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Editor: Prof. Dr. Eray YURTSEVEN

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ACADEMIC STUDIES AND NEW VISIONS IN HEALTH SCIENCES

Editor

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853 Sokak No:13 P.10 Kemeraltı-Konak/İzmir
Tel: 0 232 484 88 68
www.duvaryayinlari.com
duvarkitabevi@gmail.com

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Chapter 1

Minimally Invasive Restorative Techniques

İrem KAYA[1]

Minimally invasive dentistry is a conservative approach aimed at managing dental diseases, particularly caries, with the least possible removal of tooth structure (Tyas et al., 2000). The primary objective of this concept is to preserve as much sound dental tissue as possible while controlling carious lesions through minimal intervention. Advances in adhesive materials, technological developments, and the increasing emphasis on preventive strategies have contributed to the growing importance of minimally invasive dentistry. Within this framework, unnecessary removal of enamel and dentin is avoided, and demineralized areas are managed by promoting remineralization to maintain the integrity of tooth structure (Dönertaş, 2022).

The concept of minimally invasive dentistry is based on five fundamental principles: promoting remineralization of early lesions, reducing cariogenic bacterial activity and controlling demineralization, treating cavitated lesions with minimal loss of tooth structure, repairing or replacing defective restorations when necessary, and preventing the development of new lesions (Tyas et al., 2000).

Early detection and accurate assessment of caries are essential components of this approach. Proper diagnosis at an early stage allows clinicians to prevent unnecessary removal of healthy tissue and to select the most appropriate treatment strategy (Tyas et al., 2000). Subsequently, management includes controlling the disease process at a micro level and restoring irreversible damage where present (Dönertaş, 2022). Compared with conventional restorative approaches, minimally invasive techniques are less aggressive and are generally better accepted by patients (Tyas et al., 2000).

Assessment of Caries Risk and Identification of Early Lesions

Radiographic examination remains one of the most commonly used methods for detecting carious lesions, particularly on approximal surfaces; however, its diagnostic accuracy is limited for occlusal surfaces and early-stage lesions confined to enamel or superficial dentin (Angnes et al., 2005; Ricketts et al.,

[1] Sinop Ağız Diş Sağlığı Merkezi
Orcıd no :0000-0003-4125-1888

1995). In contrast, fibre-optic transillumination (FOTI) has demonstrated high reliability in identifying approximal caries, especially in anterior teeth (Davies et al., 2001).

Fluorescence-based technologies, including laser fluorescence and quantitative light-induced fluorescence (QLF), may exhibit reduced specificity, as they are sensitive not only to carious tissues but also to other organic materials such as plaque, calculus, and stains (Hamilton et al., 2006; Neves et al., 2011). Moreover, recently introduced diagnostic approaches—such as light-based fluorescence systems, electrical impedance, and photothermal radiometry—have shown potential; nevertheless, their routine clinical use remains limited due to insufficient supporting evidence (Hamilton et al., 2006)(Neves et al., 2011).

Overall, radiography and FOTI appear to be more reliable for detecting approximal caries, whereas no single diagnostic method has demonstrated adequate accuracy for occlusal surfaces, particularly in pits and fissures, emphasizing the need for a combined diagnostic strategy (Diniz et al., 2012) A similar limitation has been reported in the primary dentition, where newer technology-based systems have not consistently demonstrated reliable performance for approximal caries detection (Chawla et al., 2012).

In addition to these methods, visual–tactile examination remains an essential component of caries detection. Several indices have been developed to support caries assessment, including the International Caries Detection and Assessment System (ICDAS), the Nyvad index, the PUFA index, and the CAST index (Pitts, 2004)(de Souza et al., 2012; Pitts, 2004). ICDAS and the Nyvad index are more frequently applied in clinical practice, while PUFA and CAST provide a broader assessment of disease severity. However, the clinical applicability of these indices is still limited by the lack of sufficient long-term evidence and standardization (de Amorim et al., 2012).

Although the DMF index is widely used for screening cavitated dentin lesions, contemporary approaches emphasize the importance of also detecting early enamel lesions in both clinical and epidemiological settings.

Assessment and Prediction of Caries Risk

Dental caries is a dynamic and multifactorial disease process. Caries risk refers to the likelihood of future disease development, encompassing both the formation of new lesions and the progression or reactivation of existing ones. Because this process is influenced by factors that may change over time, risk assessment is inherently complex and generally reflects only the patient’s status at a specific point. In clinical practice, the most reliable approach for evaluating lesion activity involves the combined use of indicators such as visual appearance, lesion location, tactile feedback, and gingival condition. However, current activity criteria are limited in their ability to quantify lesion progression in terms of size or depth.

Despite these limitations, caries risk assessment remains a fundamental component of contemporary clinical decision-making and serves as the basis for individualized oral health management strategies. Substantial evidence indicates that past and current caries experience particularly the presence of active lesions continues to be the most reliable predictor of future caries development (Demers et al., 1990). Nevertheless, this observation provides limited guidance for preventive strategies aimed at avoiding the initial onset of disease. Furthermore, caries risk is not static; it may decrease following the control of risk factors or increase rapidly under certain conditions, such as medication-induced reductions in salivary flow.

Caries risk prediction is still evolving, and although the available evidence is not definitive, it is widely accepted that performing a structured risk assessment is preferable to omitting it altogether (Twetman & Fontana, 2009). The outcome of this evaluation should be documented and incorporated into treatment planning. Tools such as the Cariogram have been developed to support this process by visually illustrating caries risk and the interaction between contributing factors, thereby enhancing patient understanding and motivation (Bratthall & Hänsel Petersson, 2005)

Management of Enamel and Dentin Carious Lesions Through Remineralization

Dental caries is recognized as a multifactorial biological process in which enamel undergoes ongoing cycles of demineralization and remineralization (Kidd and Fejerskov, 2004; Loesche, 1979).In the early stages, microorganisms such as *Streptococcus mutans* and *Streptococcus sobrinus* are considered key contributors to enamel demineralization, while *Lactobacillus* species become more prominent as lesion progression occurs (Loesche, 1979). This concept has traditionally been described by the "specific plaque hypothesis."

However, more recent perspectives support an ecological approach, suggesting that caries development is associated with shifts in the overall biofilm composition rather than the action of a limited number of bacterial species . In this context, the balance of the microbial community is influenced by dietary habits and the acidogenic and aciduric characteristics of oral microorganisms, which together promote conditions favorable for demineralization (Haukioja et al., 2008; Modesto et al., 2006).

Frequent consumption of fermentable carbohydrates, particularly sucrose, promotes the proliferation of cariogenic bacteria and alters the biofilm environment. These changes increase acid production and enhance mineral loss from enamel, thereby elevating the risk of caries development (Fejerskov, 2004).

Importantly, dental caries should be considered a dynamic and ongoing process rather than a static condition (E. Kidd, 2011). Enamel is continuously subjected to cycles of mineral loss and gain, and clinically detectable lesions develop only when demineralization predominates over time. The overall progression of this process is affected by several factors, such as the composition of dental plaque, how often sugars are consumed, exposure to fluoride, the rate and properties of saliva, the characteristics of enamel, and various host-related conditions (Aoba & Fejerskov, 2002).

Fluoride, Calcium–Phosphate, Xylitol, ReminPro ,Acidulated Phosphate Fluoride (APF)

Fluoride plays a critical role in the demineralization–remineralization cycle by incorporating into the enamel structure and modifying carbonated hydroxyapatite crystals, leading to the formation of fluorapatite. This transformation reduces crystal solubility and enhances mineral precipitation in the presence of calcium and phosphate, thereby promoting remineralization (ten Cate, 1999). Fluoride decreases enamel solubility both by occupying a more stable position within the crystal lattice and through its strong interactions with calcium ions .

Table 1. Topical and Systemic Fluoride Applications

Topical Fluoride Delivery	Systemic Fluoride Delivery
Fluoride-containing solutions, gels, or foams	Community water fluoridation
Fluoridated dentifrices (toothpastes)	Fluoridated salt programs
Fluoride mouthrinses	Fluoridated milk programs
Fluoride varnish applications	Oral fluoride supplements (tablets)
Sustained/controlled-release fluoride systems	Fluoridation of school drinking water

The penetration of fluoride into the biofilm depends on the type of fluoridated product used and the duration of exposure. Short-term applications tend to exert effects primarily at the surface level, whereas prolonged exposure allows deeper diffusion into the biofilm (Watson et al., 2005). However, extended application times are not always clinically feasible. Therefore, high-concentration fluoride varnishes are considered a more effective alternative in clinical practice (Marinho, 2008).

Table 2. Recommended Fluoride Supplement Dosage According to Age and Fluoride Concentration in Drinking Water

Age Group	< 0.3 ppm	0.3–0.6 ppm	> 0.6 ppm
Birth – 6 months	0 mg	0 mg	0 mg
6 months – 3 years	0.25 mg	0 mg	0 mg
3 – 6 years	0.5 mg	0.25 mg	0 mg
6 – 16 years	1 mg	0.5 mg	0 mg

The ability of fluoride to support remineralization depends largely on the presence of calcium and phosphate ions in the local environment. During intense acid challenges, rapid depletion of these ions may result in net mineral loss (Featherstone, 2003). The primary sources of calcium and phosphate are saliva and dissolved tooth minerals; however, these sources may not always be sufficient. Consequently, the external supply of bioavailable calcium and phosphate can further enhance the remineralization process (Reynolds, 2008).

Within this framework, casein phosphopeptide–amorphous calcium phosphate (CPP–ACP) complexes have attracted increasing interest. These complexes stabilize calcium and phosphate ions, maintaining high local concentrations at the tooth surface and within dental plaque, thereby inhibiting demineralization and facilitating remineralization (Cochrane et al., 2008; Reynolds et al., 2008; Reynolds & del Rio, 1984).

From a preventive perspective, maintaining a state of supersaturation of calcium, phosphate, and fluoride ions at the tooth surface is essential for controlling caries development. Since dental caries is largely preventable, early intervention before the onset of clinical symptoms is the most effective strategy. Regular toothbrushing with fluoride-containing toothpaste contributes significantly to plaque control and reduces the risk of caries formation . Even in cavitated dentin lesions, effective plaque control can help slow disease progression (Nyvad & Fejerskov, 1986).

Xylitol, a sugar alcohol classified among polyol carbohydrates, is considered non-cariogenic because it cannot be metabolized by *Streptococcus mutans*. In addition to this property, xylitol exhibits antimicrobial activity and has been reported to inhibit the adhesion of *S. mutans* to tooth surfaces. Comparative studies evaluating xylitol-containing chewing gums with those containing sucrose or sorbitol have demonstrated that xylitol significantly increases salivary flow, thereby contributing to a reduction in caries risk (Heymann & Grauer, 2013).

The use of xylitol gum stimulates salivary secretion, enhancing the protective functions of saliva. Stimulated saliva contains higher concentrations of bicarbonate and phosphate ions compared to unstimulated saliva. This results in an increase in plaque pH and an improvement in the buffering capacity of saliva, which helps prevent enamel demineralization. Furthermore, the presence of calcium, phosphate, and hydroxyl ions in saliva supports the remineralization of enamel surfaces (Goswami et al., 2012).

