ensuring team readiness and safety during perioperative emergencies, as well as throughout all phases of the operative care process [89–91]. Continuous education and regular multidisciplinary simulations are essential tools for maintaining high levels of knowledge and preparedness among nurses—not only in the management of MH but across all care settings more broadly. Moreover, the integration and routine use of digital technologies and informatics tools in clinical practice can support nurses and all stakeholders involved in health management in making informed decisions, thus enhancing the quality and safety of patient care [92–94]. The adoption of emerging technologies such as artificial intelligence (AI) and technology in general, consolidate in clinical practice review [95–100], may further enhance team performance and safety, particularly in sensitive areas like the perioperative environment. Ongoing collaboration among clinicians, educators, and policymakers is strongly recommended to ensure the continuous updating and widespread dissemination of emergency protocols and innovative training methods.



Figure 2. Perspectives for Clinical Practice, and Policy in the Perioperative Management of MH.

4.2. Strengths and Limitations

This narrative review was conducted with methodological rigor, adhering to the SANRA method for qualitative assessment of data finding [31] and the PICOS framework [32]. The comprehensive literature search across major databases and the independent screening by multiple reviewers ensured the inclusion of relevant studies and minimized selection bias. The review provides a structured synthesis of current evidence, with particular attention to practical interventions such as simulation-based training and cognitive aids, supporting applicability to clinical practice. Despite everything, clear limitations must be taken into account. The main limitations include the narrative design, which may be prone to subjective interpretation and does not allow for quantitative synthesis. The inclusion of studies published only in English may introduce language and publication bias. Most included studies were case reports or descriptive in nature, with small sample sizes and limited generalizability. Furthermore, only a minority explicitly adopted simulation-based approaches, which further underlines the need for additional, more robust investigations in this field. Additionally, the predominance of research from the USA may restrict evident applicability to other contexts. The exclusion of gray literature and the heterogeneity of interventions further limit the strength of conclusions. Future studies employing more robust methodologies and larger, diverse populations are warranted to strengthen the evidence base.

5. Conclusions

Perioperative nurses emerge as central actors in MH management, responsible not only for risk assessment but also for maintaining readiness through continuous education and multidisciplinary simulation training. The integration of digital technologies

and informatics tools holds promise for supporting clinical decision-making and fostering more coordinated emergency responses. Moreover, emerging innovations such as AI could further optimize team performance and patient outcomes in this high-stakes environment. However, the sustainability and long-term impact of these interventions remain underexplored, warranting further rigorous research across diverse healthcare settings. Strengthening collaboration among clinical staff, educators, and policymakers will be crucial to standardizing training programs, disseminating updated protocols effectively, and ultimately improving perioperative safety for MH-susceptible patients.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/surgeries6030078/s1>: File S1: SANRA Check List; File S2: Search Strategy.

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