ReminPro is a commercially available agent developed for the management of white spot lesions. It contains hydroxyapatite, fluoride, and xylitol, providing protective effects against demineralization and erosion. As a water-based formulation, it is used both to treat early enamel lesions and to reduce dentin hypersensitivity (Kamath et al., 2013).(Kamath et al., 2013)

Although the number of studies on ReminPro is limited, available evidence suggests beneficial effects on enamel properties. In one study, its application following bleaching treatment resulted in a significant increase in enamel microhardness (Kamath et al., 2013). Another in vitro study compared the effects of casein phosphopeptide-amorphous calcium phosphate fluoride (CPP-ACPF) and ReminPro on enamel surface roughness after bleaching. Both agents were found to significantly reduce surface roughness, with no statistically significant difference between them (Heshmat et al., 2014).

Fluoride-containing gels may include various fluoride compounds such as acidulated phosphate fluoride (APF), stannous fluoride, sodium fluoride (NaF), or amine fluoride (Shern et al., 1976). APF gels, typically containing 1.23% fluoride (approximately 12,300 ppm), are formulated from NaF, orthophosphoric acid, and hydrofluoric acid. Brudevold et al. (1963) reported that the incorporation of phosphoric acid shifts the hydroxyapatite–fluorapatite (HAP–FAP) equilibrium in favor of fluorapatite, thereby enhancing enamel resistance. However, due to their acidic nature, APF gels may also exert an erosive effect on certain restorative materials (Burwell et al., 2009).

Minimally Invasive Approach in Dentistry

1.Improvement of Oral Hygiene and Dietary Modification

Dental caries is a multifactorial infectious disease primarily caused by plaque-forming bacteria that ferment dietary carbohydrates on the tooth surface. Therefore, effective removal of dental plaque has been shown to play a key role in preventing both the initiation and progression of caries. Maintaining good oral hygiene through mechanical plaque control methods, such as toothbrushing and flossing, is considered fundamental for preventing early enamel lesions (Addo-Yobo et al., 1991).

Toothbrushing duration is one of the most easily controllable factors influencing plaque removal efficiency. Brushing for 2 minutes has been reported to be approximately 26% more effective in plaque removal compared to brushing for only 45 seconds (Pearson & Hutton, 2002).

Among dietary carbohydrates, sucrose is recognized as the most cariogenic. Substituting sucrose with non-cariogenic sweeteners has been associated with a reduction in caries incidence (Krasse, 1965). Additionally, to minimize caries risk, highly cariogenic foods should be consumed during main meals rather than between meals. Snacks should preferably include non-acidogenic or anticariogenic options, such as xylitol-containing products or cheese (Jensen, 1999)

2.Application of Pit and Fissure Sealants

Pit and Fissure Sealants

Pit and fissure sealants are preventive materials applied to the occlusal surfaces of caries-prone posterior teeth, forming a physical barrier that limits bacterial access to nutrients and reduces acid production and subsequent mineral loss. Introduced in the 1960s, this approach is widely used both to prevent caries in sound teeth and to arrest the progression of early non-cavitated lesions (Schwendicke et al., 2015).

Currently, resin-based, glass ionomer-based, and polyacid-modified sealants are commonly used in clinical practice (Anusavice et al., 2012). Although these materials demonstrate comparable retention rates, opaque and colored sealants offer advantages in terms of clinical visibility and evaluation (Waggoner & Siegal, 1996). Glass ionomer sealants are particularly beneficial in situations where moisture control is challenging, as they can chemically bond to enamel and dentin without the need for acid etching (Aboush & Jenkins, 1986; Waggoner & Siegal, 1996).

Sealant application techniques can be classified as invasive or non-invasive. The invasive approach involves the enlargement of narrow and deep fissures and the removal of organic debris and superficial enamel to enhance material penetration. In contrast, the non-invasive technique relies solely on surface cleaning, providing a more conservative option. Findings from clinical studies and systematic reviews suggest that pit and fissure sealants are both safe and effective in the prevention and arrest of non-cavitated carious lesions, showing a preventive benefit that is similar to or even greater than that achieved with fluoride varnishes (Ahovuo-Saloranta et al., 2013; Beauchamp et al., 2009).

3.Antimicrobial Agents

Besides routine mechanical plaque control methods like toothbrushing and flossing, antimicrobial agents are also important in helping prevent and manage dental caries (Balakrishnan et al., 2000). These agents act by targeting microorganisms within dental plaque, thereby reducing plaque accumulation, inhibiting new plaque formation, selectively suppressing cariogenic bacteria, and interfering with their virulence factors.

Antimicrobial agents are available in different forms, such as mouthrinses, toothpastes, gels, and varnishes. Common examples include phenolic compounds (e.g., triclosan), plant-derived substances (e.g., sanguinarine), metal ions such as zinc, tin, and copper, enzymes (e.g., glucanase and amyloglucosidase/glucose oxidase), essential oils (e.g., thymol and menthol), anionic agents such as sodium dodecyl sulfate, and cationic agents including chlorhexidine and cetylpyridinium chloride. The efficacy of these agents can be enhanced through slow-release formulations, which prolong their activity within the oral environment (Marsh, 1992).

4.Silver Diamine Fluoride (SDF) Application

Silver diamine fluoride (SDF) represents a non-restorative approach for the management of dental caries. It is a colorless solution, typically used at a 38% concentration, containing approximately 253,900 ppm silver and 44,800 ppm fluoride ions(Zheng et al., 2022). The silver component exhibits strong antimicrobial activity, inhibiting the growth of cariogenic biofilms, while fluoride promotes remineralization and reduces demineralization during acid challenges(Yan et al., 2022)

In addition, SDF contributes to the preservation of dentin structure by inhibiting proteolytic enzymes present in dentin and saliva, thereby preventing collagen degradation. Evidence from systematic reviews has demonstrated that SDF is an effective cariostatic agent for arresting carious lesions(Gao et al., 2016).

The use of silver diamine fluoride (SDF) for caries management was first introduced in Japan in the 1960s . This approach is based on the ability of silver and fluoride ions in SDF to enhance enamel resistance against caries(Yamaga et al., 1972). Due to its ease of application and low cost, SDF has emerged as a promising option in primary caries management.

Increasing emphasis on non-invasive treatment strategies for improving public oral health has led to growing research interest in SDF, particularly for arresting active carious lesions. Evidence from high-quality clinical trials has renewed attention toward the use of 38% SDF in caries treatment, and recent meta-analyses have confirmed its effectiveness in arresting caries progression(Chibinski et al., 2017).

Contraindications for the Use of Silver Diamine Fluoride

The use of silver diamine fluoride (SDF) is not recommended in the following situations(Sayed et al., 2019):

- Presence of spontaneous or severe pain associated with caries
- Deep carious lesions with clinical and radiographic signs indicating proximity to the dental pulp
- Patient refusal due to potential discoloration caused by SDF application
- Known allergy to silver

Silver diamine fluoride (SDF) has been associated with several adverse effects, including gingival irritation, ulceration, inflammation, pain, and a metallic taste. Due to its high pH, it may also cause transient burns on the oral mucosa or skin following application. The most commonly reported side effect is tooth discoloration, typically presenting as black or brown staining caused by silver phosphate formation(Uçar & Akyildiz, 2022).

This discoloration, particularly in anterior teeth, may raise aesthetic concerns for both children and their parents. To reduce this effect and improve patient acceptance, the application of potassium iodide solution following SDF treatment has been suggested(Roberts et al., 2020). Additionally, nano-silver fluoride (NSF) has emerged as a potential alternative with similar anticaries properties.

5.Resin Infiltration Technique

In a manner similar to the use of fissure sealants for preventing occlusal caries, the application of low-viscosity resins has been proposed for the management of smooth surface lesions (Paris & Meyer-Lueckel, 2010). Resin infiltration is a technique based on enhancing enamel permeability through a preliminary conditioning step, followed by the penetration of a resin-based infiltrant into the porous lesion body.

This approach improves the optical properties of demineralized enamel by reducing light scattering and restoring a more natural, healthy enamel appearance.

The resin infiltration procedure involves several sequential steps:

- Rubber dam isolation is recommended to protect soft tissues and ensure a clean and dry working field.
- After cleaning the tooth surface with a prophylaxis paste, the superficial enamel layer is conditioned using 15% hydrochloric acid (HCl) gel for approximately 120 seconds, with occasional agitation to enhance its effectiveness.

- The treated surface is then thoroughly rinsed with a water spray for about 30 seconds to remove any residual acid.
- To eliminate moisture trapped within the porous lesion body, ethanol (Icon-Dry) is applied for 30 seconds, followed by drying with oil-free air. This step may be repeated at least once to maximize dehydration.
- Following surface preparation, the resin infiltrant is applied to the lesion and light-cured. This application can be repeated to further reduce enamel porosity.
- Finally, the treated enamel surface is polished using discs and silicone polishers to minimize surface roughness and reduce the risk of discoloration caused by staining agents.

6.Enamel Microabrasion Technique

Enamel microabrasion was first introduced in 1984 for the removal of superficial fluorosis stains using 18% hydrochloric acid (HCl)21. Later, Croll and Cavanaugh modified this approach in 1986 by combining HCl with pumice to enhance its effectiveness (Croll & Cavanaugh, 1986).

This technique relies on the controlled use of acidic and abrasive materials such as 37% phosphoric acid with pumice or 6% HCl with silica applied to the enamel surface using a low-speed handpiece and rubber cup. When needed, it can also be combined with bleaching procedures to enhance aesthetic results (Pini et al., 2015).

Ozone Therapy

Ozone is a reactive oxygen species generated from atmospheric oxygen under ultraviolet radiation and is recognized for its potent antimicrobial activity (Bocci, 2006). In dental applications, it is produced using ozone-generating devices and applied directly to the treatment area. Its mechanism of action involves oxidation of cellular components, disruption of glycoproteins and amino acids, inhibition of enzymatic processes, and destruction of microbial cell membranes, ultimately leading to bacterial cell death.

Evidence indicates that ozone application can significantly decrease the levels of cariogenic microorganisms, including *Streptococcus mutans* and *Lactobacillus* species (Azarpazhooh & Limeback, 2008). It has also been reported to be useful as a cavity disinfectant following caries removal (Magni et al., 2008). A key advantage of ozone therapy is that it does not leave any residual by-products after application, making it a favorable option in clinical practice .

Air Abrasion for Cavity Preparation

The concept of air abrasion in dentistry was first explored in the early 1940s by Dr. Robert Black and later introduced clinically with the Airdent system (S.S. White) in 1951 (Black, 1945)(Hegde & Khatavkar, 2010). Despite its initial promise, the technique did not gain widespread acceptance due to several limitations.

One major drawback was its inability to produce well-defined cavity walls, which were required for restorative materials commonly used at the time, such as amalgam and gold. Additionally, the introduction of high-speed air turbine handpieces in the late 1950s provided a faster and more efficient alternative for cavity preparation. Furthermore, inadequate suction systems made effective removal of abrasive particles difficult, reducing its clinical practicality(Black, 1945; Hegde & Khatavkar, 2010)

Despite the core principle of air abrasion remaining unchanged, improvements in adhesive technologies, restorative materials, isolation methods, and high-volume suction systems have contributed to its renewed popularity in modern dentistry (Hegde & Khatavkar, 2010).

Advantages:

- Pain during tooth structure removal is minimized or may be completely eliminated.
- The procedure is performed without vibration, improving patient comfort.
- The sound generated is relatively mild and comparable to that of a vacuum device.
- Advanced nozzle designs provide better precision and operator control.
- It allows treatment of anxious patients without the need for local anesthesia, particularly those sensitive to rotary instruments.
- Suitable for conservative cavity preparations, especially Class I, IV, and V lesions.
- Particularly beneficial in pediatric dentistry due to its minimally invasive nature.
- Effective in the management of early carious lesions that may not be easily detected clinically or radiographically when applied appropriately.

Disadvantages:

- Requires a learning period, as many clinicians may not be familiar with the technique.
- Does not allow the formation of sharp and well-defined cavity margins.
- Provides limited tactile feedback during the removal of tooth structure.

- Currently limited to small cavity preparations and not suitable for procedures such as crown preparation (Christensen, 1996).

Laser

The term LASER (Light Amplification by Stimulated Emission of Radiation) refers to the amplification of light through stimulated emission. Its scientific basis originates from Einstein's theoretical work published in 1916 (Fuller, 1991).

Since its introduction into dentistry, lasers have been extensively studied for their role in caries prevention. Their effectiveness in preventive dentistry is mainly attributed to their interaction with dental hard tissues. Laser irradiation can alter the physical properties of enamel and promote the recrystallization of hydroxyapatite, thereby enhancing resistance to demineralization (Elton et al., 2009).

Several laser systems approved by the Food and Drug Administration (FDA) are widely utilized in dentistry, including argon, diode, Nd:YAG, CO_2, Er:YAG, and Er,Cr:YSGG lasers.

Laser-induced thermal effects on enamel can lead to alterations in its chemical composition, physical structure, and crystalline arrangement. Processes such as surface melting, fusion, and subsequent recrystallization may occur. These modifications are associated with a reduction in water and carbonate content, along with increased enamel hardness and decreased permeability. Such changes are thought to influence the release of calcium, phosphate, and fluoride ions during acid exposure (Serdar Eymirli & Dilek Turgut, 2019; Subramaniam & Pandey, 2014).

In clinical dentistry, erbium lasers are frequently used for caries removal. When applied under appropriate parameters, these lasers enable effective elimination of carious tissue in both primary and permanent teeth while preserving the natural structure of dentinal tubules (Lizarelli et al., 2003).

Atraumatic Restorative Treatment (ART)

Atraumatic Restorative Treatment (ART) is a minimally invasive approach first described by Frencken in 1991 and later supported by the World Health Organization in 1994 (Giacaman et al., 2018). It is based on removing demineralized carious tissue with hand instruments and then restoring the cavity with a suitable material. This technique not only restores the affected area but also provides a preventive effect by sealing adjacent pits and fissures. High-viscosity glass ionomer cement is commonly used due to its ease of handling and self-curing properties, demonstrating favorable survival rates, particularly in single-surface restorations . Additionally, glass ionomer materials are biocompatible, chemically bond to tooth structure, and continuously release fluoride, contributing to their preventive benefits (Frencken & Holmgren, 1999).

Stepwise Caries Removal Technique

Stepwise caries removal is a minimally invasive approach designed to reduce the risk of pulp exposure by eliminating carious tissue in two stages. In the initial phase, partial caries removal is performed, intentionally leaving softened dentin near the pulp, followed by placement of a temporary restoration for up to 12 months (Giacaman et al., 2018). During this period, the remaining dentin tends to become harder, drier, and less infected, resembling characteristics of inactive lesions (Bjørndal et al., 1997).

In the second stage, the temporary restoration is removed, residual carious tissue is eliminated to sound dentin, and a definitive restoration is placed. This method promotes the natural defense mechanisms of the pulp dentin complex, including tertiary dentin formation and dentin sclerosis, thereby supporting pulp vitality and minimizing the likelihood of exposure (Bjørndal et al., 1997) .

Although studies have shown that this technique may be more effective than direct restoration in preventing pulp exposure, it requires an additional treatment session, which may increase time, cost, and patient discomfort. It is generally not preferred for primary teeth due to their limited lifespan; instead, selective caries removal may be applied (Banerjee et al., 2017). However, according to the 2022 AAPD guidelines, stepwise caries removal should be considered in both primary and permanent teeth with deep caries where there is a risk of pulp exposure and the pulp is either normal or reversibly inflamed .

Use of Intraoral Scanners and CAD/CAM Systems

Intraoral scanners combined with computer-aided design and manufacturing (CAD/CAM) systems enable the fabrication of fast and effective restorations in both primary and permanent teeth within a minimally invasive framework (Akarçay & Ulu Güzel, 2022). Digital models can be obtained either directly through intraoral scanning or indirectly by digitizing conventional impressions or dental casts.

These technologies allow the production of restorations that closely adapt to the cavity and surrounding tissues while preserving tooth structure (Akarçay & Ulu Güzel, 2022; Fleming et al., 2011). Following appropriate cavity preparation, CAD/CAM-fabricated restorations provide a conservative treatment option with excellent fit and clinical performance in both primary and permanent dentitions (Bilgin et al., 2016).

Chemomechanical Caries Removal Methods

Chemomechanical caries removal is a minimally invasive technique developed as an alternative to conventional cavity preparation, aiming to preserve healthy tooth structure (Yazici et al., 2003). Traditional methods, which rely on high-speed rotary instruments and the concept of extension for prevention, may cause discomfort, noise, vibration, and unnecessary removal of sound tissue, potentially weakening the tooth over time.

In contrast, the chemomechanical approach involves the application of chemical agents to selectively soften and remove infected dentin. These agents are typically either sodium hypochlorite-based (such as GK-101, Caridex, and Carisolv) or enzyme-based (such as Papacarie and Biosolv), offering a more conservative and patient-friendly treatment option.

Chemomechanical caries removal relies on applying a chemical agent that softens and modifies carious dental tissue, making it easier to remove. The softened dentin is then gently eliminated using hand instruments (Hamama et al., 2014).

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Chapter 2

The Role of Psychiatric Nursing and Evidence-Based Approaches in the Prevention and Intervention of Peer Bullying

Serpil YILMAZ [1]

1. Introduction

Peer bullying is defined as a critical public health problem that emerges in childhood and adolescence, exhibits a deliberate and repetitive pattern, and threatens the mental, social, and academic development of individuals. This phenomenon, whose prevalence is increasing globally, is not only a disciplinary problem confined to school boundaries, but a systematic form of violence affecting all layers of the socio-ecological system. Especially in the digitalized world, the transfer of bullying to the cyber dimension has narrowed the safe spaces of victims and expanded the scope of the risk (World Health Organization [WHO], 2019; United Nations Educational, Scientific and Cultural Organization [UNESCO], 2019).

Current evidence shows that bullying is not a temporary developmental stage but a significant public health concern with potential long-term psychological consequences. Despite this, bullying is often perceived as a common "equal" conflict in many educational and care settings, which limits the opportunity for systematic clinical and preventive interventions (Armitage, 2021). However, bullying involves an asymmetrical relationship where the victim has difficulty defending themselves, making professional intervention necessary. A review of the current literature reveals that bullying studies are largely concentrated in the fields of psychology and educational sciences; particularly focusing on depressive symptoms, self-efficacy, and other psychosocial variables (Ariani, 2025; Liu et al., 2023; Ye et al., 2023; Gürer et al., 2025).

In contrast, it is noteworthy that the theoretical and practical contributions of the nursing discipline, especially the psychiatric nursing perspective, remain relatively limited in this process. However, psychiatric nursing is an interdisciplinary bridge discipline that can manage preventive mental health, early risk assessment, therapeutic communication, and holistic intervention processes (Videbeck, 2020). Psychiatric nurses hold a strategic role in preventing

[1] (Assoc. Prof. Dr.), Hitit University, Faculty of Health Sciences, Department of Psychiatric Nursing, ORCID: 0000-0002-9259-9975, serpilyilmaz@hitit.edu.tr

and addressing bullying through early identification, risk assessment, and evidence-based interventions (Centers for Disease Control and Prevention [CDC], 2024).

In this context, addressing psychiatric nursing-based approaches in the prevention and management of peer bullying within an evidence-based framework is a fundamental requirement for improving the quality of nursing care. This book chapter aims to discuss the place of nursing interventions in the processes of protecting and improving mental health by looking at the phenomenon of bullying from the perspective of psychiatric nursing.

2. Definition and Basic Characteristics of Peer Bullying

Peer bullying is defined as a child or adolescent being subjected to intentional, repetitive negative behaviors by their peers, characterized by a significant power imbalance between the parties (UNESCO, 2019; WHO, 2019). The three fundamental components of this definition—intentionality, persistence, and power imbalance—are the distinguishing criteria that differentiate bullying from ordinary interpersonal conflicts. In current literature, bullying is considered not merely an isolated act of aggression, but rather a dynamic process that systematically negatively impacts the victim's psychosocial well-being by eroding their coping capacity (Ariani, 2025; Ye et al., 2023). This process is not limited to individual characteristics but is shaped by the interaction of relational and environmental factors (Gürer et al., 2025).

Key characteristics that distinguish peer bullying from ordinary conflicts and disagreements include the persistence of the behavior, the victim's vulnerability, and the psychological devastation caused by the bullying (Armitage, 2021). In particular, power imbalance can limit the victim's capacity to defend themselves, paving the way for the development of a chronic stress response. This harm can lead to withdrawal from social relationships and impairment of academic functioning, along with the development of feelings of fear, helplessness, shame, and loneliness (Arseneault, 2018).

Global reports show that the experience of bullying exposes not only victims but also perpetrators and bystanders to serious mental health risks such as substance abuse, anxiety, and depression (UNESCO, 2019; American Psychological Association [APA], 2015). This multifaceted impact reveals that bullying is not an individual problem but a mental health issue that needs to be addressed at the systemic level.

3. Types of Peer Bullying

Peer bullying is a multidimensional phenomenon that can threaten an individual's physical, psychological, and social well-being. The current literature classifies bullying types based on the visibility of behavior and its effects on the victim (UNESCO, 2019; CDC, 2024). This classification is clinically important for planning intervention and determining risk levels. Each type carries distinct risks and intervention requirements.

3.1. Physical Bullying

Physical bullying includes direct bodily attacks such as hitting, pushing, kicking, hair pulling, and damaging personal belongings (CDC, 2024). This type of bullying is more visible and is often noticed more quickly by teachers and school administration. However, individuals who are subjected to physical bullying may develop not only physical injuries but also intense feelings of fear, anxiety, and insecurity (Agustiningsih et al., 2024; Wolke & Lereya, 2015). Repeated experiences of physical bullying not only lay the groundwork for the emergence of post-traumatic stress symptoms, but their effects can extend to general health outcomes in adulthood (Idsoe et al., 2012; Takizawa et al., 2014). Psychiatric nurses play a crucial role in assessing trauma symptoms and accompanying psychological effects in individuals who have experienced physical bullying. This assessment should include safety planning, crisis intervention, and referral to advanced mental health services when necessary.

3.2. Verbal Bullying

Verbal bullying encompasses verbally aggressive behaviors such as insults, mockery, belittling, threats, and derogatory nicknames (UNESCO, 2019). Often underestimated because it leaves no physical marks, this type of bullying can damage the victim's self-esteem and lead to long-term mental health problems. It has been noted that symptoms of depression and anxiety increase in children and adolescents exposed to verbal bullying (Armitage, 2021). Furthermore, it is stated that continuous verbal abuse can negatively affect children's mental health, paving the way for the development of emotional problems. Psychiatric nurses are in a critical position to assess emotional symptoms early and initiate preventive mental health interventions.

3.3. Social (Relational) Bullying

This includes behaviors that target an individual's social relationships; exclusion, ignoring, spreading gossip, and isolating from the group (Volk et al., 2014). This type of bullying is often difficult to detect because it usually occurs secretly.

Individuals who are subjected to social bullying frequently experience loneliness, social withdrawal, and school avoidance behaviors. Relational bullying can have deeper and more lasting psychological consequences due to the developmental importance of peer acceptance during adolescence. A comprehensive literature review by Sari et al. (2025) suggests that adolescent victims of bullying experience social withdrawal and hopelessness symptoms much more intensely than their non-victimized peers, and this directly weakens their sense of belonging to school. Furthermore, the PISA 2022 Turkey results published by the OECD (2024) show that relational and verbal bullying is one of the most fundamental risk factors for school avoidance and loss of academic achievement. The active participation of psychiatric nurses in school-based observation and screening processes can facilitate the early identification of social bullying.

3.4. Cyberbullying

Cyberbullying encompasses bullying behaviors carried out through social media, messaging applications, and online platforms (Kowalski et al., 2014). The continuity and wide reach of digital environments can cause victimization to continue without time and space limitations. Anonymity and the rapid spread of content can increase the psychological pressure on the victim. Cyberbullying is associated with sleep problems, intense anxiety, and feelings of helplessness in children and adolescents (World Health Organization [WHO], 2020). Psychiatric nurses have an important role in raising awareness about digital risks and supporting safe technology use. In this context, both individual counseling and school-based psycho-educational programs can be planned.

4. Mental Health Risks in Peer Bullying

Individuals exposed to peer bullying may experience numerous mental health problems such as depression, anxiety, low self-esteem, social withdrawal, and impaired academic functioning (Armitage, 2021; Moore et al., 2017). These symptoms often manifest as internalized problems and tend to become chronic if not recognized early. When longitudinal, prospective cohort, and meta-analytic studies are considered together, it is seen that the effects of bullying in childhood and adolescence are not limited to short-term psychological distress, but are significantly associated with various mental health problems in adulthood, including depression, anxiety disorders, and suicidal ideation (Copeland et al., 2013; Lereya et al., 2015; Moore et al., 2017; Arseneault, 2018; Dieter Wolke &

Lereya, 2015). These findings suggest that repeated bullying experiences, particularly during childhood, can be an independent risk factor for the development of mental illness in adulthood, even when controlling for accompanying environmental and individual risk factors.

Peer bullying is associated with academic failure, school avoidance, and impaired social relationships; these effects can extend from childhood through adolescence and young adulthood (UNESCO, 2019; WHO, 2019). These multifaceted effects demonstrate that bullying plays a decisive role not only on individual mental health but also on developmental and functional domains. These findings reveal that peer bullying is a significant risk factor affecting an individual's mental well-being in a multidimensional way.

Psychiatric nursing plays a critical role in the early detection of mental health risks associated with bullying, the identification of at-risk individuals, and the planning of appropriate protective and preventive interventions. In this context, psychiatric nurses take active responsibility in systematic mental health assessment, the use of risk screening scales, early detection of crisis symptoms, and the implementation of safe referral processes. Nursing-based early diagnosis and follow-up approaches are considered an effective strategy in reducing the long-term psychological consequences of bullying (Videbeck, 2020). In addition, integration into school-based mental health programs, continuous follow-up, and cooperation with the family are among the key components that increase the effectiveness of the intervention.

5. Prevention Approach in Psychiatric Nursing

Psychiatric nursing is a fundamental discipline that holistically addresses preventive, early diagnostic, and curative approaches in the prevention and reduction of the effects of peer bullying. This approach is structured at the primary, secondary, and tertiary levels in line with public health-based protection steps; it includes individual, family, school, and community-focused interventions (Stuart, 2013; Ttofi & Farrington, 2011; Espelage & Swearer, 2010). School-based bullying prevention programs have been reported to be effective in reducing bullying behaviors and victimization through social-emotional learning components and coping skills training (Gaffney et al., 2019; Polanin et al., 2022). Nursing practices are not only supportive but also an effective component of preventive mental health services.

5.1. Primary Prevention: Protective Mental Health

Primary prevention aims to minimize risk factors and strengthen protective factors before peer bullying even occurs. Psychiatric nurses play an active role in the planning, implementation, and evaluation of programs aimed at improving mental health in school and university ecosystems. This professional role encompasses a wide range of activities, from needs analysis to program development, from the implementation process to the evaluation of results.

In this context, it is reported that life skills training, such as empathy development, healthy communication skills, problem-solving, emotional awareness, and social-emotional learning-based approaches, are recommended as elements that support the effectiveness of violence and bullying prevention in the school environment (WHO, 2019).

There is strong evidence that protective mental health programs increase prosocial behaviors and reduce bullying tendencies in students. Comprehensive meta-analyses examining the overall effectiveness of school-based interventions; Studies show that anti-bullying programs reduce bullying behaviors by approximately 19–20% and the rate of being bullied by approximately 15–16% (Gaffney et al., 2019; Ttofi & Farrington, 2011). The findings particularly highlight that school-wide and multi-component programs demonstrate higher effectiveness. Peer education, empathy-focused approaches, and interventions based on social problem-solving skills have been shown to reinforce positive social relationships among students and reduce victimization levels (van der Ploeg et al., 2016; Salmivalli, 2014). The literature reveals that practices such as social skills training and peer mediation strengthen students' conflict resolution abilities, defending behaviors, and self-efficacy perceptions (Moore et al., 2017; Polanin et al., 2012). Such initiatives are of strategic importance in terms of increasing mental resilience and building a positive school climate (Sancassiani et al., 2015).

Psychiatric nurses play a "catalyst" role in creating a safe school climate by working in collaboration with teachers, school administration, and families. In this process, the nurse, as a coordinator and facilitator, leads the institutionalization of a protective mental health culture. International guidelines confirm that nursing interventions, especially those integrating family participation, significantly reduce risk factors on both the victim and perpetrator sides (CDC, 2024; UNESCO, 2019).

5.2. Secondary Prevention: Early Detection and Risk Screening

Secondary prevention aims to identify individuals at risk of being exposed to or exhibiting bullying behavior at an early stage. Psychiatric nurses can identify at-risk individuals through structured mental health screening tools, systematic observation, individual interviews, and self-report scales (CDC, 2024). This early identification allows for intervention before symptoms worsen.

In recent years, digital mental health screening and early warning systems have emerged as innovative tools supporting nursing practices within the scope of secondary prevention. These systems enable timely intervention by allowing for the early detection of depression, anxiety, stress, and bullying experiences.

Systematic reviews show that web-based tools and mobile health (m-Health) applications can reduce barriers such as geographical barriers, cost, and stigma (Ebert et al., 2019). Similarly, Andersson and Titov (2014) state that internet-based psychological interventions increase accessibility compared to traditional face-to-face therapies and offer an effective alternative, especially for individuals with limited access to mental health services.

Despite the popularity of mobile applications for adolescents, many do not yet have sufficient clinical evidence, and it is stated that these tools should be used under expert supervision (Grist et al., 2017). In this context, psychiatric nurses can create safe, ethical, and individualized monitoring plans by integrating digital data with clinical assessment processes.

The simultaneous tracking of cyberbullying through digital traces and the use of AI-supported early warning systems have the potential to shorten the intervention time in case management processes (Kowalski et al., 2019; Torous et al., 2021). However, these technologies must be implemented within the framework of ethical boundaries, data security, and privacy principles. Therefore, the use of technology should be considered as a tool that supports clinical judgment, not replaces it.

5.3. Tertiary Prevention: Intervention and Rehabilitation

Tertiary prevention focuses on reducing the psychological effects of peer bullying, restoring functionality, and preventing recurrence. Psychoeducation, supportive counseling, and regular follow-up for issues such as depression, trauma symptoms, anxiety, and social withdrawal in individuals who have experienced bullying are among the basic interventions of psychiatric nursing (Videbeck, 2020). These interventions may include individual, group, and family-based practices.

This process is addressed in the literature within the scope of case management, and it is reported that nurse-led multidisciplinary care models strengthen service coordination and support participation in treatment processes (Moore et al., 2017). This role is based on a holistic care approach that includes assessment, referral, follow-up, and patient advocacy functions.

Counseling for families, strengthening coping skills, and activating social support systems are fundamental components of the rehabilitation process. Strong family support is reported to be a protective factor against the long-term mental health effects of bullying (Arseneault, 2018). This holistic approach has the potential to reduce the long-term consequences of peer bullying, such as antisocial behaviors and chronic mental disorders that can carry over into adulthood (Wolke & Lereya, 2015). Furthermore, activating social support systems through nurses is considered a factor that can strengthen an individual's psychological resilience and positively contribute to the recovery process.

6. Psychiatric Nursing-Based Intervention Approaches

Psychiatric nursing-based interventions encompass evidence-based, multi-level practices aimed at reducing the individual, family, and school-based impacts of peer bullying. Recent systematic reviews and school-based nursing interventions demonstrate that nurse-led education, empathy development, psycho-education, and counseling programs can be effective in reducing bullying behaviors and mental health consequences (e.g., stress, anxiety, low self-esteem) (Yosep et al., 2023; Celdrán-Navarro et al., 2023).

6.1. Interventions for Individuals Experiencing Bullying

Psychopathologies such as depression, anxiety, post-traumatic stress symptoms, low self-esteem, and social withdrawal are frequently observed in individuals who have been bullied. Psychiatric nurses support the victim in expressing their feelings in a safe therapeutic environment. Through psychoeducation, they encourage cognitive restructuring processes that emphasize that bullying is not related to the individual's self-worth and guide the individual in developing effective coping mechanisms (Yosep et al., 2023; Celdrán-Navarro et al., 2023; Agatha et al., 2025).

Studies have shown that interventions focusing on supportive counseling, problem-solving skills training, and strengthening social support networks improve psychological well-being in children and adolescents (Sancassiani et al., 2015; Arseneault, 2018; Moore et al., 2017). Structuring these interventions with Cognitive Behavioral Therapy (CBT) techniques strengthens individuals' coping skills and self-efficacy perceptions, leading to significant reductions, particularly in anxiety and internalization problems (Kowalski et al., 2019; Farrer et al., 2013).

Psychiatric nurses play a critical role in the early detection of suicidal ideation and self-harming behaviors in high-risk students through regular monitoring. Longitudinal studies confirm a significantly increased risk of suicide and suicide attempts among young people who are victims of peer bullying (Haltigan & Vaillancourt, 2014; Troop-Gordon, 2017).

School-based mental health screening and monitoring practices increase the likelihood of timely identification of at-risk students and referral to appropriate specialist services (SAMHSA, 2020; WHO, 2021). In this process, the nurse acts as a bridge between the crisis intervention team and the victim. 6.2 Interventions for Bullying Individuals

Research shows that bullying individuals exhibit significantly more difficulty with emotion regulation, lack of empathy, and externalizing behaviors. Current meta-analytic and empirical findings emphasize that dysfunctional emotion regulation strategies and internalizing/externalizing symptoms underlie the relationship between peer bullying and psychosocial maladjustment (Al-Alawi et al., 2025; Ng et al., 2022). In this context, the psychiatric nursing approach prioritizes therapeutic, rehabilitative, and developmental interventions that focus on the psychosocial needs at the root of the behavior, rather than punitive methods (CDC, 2024). The literature reveals that a significant portion of children exhibiting bullying behavior have themselves experienced victimization in the past (bully-victim status), and that post-traumatic stress symptoms in these individuals can be masked by antisocial behaviors (Wolke & Lereya, 2015). Interventions include empathy development programs, anger management and emotion regulation training, and social skills-based group interventions. International guidelines and meta-analyses report that school-based social-emotional learning and holistic mental health programs are effective in reducing the frequency and severity of bullying behaviors (World Health Organization [WHO], 2020; Gaffney et al., 2019). Recent meta-analytic findings examining program components show that cognitive-behavioral techniques, emotion regulation training, and social problem-solving modules are effective in reducing aggression levels and increasing prosocial behaviors (Gaffney et al., 2021; Ttofi & Farrington, 2011). Furthermore, it is emphasized that parent management training and family-based interventions for families of students exhibiting bullying tendencies play a significant role in reducing domestic conflict and extinguishing bullying behavior (UNESCO, 2019; Ttofi & Farrington, 2011).

6.3. Interventions for Bystanders

Peer bullying not only affects the victim and perpetrator but also leaves profound psychological, social, and behavioral impacts on bystanders who witness the process. These individuals may experience complex emotions such as guilt, fear, anxiety, and helplessness; remaining passive risks indirectly reinforcing bullying behavior (Salmivalli, 2014). Current findings show that peer victimization is directly related to internalization problems in adolescents, and the classroom social context plays a decisive role in this relationship (Gini et al., 2024).

The psychiatric nursing approach aims to break the bullying cycle by encouraging students to develop safe and supportive bystander roles. Meta-analyses examining the effectiveness of bystander-focused school programs show that such interventions significantly increase students' intervention behavior and self-efficacy perception (Polanin et al., 2012; Salmivalli, 2014). Furthermore, meta-analytic findings have shown that the implementation of holistic and school-wide programs significantly reduces bullying and victimization rates and positively transforms the school climate (Gaffney et al., 2019; Ttofi & Farrington, 2011).

In this process, psychiatric nurses facilitate the transition of students from a "passive bystander" role to an "active advocate" role by providing empathy-based psychoeducation, developing social responsibility awareness, and teaching safe reporting methods (anonymous reporting, etc.). These interventions are of strategic importance in reducing the psychosocial effects of bullying by strengthening the classroom climate and peer support mechanisms.

6.4. Multi-Stakeholder Collaboration: Family and School Integration

Family and school collaboration stands out as a fundamental element in combating peer bullying. Psychiatric nurses help families understand their children's behavior by offering counseling and guidance, supporting positive parenting skills, and contributing to strengthening family communication (UNESCO, 2019). This approach goes beyond student-focused interventions and encourages the informed participation of families and school staff. Parent meetings and guidance sessions play a role in reducing risks for both bullying and victimized students (Ttofi & Farrington, 2011; CDC, 2024).

In school-based interventions, psychiatric nurses contribute to the creation of a safe school climate in collaboration with school administration, teachers, and psychological counselors. Developing institutional anti-bullying policies and implementing and monitoring school-based mental health programs are among the important responsibilities of nursing (National Association of School Nurses [NASN], 2021; World Health Organization [WHO], 2021). Research shows that holistic and multidisciplinary school interventions improve the school climate, increase students' help-seeking behaviors, and significantly reduce bullying and victimization rates (Gaffney et al., 2019; Ttofi & Farrington, 2011; Kutcher et al., 2015). Current evidence confirms that multi-stakeholder approaches are the most effective method in reducing bullying-related mental health problems and preventing risky behaviors (Lekamge et al., 2025; WHO, 2021). In particular, interventions adopting a "whole school approach" have been shown to improve students' socio-emotional skills while having a protective effect against risky behaviors such as bullying (Lekamge et al., 2025).

7. Psychiatric Nursing Care Process and Diagnoses

Psychiatric nurses structure their interventions on a scientific basis by structuring the nursing care process in children and adolescents who are exposed to or exhibit bullying behavior, according to standardized terminologies such as NANDA I nursing diagnoses, NIC nursing interventions, and NOC outcome measures. These classification systems allow for the evaluation of not only the individual's psychopathology at the diagnostic level but also their self-perception, coping skills, social relationships, and safety needs within a holistic framework (Avşar & Ayaz-Alkaya, 2018; Celdrán-Navarro et al., 2023; Dolgun, 2018).

In the literature on nursing practices in the context of peer bullying, there are comprehensive reviews evaluating multidimensional interventions aimed at reducing psychosocial effects, and it is reported that both nursing-based interventions support individual psychological well-being and emphasize the importance of systematic care processes (Agatha et al., 2025).

7.1. Common Nursing Diagnoses and Interventions in Peer Bullying

The most common nursing diagnoses in children and adolescents exposed to peer bullying are decreased self-esteem, social isolation, traumatic stress symptoms, ineffective coping, and risk of self-harm. Interventions for these diagnoses include psychoeducation, cognitive restructuring, trauma-focused care, social skills development, and crisis intervention. A structured diagnosis-intervention-outcome mapping is presented in Table 1.

Table 1. Psychiatric nursing diagnoses, interventions, and outcome measures in peer bullying

Nursing Diagnosis (NANDA-I)	Related Factors / Symptoms	Nursing Interventions (NIC)	Expected Outcomes / Measures (NOC)
Low Self-Esteem	Chronic exposure to verbal/social bullying, feelings of worthlessness, inadequacy	- Psychoeducation: Enhance self-esteem - Cognitive restructuring - Supportive counseling / individual sessions	- Self-Esteem ↑ - Self-Efficacy ↑
Social Isolation	Peer rejection, loneliness, social withdrawal	- Social Skills Development - Group therapy / support groups - Provide social interaction opportunities	- Social Interaction ↑ - Social Participation ↑
Post-Traumatic Stress	Experiences of violence or threat, nightmares, avoidance behaviors	- Trauma-focused care - Ensure safe environment - Relaxation and stress reduction techniques	- Trauma Symptoms ↓ - Anxiety Level ↓
Ineffective Coping	Deficits in problem-solving, withdrawal, emotion regulation difficulties	- Strengthen coping skills - Emotion regulation training - Problem-solving and decision-making skills training	- Coping Behaviors ↑ - Problem-Solving Ability ↑
Risk of Self-Harm	Feelings of helplessness, severe depressive symptoms, suicidal thoughts	- Risk assessment and monitoring - Crisis intervention - Involve family and support systems	- Safety Behaviors ↑ - Suicidal Ideation ↓

Nursing interventions planned in line with the diagnoses in the table include psychoeducation, establishing a safe therapeutic relationship, developing coping skills, strengthening social support systems, and multidisciplinary referral when necessary. Thus, psychiatric nursing offers a structured, systematic care model in reducing the short- and long-term psychological effects of peer bullying. The roles of school nurses in bullying prevention and early intervention programs are defined to include risk screening, individual counseling, family involvement, and social-emotional skills training (National Association of School Nurses, 2022). Research has shown that such multi-component school-based interventions increase students' help-seeking behaviors and improve the school climate (Gaffney et al., 2019).

Multi-component interventions in which nurses play an active role are described in programs conducted by the Finnish Institute for Health and Welfare (THL, 2021). Literature has shown that such interventions increase self-esteem and reduce depressive symptoms in students who have been bullied (Gaffney et al., 2019). The leadership of nurses in individual monitoring, coordination of peer support groups, and family interviews contributes to the sustainability of school-based mental health services. These findings demonstrate that psychiatric nursing can assume not only a supportive but also a therapeutic and systemic transformative role.

7.2. Clinical Practice Example: Psychiatric Nursing Process for an Adolescent Victimized by Peer Bullying

Case Summary: Z.K., a 14-year-old 8th-grade student, was referred to the school health unit due to increased absenteeism, declining academic performance, and marked social withdrawal over the past three months. Initial assessment revealed systematic social exclusion by classmates, spreading of humiliating rumors, and mocking messages via social media (cyberbullying). Z.K. expressed dysfunctional beliefs such as “Nobody wants me,” “I’m worthless,” and “I don’t want to go to school,” along with sleep difficulties, loss of appetite, and periodic crying episodes.

Nursing Assessment and Diagnosis: A psychiatric nurse conducted a systematic mental health assessment using standardized tools. The Children’s Depression Inventory (CDI) (Kovacs, 1985; Öy, 1991) assessed depressive symptoms, and the Rosenberg Self-Esteem Scale (RSES) (Rosenberg, 1965; Çuhadaroğlu, 1986) assessed self-esteem. Initial scores indicated clinically significant depression and low self-esteem. Suicidal risk evaluation revealed passive death thoughts but no active plan, though high-risk indicators were present. Using NANDA-I taxonomy, diagnoses of Situational Low Self-Esteem, Social Isolation, Ineffective Coping, and Risk of Self-Harm were established.

Planned Interventions (NIC) and Expected Outcomes (NOC): A safe environment was provided through therapeutic communication. Interventions included individual sessions focused on cognitive restructuring, psychoeducation to strengthen self-esteem, and social skills development. Family meetings emphasized that the situation was a mental health concern requiring intervention, not just “adolescent sensitivity,” providing parental awareness training. A collaborative “safety plan” with school administration addressed cyberbullying content.

Effectiveness was monitored using NOC outcome measures: Self-Esteem, Social Interaction, and Depression Control, comparing pre- and post-intervention scores.

Follow-Up and Clinical Outcome: After three months, Z.K. regularly attended sessions, showed increased academic motivation, significant reductions in CDI scores, and marked improvement in RSES scores. The student reestablished healthy social connections, absenteeism ceased, and the family developed a supportive attitude.

This case demonstrates psychiatric nursing's role in early identification, crisis prevention, and multi-stakeholder coordination while highlighting the clinical applicability of NANDA-I, NIC, and NOC frameworks.

8. Conclusion and Psychiatric Nursing-Based Intervention Recommendations

The literature shows a strong association between peer bullying and depression, anxiety, low self-esteem, and suicidal ideation. This reveals that bullying is not a temporary problem and carries long-term mental health risks.

School-based social-emotional learning and multi-component interventions have been found to be effective in reducing bullying behaviors and victimization. However, the roles of psychiatric nurses in these programs are often limited or unclear. Digital mental health applications increase accessibility and reduce stigma; however, their systematic integration into the nursing care process is still limited.

Recommended intervention areas:

- Primary prevention: Psychiatric nurses taking an active role in preventive programs that strengthen empathy, emotional regulation, and communication skills.
- Secondary prevention: Integration of standard screening protocols and digital systems for early identification of at-risk students.
- Tertiary prevention: Implementation and evaluation of structured nursing interventions for individuals experiencing bullying.
- Policy and practice models: Development of sustainable school mental health policies where nurses assume autonomous and competent roles.

Psychiatric nursing offers a holistic approach encompassing prevention, early detection, clinical assessment, and case management. Multi-component, school-based programs, implemented with the active participation of nurses, contribute to reducing bullying and protecting child and adolescent mental health. Widespread adoption of such interventions can reduce the burden on individual and societal mental health in the long term.

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Chapter 3

Handheld Dental X-Ray Devices: Indications, Radiation Protection, And Image Quality

Merve YÜCE[1], Birdal AYKUT[2], Birsay GÜMRÜ[3]

Radiographic imaging is crucial for diagnosis and treatment planning in clinical dentistry. Conventional intraoral X-ray devices are usually installed as fixed systems (either floor- or wall-mounted) or used as mobile units (e.g., tripod-based devices). Recent technological advances have enabled the development of portable, rechargeable handheld intraoral X-ray devices (Altındağ *et al*., 2023).

Handheld X-ray devices were introduced in the early 1990s as a portable option to conventional wall-mounted units. In the beginning, they were developed to support dental care by enabling intraoral radiographic imaging in field conditions during military operations. However, the use of handheld X-ray technology has expanded over the past decade and has become more common in routine clinical practice (Martins *et al*., 2023; Ramesh *et al*., 2018).

Portable handheld dental X-ray devices offer several practical advantages, most notably reduced size and weight, which facilitate transport and point-of-care imaging. Consequently, these systems may be particularly useful in surgical settings (e.g., intraoperative imaging), forensic dentistry, community-based services, and home-care settings (Martins *et al*., 2023).

This chapter summarizes current evidence on handheld dental X-ray devices, focusing on commonly reported indications, guidelines and standards, device design features, radiation protection considerations, image quality, and comparative dosimetry relative to conventional wall-mounted systems.

Indications and Guidelines/Regulations

Handheld systems are increasingly encountered in settings where conventional fixed units are impractical. Permitted or commonly cited indications for handheld intraoral X-ray devices include use in temporary health clinics, nursing homes and home-care settings, imaging of patients with special

[1] Research Assistant, DDS, Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Marmara University, ORCID ID: 0009-0001-4011-6388
[2] Research Assistant, DDS, Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Marmara University, ORCID ID: 0009-0004-7847-9127
[3] Professor, DDS, PhD, Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Marmara University, ORCID ID: 0000-0002-7734-4755

needs (medical, mental, or psychological) requiring assistance, radiography of sedated patients who cannot comply with positioning requirements, forensic applications (e.g., autopsy), disaster or emergency situations, and social assistance programs such as dental health camps (Ramesh *et al*., 2018).

Various manufacturers have introduced handheld dental X-ray devices for clinical use. With their increasing availability, additional features, affordability, and wider adoption in dental practice, some countries and professional organizations have been compelled to issue recommendations to support their accurate and safe use (Berkhout *et al*., 2015). Their incorporation into practice should be combined with meticulous monitoring of occupational exposure and appropriate training in radiological protection (Batista *et al*., 2021).

In 2015, the European Academy of DentoMaxilloFacial Radiology (EADMFR) released a position statement recommending the use of handheld X-ray units be limited to circumstances where fixed equipment is impractical, such as dental treatment in operating rooms, emergency clinics, surgical units (e.g., where patients may be under general anaesthesia or sedation), residential homes, facilities for patients with special needs, detention centres, and remote or underdeveloped regions lacking dental care services. The same document also states that handheld devices should not be used for everyday dental radiography procedures in dental practices and should be reserved for cases in which it is impractical or impossible to transfer the patient to a facility equipped with a fixed X-ray unit (Berkhout *et al*., 2015).

In contrast, Geist noted that the American Dental Association (ADA) has not issued specific restrictions on the use of handheld systems (Geist, 2021). Citing ADA and Public Health England (PHE) guidelines, Zenóbio *et al*. stated that proper use of portable devices does not present a higher radiation risk to either the operator or the patient in comparison with conventional dental radiography units (Zenóbio *et al*., 2019).

The diagnostic standards for dental radiography outlined by the German Federal Association of Dentists mandate an imaging voltage of ≥60 kilovolts (kV), a spatial resolution of ≥5 line pairs per millimetre (lp/mm), and a distance of ≥200 millimetres (mm) between the focal spot and the tip of the X-ray tube. The average effective dose is about 0.005 millisieverts (mSv) for analogue and 0.003 mSv for digital dental imaging. The question of whether handheld X-ray units can reproducibly and safely meet these requirements remains debated, which has limited their use in Western Europe (Nitschke *et al*., 2021).

Device Overview and Design Features

Structure of handheld dental X-ray devices

Handheld intraoral dental X-ray devices are composed of an X-ray tube assembly. The exposure switch is located directly on the body of the device. The physical form of the device is generally comparable to that of a large handheld camera or a hair dryer. Many models incorporate a protective shield, removable or permanently fixed at the tip of the cone, designated to minimize backscatter radiation to the operator. Because the device is held by the operator, exposures are typically performed with the operator standing beside the patient. These devices are used with intraoral receptors to produce images similar to those obtained with wall-mounted units (Smith *et al*., 2019).

In a phantom-based comparative study focusing on positioning accuracy, Lommen *et al*. reported that wall-mounted devices achieved better centeredness, whereas handheld devices showed better perpendicular angulation, indicating that device handling may influence positioning outcomes depending on the parameter assessed (Lommen *et al*., 2021).

Design types

Two basic design types commonly described for handheld dental X-ray devices are pistol-style (handle and trigger) and camera-style units. For well-constructed devices with appropriate design characteristics, such as backscatter shielding, studies reported annual effective operator doses that are comparable to, or in some settings lower than, those associated with wall-mounted devices and below occupational dose limits. However, results may vary substantially between devices due to differences in design characteristics, highlighting the need for device-specific evaluation (Leadbeatter *et al*., 2021).

Device examples and market notes

Handheld dental X-ray devices are classified as FDA-cleared devices, non–FDA-cleared devices, and tube-based X-ray fluorescence (XRF) units (Ramesh *et al*., 2018).

Among these, NOMAD™ (Aribex, Orem, UT, USA), which received United States Food and Drug Administration (U.S. FDA) clearance as a medical device in 2005, is one of the most widely used FDA-cleared handheld X-ray devices. Until recently, the use of this device was predominantly within the domain of forensic dentists, with the purpose of facilitating post-mortem identification of victims in mass-fatality incidents. Notable examples of this include the 2004 Indian Ocean tsunami and Hurricane Katrina in 2005. Notwithstanding the effective implementation of the NOMAD™ unit in such circumstances, the use of such devices in private dental offices has been subject to regulation in some US states in accordance with the safe operation of radiation-emitting devices (McGiff *et al*., 2012).

Overall, differences in device design and regulatory status highlight the need to evaluate handheld units in clinical settings in terms of both radiation protection and image quality.

Radiation Protection and Operator Safety

In opposition to deterministic effects (e.g., cataracts and skin injury) that manifest above certain dose thresholds, stochastic effects (e.g., carcinogenesis) are generally discussed using the linear no-threshold (LNT) model, suggesting that even low ionizing radiation doses may possess long-term biological risks, especially with repeated exposure. No radiation dose is completely risk-free, according to the International Commission on Radiological Protection (ICRP). In order to evaluate cumulative exposures over time and to improve radiation safety procedures, further clinical research is required (Abubakr *et al*., 2025).

When using X-ray equipment in the United Kingdom (UK), a controlled area is typically set aside to avoid unnecessary exposure of staff and the general public. The "controlled area" is defined as the zone extending 1.5 m in any direction from the patient and the X-ray tube head and includes any location in the path of the primary X-ray beam. It is considered that radiation outside the controlled area is attenuated adequately by effects of distance or appropriate shielding measures. Furthermore, the operator should be outside the controlled area, at a distance of at least 2 m from the X-ray source. Handheld portable X-ray devices violate the rule of restricted access to the controlled area because they are held by the operator. Manufacturers have attempted to address this issue by incorporating lead shielding within the device and often providing a lead-embedded acrylic protective shield at the tip of the X-ray tube head, with the intention of establishing a protective zone against backscatter (Makdissi *et al*., 2016).

A number of studies have been carried out with a view to developing protocols for maximizing operator safety and minimizing exposure to radiation. The following protection measures have been reported as effective in reducing operator dose and enhancing protection against scattered (secondary) radiation during radiographic examinations performed with portable, handheld dental X-ray devices: 1) operating the device with arms entirely extended to increase the distance from the body, 2) using a backscatter shield on the cylinder, 3) using a longer cylinder, 4) wearing a protective apron, 5) wearing lead gloves where appropriate, and 6) using a rectangular collimator. It is of paramount importance to exercise caution in this regard, given that the operator is in close proximity to both the patient and the radiation source. Furthermore, staff members and the general public should be advised to avoid standing in the primary X-ray beam path and to keep a 2 m distance from both the patient and the radiation source (Martins *et al*., 2023).

Beam-aiming devices, rectangular collimation, X-ray receptor positioning, focus–skin distance, and backscatter shielding should all receive special attention. It is also imperative to ensure that the unit produces reproducible dose output under varying environmental and operating conditions (e.g., temperature and battery status). Handheld devices are portable and therefore battery-operated, requiring daily charging. Battery power may decrease during repeated operations, degrading the tube output quality and potentially compromising radiation safety and/or image quality. Therefore, the device must provide a clear warning whenever the battery power is low or the tube current or operating potential falls below the desired value (Berkhout *et al*., 2015).

When using handheld devices, operator exposure (finger and whole-body dosimetry) should be monitored unless it is proved that dose limits for the general public are not likely to be surpassed (Berkhout *et al*., 2015). Protective measures such as device-mounted lead shielding, the use of protective lead aprons, and rectangular collimation have been shown to reduce operator dose and improve protection against scattered (secondary) radiation during radiographic examinations performed using handheld devices (Ivanović, 2024). Rectangular collimation is a well-established dose reduction measure in intraoral radiographic procedures and has been associated with a substantial reduction in patient dose compared with circular collimation (often reported as approximately 50%) (Patel, 2023).

Finally, to minimize risk, staff should be trained in correct handling of the device and should strictly adhere to the manufacturer's instructions (Ivanović, 2024).

Evidence on Image Quality

Ruiz *et al*. reported that, based on objective image-quality metrics, radiographic images acquired using a handheld X-ray unit demonstrated lower homogeneity and contrast, higher brightness and noise relative to those acquired using a wall-mounted system (Ruiz *et al*., 2025a). These quality characteristics may not be ideal for caries assessment, as dentomaxillofacial radiologists generally favour radiographic images of lower brightness and higher contrast for the diagnosis of caries lesions (Ruiz *et al*., 2025a).

In another study focusing on diagnostic performance, Ruiz *et al.* evaluated the effect of a handheld X-ray device on proximal caries lesion diagnosis using different digital imaging systems and concluded that the handheld unit performed similarly to a wall-mounted device, irrespective of the digital radiography system used (Ruiz *et al.*, 2025b).

Importantly, limited clinical (*in vivo*) evidence is available. In a non-inferiority clinical trial comparing handheld and wall-mounted devices for bitewing radiography, Hoogeveen *et al.* reported no significant difference in subjectively assessed diagnostic image quality and concluded that the handheld system was non-inferior to the wall-mounted unit (Hoogeveen *et al.*, 2021).

Overall, available evidence suggests that handheld devices may exhibit less favourable objective image-quality characteristics under certain conditions, while diagnostic performance and/or clinically assessed image quality can remain comparable for specific tasks and protocols (Ruiz *et al.*, 2025a; Ruiz *et al.*, 2025b; Hoogeveen *et al.*, 2021).

Consistent with this variability, Nitschke *et al.* reported that, in accordance with the German Federal Medical Association guidelines, the image quality of a handheld X-ray unit was at a minimum comparable to that of a wall-mounted unit (Nitschke *et al.*, 2021).

Evidence on Dosimetry (Operator and Patient)

Smith *et al.* reported the yearly radiation exposure for operators from five handheld X-ray devices was higher than that from a wall-mounted X-ray unit and therefore advised that handheld units should only be used when wall-mounted devices are not practical (Smith *et al.*, 2019). In contrast, Rottke *et al.* suggested that the use of handheld X-ray devices does not necessarily increase operator radiation risk when used in accordance with the manufacturer's specifications (Rottke *et al.*, 2018).

In their study evaluating the exposure parameters and image quality of a portable intraoral X-ray unit, Zenóbio *et al.* reported that the scatter radiation received by the operator was reduced to acceptable levels when a shielding of the device - particularly the lead-equivalent acrylic backscatter shield - was used. During a periapical radiographic examination of the maxillary left molar, the highest absorbed doses were detected in salivary glands and the oral mucosa, and the patient entrance skin dose was also reported. It was concluded that, under standardized image acquisition conditions (with the unit mounted on a tripod), the obtained images were comparable in quality to those produced by conventional intraoral radiographic devices (Zenóbio *et al.*, 2019).

Gray *et al*. compared dental staff doses from handheld intraoral X-ray devices and traditional wall-mounted systems using both conventional films and digital receptors within the same clinical settings and with the same operators, and reported that the average monthly deep dose equivalent was 0.28 μSv for handheld systems versus 7.86 μSv for wall-mounted devices, with the difference reaching statistical significance (Gray *et al*., 2012).

More recently, Abubakr and Hajee conducted a quantitative dosimetry study evaluating occupational radiation exposure resulting from the use of three handheld dental X-ray devices (UAX-01, HyperLight-G, and EzRay Air P). Dose equivalents were measured at different operator sites, including the orbital surface, thyroid/neck, chest, fingers, and pelvic/gonads, both with and without a protective shield, using calibrated thermoluminescent dosimeters (TLDs) mounted on a mannequin. Significant differences were found between devices and anatomical regions in terms of unshielded operator doses, with particularly higher exposures observed at the hands and around the orbital region. In most regions, shielding considerably decreased measured doses. Additionally, significant cumulative exposure was observed in two months of *in vivo* monitoring during routine clinical use of one device, particularly at the sensor-holding finger. These findings demonstrated that operator doses may approach or exceed recommended limits in high workload settings where protective measures are not consistently implemented. As a result, protective measures and regular dose monitoring are necessary (Abubakr & Hajee, 2025).

Similarly, in a phantom-based comparative study, Raju *et al*. reported that under standardized mandibular molar radiography conditions, a handheld intraoral X-ray device delivered significantly higher radiation doses to both the operator and the patient-equivalent phantom than a wall-mounted system, without providing any improvement in diagnostic image quality (Raju *et al*., 2025).

Taken together, dosimetry findings vary across devices and study protocols, underscoring the importance of model-specific assessment, consideration of clinical workload, and consistent implementation of protective measures.

Clinical Implications and Conclusion

Current evidence suggests that handheld X-ray devices offer practical benefits such as wireless operation, portability, and ease of use in patients with special needs or limited co-operation. However, since operator exposure and image quality may be less favourable depending on the device and operating conditions, they should typically be regarded as supplementary and reserved for circumstances where stationary equipment cannot be used. Radiation protection principles, such as proper positioning, the use of backscatter shielding and collimation, adherence to controlled-area concepts, and consistent use of personal protective equipment, should be strictly applied when their use is necessary. To reduce risk and guarantee safe and efficient use, ongoing staff training, rigorous adherence to manufacturer's instructions, and suitable monitoring of occupational exposure are essential. Lastly, more clinical research is required because a large amount of the available data is phantom based.

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Chapter 4

Antimicrobial Management of Emerging Opportunistic Infections in Liver Transplant Recipients

Adem KÖSE[1]

ABSTRACT

Liver transplantation remains the definitive treatment for end-stage liver disease, yet infectious complications continue to represent a major cause of morbidity and mortality among transplant recipients. Opportunistic infections are particularly important due to the complex immune dysfunction associated with chronic liver disease and post-transplant immunosuppression. This chapter provides a comprehensive framework for the antimicrobial management of emerging opportunistic infections in liver transplant recipients.

The risk and clinical presentation of opportunistic infections vary according to the time elapsed after transplantation. Early post-transplant infections are commonly associated with surgical complications, healthcare exposures, and multidrug-resistant bacterial pathogens. The intermediate period represents the highest risk for opportunistic infections, characterized by viral reactivations such as cytomegalovirus and Epstein–Barr virus, as well as invasive fungal infections. In the late post-transplant period, infection patterns increasingly resemble those observed in the general population but may present with greater severity due to chronic immunosuppression.

Effective antimicrobial management in liver transplant recipients requires a patient-specific and dynamic approach that integrates pathogen-directed therapy, careful evaluation of immunological status, and stewardship principles. Treatment strategies should balance prompt infection control with preservation of graft function, minimization of drug toxicity, and avoidance of antimicrobial resistance. Multidisciplinary collaboration, ongoing reassessment of immunosuppressive therapy, and individualized antimicrobial decision-making are essential to optimize clinical outcomes in this high-risk population.

Keywords: liver transplantation, opportunistic infections, antimicrobial management, immunosuppression, antimicrobial stewardship

[1] Assoc. Prof. Dr., Department of Infectious Diseases and Clinical Microbiology
Faculty of Medicine, Inonu University, Malatya, Turkiye
ORCID ID: 0000-0002-1853-1243, email: adem.kose@inonu.edu.tr

1. INTRODUCTION

Liver transplantation (LT) represents the definitive therapeutic option for patients with end-stage liver disease (ESLD) and selected cases of acute liver failure (ALF). Advances in surgical techniques, perioperative management, and immunosuppressive strategies have markedly enhanced short- and long-term transplant outcomes [1]. Nevertheless, infectious complications continue to pose a major challenge and remain among the leading causes of morbidity and mortality in liver transplant recipients. Particularly, opportunistic infections have a critical importance. These infections arise as a consequence of the pre-existing immune dysfunction related to chronic liver disease, and post-transplant immune reconstitution [2].

The risk and clinical profile of opportunistic infections after liver transplantation are also strongly influenced by time since transplantation. Early post-transplant infections are often related to surgical factors and intense immunosuppression, whereas intermediate-phase infections are dominated by viral reactivations and classic opportunistic pathogens. In the late post-transplant period, infections increasingly resemble those seen in the general population but tend to be more severe and complicated by antimicrobial resistance. Recognition of this temporal framework is essential for rational risk stratification and antimicrobial decision-making [3].

Over the past two decades, the epidemiology of opportunistic infections in liver transplant recipients has evolved substantially. While classical pathogens such as cytomegalovirus (CMV), Epstein–Barr virus (EBV), and invasive fungal organisms remain clinically significant, emerging opportunistic infections have gained increasing relevance. These include atypical viral reactivations, invasive mold infections and multidrug-resistant bacterial pathogens exhibiting opportunistic behavior. Opportunistic infections in liver transplant recipients should not be regarded as isolated clinical events. Infections can precipitate secondary complications, including acute rejection, chronic graft dysfunction, and susceptibility to additional opportunistic pathogens. Additionally, antimicrobial therapies themselves may adversely affect transplant outcomes through nephrotoxicity, hepatotoxicity, myelosuppression, or interactions with immunosuppressive agents. Antimicrobial management must be conceptualized as a dynamic and integrative process, closely aligned with ongoing reassessment of immunosuppressive strategies. Antimicrobial management in liver transplant recipients have to based on pathogen-specific treatment algorithms [2, 3].

Therapeutic antimicrobial decisions must balance prompt infection control with preservation of graft function, minimization of drug-related toxicities, avoidance of clinically significant drug–drug interactions, and mitigation of antimicrobial resistance [3]. This chapter aims to provide a principle-based framework for the antimicrobial management of emerging opportunistic infections in liver transplant recipients.

2.EVALUATION OF PATIENT'S IMMUNOLOGICAL STATUS

From an antimicrobial management perspective, understanding this background is essential to interpret infection risk, atypical presentations, and treatment responses, while avoiding unnecessary mechanistic detail. Patients with end-stage liver disease exhibit a well-recognized state of cirrhosis-associated immune dysfunction, characterized by impaired innate immune responses, reduced opsonic activity, and altered cellular immunity. Defects in neutrophil function, complement production, and antigen presentation contribute to increased susceptibility to bacterial translocation and systemic infections even before transplantation. This immune dysregulation does not resolve immediately after transplantation and may persist into the early post-transplant period [4].

Immunosuppression remains the dominant driver of post-transplant infectious risk. Calcineurin inhibitors, antimetabolites, corticosteroids, and mTOR inhibitors exert complementary effects on host defense, predominantly impairing cell-mediated immunity. This immunological changes viral reactivation, reduces control of intracellular pathogens, and blunts inflammatory responses, often resulting in attenuated or atypical clinical presentations of opportunistic infections. Episodes of acute rejection, treatment with high-dose corticosteroids, or escalation of immunosuppressive regimens may abruptly increase susceptibility to opportunistic infections and necessitate reassessment of antimicrobial strategies. Conversely, reduction of immunosuppression may improve immune control. Viral reactivations, particularly cytomegalovirus (CMV) and Epstein–Barr virus (EBV), play a pivotal role in shaping post-transplant infectious risk. Beyond their direct pathogenic effects, these viruses exert immunomodulatory influences that predispose recipients to secondary opportunistic infections, including invasive fungal disease and multidrug-resistant bacterial infections. Opportunistic infections frequently signal an unfavorable net state of immunosuppression and should prompt both targeted antimicrobial therapy and reassessment of immunosuppressive strategies [4, 5].

In summary, immune dysfunction after liver transplantation creates a dynamic and heterogeneous risk environment for opportunistic infections. For antimicrobial management, the key implication is not detailed immunological mechanisms but recognition of when and why immune vulnerability is heightened. Integrating this understanding into clinical practice allows for more rational antimicrobial selection, appropriate treatment duration, and timely adjustment of immunosuppression, forming the foundation for effective infection management in liver transplant recipients [5].

3.TIMING OF OPPORTUNISTIC INFECTIONS AFTER LIVER TRANSPLANTATION

Transplantasyondan geçen süre, karaciğer nakli yapılan hastalarda fırsatçı enfeksiyonları öngörmek için pratik ve klinik açıdan yararlı öngörü sunar [6].

3.1. Early Post-Transplant Period (0–30 Days): The early post-transplant period is primarily influenced by surgical factors, perioperative complications, and intense immunosuppression. Opportunistic infections during this phase are more commonly reflect healthcare-associated exposures and impaired innate immune defenses. Bacterial infections predominate, often associated with invasive devices, biliary complications, reoperations, or prolonged intensive care unit stays. Multidrug-resistant Gram-negative organisms are of particular concern. Opportunistic fungal infections may occur in high-risk patients, especially those with massive transfusion requirements, reoperation, or early graft dysfunction. From an antimicrobial management perspective, this period often necessitates early empirical broad-spectrum therapy, guided by local epidemiology and individual risk factors. Frequent reassessment and prompt de-escalation based on microbiological data are essential to minimize toxicity and resistance selection. Classical viral opportunistic infections are less prominent but may occur in patients receiving aggressive induction therapy [6].

3.2. Intermediate Post-Transplant Period (1–6 Months): The intermediate period represents the highest-risk window for opportunistic infections after liver transplantation. Continious immunosuppression, antimicrobial exposure, and incomplete immune recovery converge to create optimal conditions for opportunistic pathogens. Latent viral reactivations, particularly cytomegalovirus (CMV) and Epstein–Barr virus (EBV), dominate this phase and frequently influence antimicrobial decision-making beyond direct antiviral therapy. Invasive fungal infections, including candidiasis and aspergillosis, remain clinically significant, especially in patients with additional risk factors such as renal dysfunction, high-dose corticosteroid exposure, or prior CMV disease. Opportunistic bacterial infections, including Listeria monocytogenes and Nocardia species, should be considered in patients with atypical clinical presentations [6].

3.3. Late Post-Transplant Period (>6 Months): Beyond six months after transplantation, infection patterns increasingly resemble those observed in the general population. Late opportunistic infections may include delayed viral reactivations, severe community-acquired viral infections, and opportunistic bacterial or fungal infections associated with chronic immunosuppression. Antimicrobial management in the late post-transplant phase emphasizes targeted therapy, stewardship principles, and reassessment of immunosuppressive intensity [6].

4.CLINICAL IMPLICATIONS OF TEMPORAL CLASSIFICATION

Although temporal classification provides a useful framework, but opportunistic infections may occur outside of classical time frames. Infections occurring during prophylaxis, reactivation following rejection therapy, and delayed onset of invasive fungal disease highlight the limitations of rigid time schedules. Effective antimicrobial management requires integration of temporal risk with patient-specific factors such as recent increases in immunosuppressive therapy, prior infections, and overall clinical course [7].

4.1. Major Opportunistic Pathogens in Liver Transplant Recipients

4.1.1. Viral Pathogens

- **Cytomegalovirus (CMV):** CMV remains the most clinically significant opportunistic viral pathogen in liver transplant recipients [8]. Beyond directly invasive tissue diseases, CMV exhibits potent indirect immunomodulatory effects, increasing susceptibility to secondary opportunistic infections, acute rejection, and graft dysfunction. CMV activity is generally accepted as an indicator of excessive or imbalanced immunosuppression [9].
- **Epstein–Barr Virus (EBV):** EBV reactivation is primarily relevant due to its association with post-transplant lymphoproliferative disorders (PTLD). EBV-related disease illustrates the limits of antimicrobial therapy in the absence of immune modulation [10].
- **Herpesviridae Viruses:** Herpes simplex virus (HSV) and varicella–zoster virus (VZV) may cause severe disease early after transplantation or during periods of intensified immunosuppression. In the late post-transplant period, community-acquired respiratory viruses can result in disproportionately severe illness, prolonged viral shedding, and secondary bacterial or fungal infections, particularly in recipients with chronic graft dysfunction [11].

4.1.2. Fungal Pathogens

- **Candida Species** are the most common opportunistic fungal pathogens in liver transplant recipients, particularly in the early and intermediate post-transplant periods. Invasive candidiasis is frequently associated with surgical complications, biliary pathology, and prolonged intensive care exposure [12].

- **Aspergillus and Other Molds:** Invasive aspergillosis represents one of the most severe opportunistic infections in liver transplantation, associated with high mortality and diagnostic delay. Risk factors include renal dysfunction, high-dose corticosteroids, CMV disease, and prolonged neutropenia. Breakthrough mold infections may occur despite prophylaxis, underscoring the importance of early recognition and appropriate antifungal selection [13].

4.1.3. Bacterial Pathogens

- **Intracellular and Unusual Bacteria:** Listeria monocytogenes and Nocardia species are classic opportunistic bacterial pathogens in transplant recipients. These organisms often present with atypical or subacute clinical features and may involve the central nervous system or disseminated disease [14, 15].
- **Multidrug-Resistant Gram-negative Bacteria:** increasingly behave as such in liver transplant recipients. Prior antibiotic exposure, prolonged hospitalization, and recurrent infections create selective pressure that favors resistant organisms, complicating empirical and definitive antimicrobial management [15].

4.1.4. Parasitic Pathogens

Parasitic opportunistic infections are less frequent but clinically significant due to diagnostic challenges and potential severity. Toxoplasma gondii reactivation and Strongyloides stercoralis hyperinfection may occur in the setting of profound immunosuppression, particularly in recipients from endemic regions or those receiving corticosteroid therapy.

5. PRINCIPLES OF ANTIMICROBIAL MANAGEMENT IN LIVER TRANSPLANT RECIPIENTS

The selection of antimicrobial therapy in liver transplant patients differs fundamentally from the treatment applied to normal patient populations. Suppressed host defence mechanisms, ongoing immunosuppression, and organ dysfunction render the decision regarding routine antimicrobial therapy a more complex process. In this patient group, antimicrobial treatment selection should be personalised, continuously monitored, and correlated with transplant-related specific conditions [16].

5.1. Empirical, Preemptive and Targeted Therapies

Effective antimicrobial management requires timely transition from empirical to targeted therapy whenever possible, supported by close clinical monitoring and serial reassessment of microbiological data [17].

- **5.1.1. Empirical therapy** is often required in the setting of acute clinical deterioration, where delays in treatment may lead to rapid progression and poor outcomes. However, indiscriminate use of broad-spectrum agents carries a substantial risk of toxicity and resistance selection.
- **5.1.2. Preemptive strategies** are particularly relevant for viral opportunistic infections, where early detection of viral replication allows timely intervention before overt clinical disease develops.
- **5.1.3. Targeted therapy,** guided by microbiological and molecular diagnostics, remains the optimal goal but may be delayed or complicated by atypical presentations and limited diagnostic sensitivity.

6. INTEGRATION OF ANTIMICROBIAL THERAPY WITH IMMUNOSUPPRESSION

Antimicrobial therapy in liver transplant recipients cannot be separated from immunosuppressive management. Opportunistic infections frequently signal excessive or poorly balanced immunosuppression, and antimicrobial therapy alone may be insufficient if underlying immune dysregulation is not addressed. Reduction or modification of immunosuppressive regimens should be considered in selected cases, particularly in severe viral infections, invasive fungal disease, or recurrent opportunistic infections. Such decisions require multidisciplinary collaboration, as inappropriate immunosuppression reduction may precipitate acute rejection [18].

7. PHARMACOKINETİC AND PHARMACODYNAMIC CONSIDERATIONS

Liver transplant recipients frequently exhibit altered pharmacokinetics due to hepatic dysfunction, renal impairment, hypoalbuminemia, and drug–drug interactions. These factors significantly affect antimicrobial exposure and therapeutic efficacy. Dose adjustments based on organ function, therapeutic drug monitoring for agents with narrow therapeutic windows, and awareness of interactions with calcineurin inhibitors, mTOR inhibitors, and antimetabolites are essential [19].

8.TOXICITY AND SAFETY CONSIDERATIONS

As antimicrobial toxicity; nephrotoxicity, hepatotoxicity, bone marrow suppression, and neurotoxicity occur more frequently and may be difficult to distinguish from transplant-related complications. Careful selection of antimicrobial agents, avoidance of overlapping toxicities, and proactive monitoring of laboratory parameters are critical components of safe antimicrobial management [20].

9.ANTIMICROBIAL RESISTANCE AND PRIOR EXPOSURE

Cumulative antimicrobial exposure is a defining feature of liver transplant recipients and a major driver of antimicrobial resistance. Recurrent infections, prolonged prophylaxis, and repeated empirical therapy create selective pressure favoring multidrug-resistant organisms. Antimicrobial management must therefore incorporate prior antimicrobial history, colonization status, and local resistance patterns. Empirical regimens should be reassessed and de-escalation should be prioritized whenever microbiological data allow [21].

10. DURATION OF THERAPY AND TREATMENT TARGETS

Treatment duration should be guided by clinical response, microbiological clearance, and resolution of radiologic findings when applicable [22].

11. DIAGNOSTIC UNCERTAINTY AND CLINICAL JUDGMENT

Diagnostic uncertainty is common in liver transplant recipients due to atypical presentations, blunted inflammatory responses, and limitations of conventional diagnostic tests. Early involvement of infectious diseases specialists and close collaboration with transplant teams improve diagnostic accuracy and support timely adjustment of antimicrobial strategies [22].

12. ANTIMICROBIAL STEWARDSHIP IN CLINICAL PRACTICE

Antimicrobial stewardship principles are particularly critical in liver transplant recipients and emphasizes appropriate initiation, early reassessment, de-escalation, and discontinuation when infection is excluded in this patient population [23].

13.CONCLUSION

Opportunistic infections remain a major determinant of morbidity, graft dysfunction, and long-term outcomes in liver transplant recipients despite advances in surgical techniques, immunosuppressive regimens, and prophylactic strategies. The evolving epidemiology of these infections, driven by dynamic immunosuppression, prolonged survival of high-risk recipients, and increasing antimicrobial resistance, continues to challenge standard management approaches. Effective antimicrobial stewardship in this population requires the implementation of a patient-specific strategy. In every treatment decision, post-transplant timing, prior antimicrobial exposure, cumulative immunosuppression, and organ function should be considered [23, 24],

Opportunistic infections should be evaluated as indicators of an unstable net state of immunosuppression and generally require parallel re-evaluation of antimicrobial and immunosuppressive strategies. Balancing timely and effective infection control with minimization of drug toxicity, avoidance of clinically significant drug–drug interactions, and prevention of antimicrobial resistance is central to optimal care. Ultimately, successful management of emerging opportunistic infections in liver transplant recipients depends on close multidisciplinary collaboration, informed clinical judgment, and continuous reassessment of risk throughout the post-transplant course [24].

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Chapter 5

Bulk-Fill Resin Composites: From Material Properties to Clinical Performance

İrem KAYA[1]

Resin-based composites (RBCs) are currently among the most commonly utilized direct restorative materials in modern dentistry, suitable for both anterior and posterior applications.Numerous clinical studies have demonstrated that these materials provide satisfactory longevity and reliable clinical outcomes (Montagner et al., 2018). Their popularity is largely attributed to several favorable characteristics, including easy manipulation, good mechanical performance, the possibility of polymerization on demand, and the availability of different shades and translucency levels that allow improved esthetic outcomes (Alrahlah, 2018). In addition, resin composites exhibit acceptable biocompatibility and are capable of bonding effectively to dental hard tissues.

Clinical investigations have reported encouraging survival rates for composite restorations, with annual failure rates estimated to range between approximately 1–5% for anterior restorations and 1–3% for posterior restorations. Another advantage of composite materials is the possibility of performing repair procedures when defects occur, which may extend the service life of the restoration. Moreover, adhesive restorative techniques allow preservation of sound tooth structure and therefore support the principles of minimally invasive dentistry (Demarco et al., 2017; Macedo et al., 2026).

Despite these advantages, conventional resin composites present certain limitations. One of the main concerns is polymerization shrinkage that occurs during the curing process. This shrinkage may lead to the development of contraction stresses at the interface between the tooth and the restorative material. Accordingly, complications such as marginal imperfections, microleakage, postoperative sensitivity, and the occurrence of secondary caries may be observed. In addition, the inherently limited depth of cure of conventional resin composites necessitates the use of an incremental placement technique, whereby the material is inserted in approximately 2 mm layers to ensure adequate polymerization throughout the restoration.

[1] Sinop Ağız Diş Sağlığı Merkezi
Orcıd no :0000-0003-4125-1888

The clinical application of direct resin composite restorations is associated with several limitations, including polymerization shrinkage and the stresses generated during this process, the degree of monomer conversion, and the inherently limited depth of cure of conventional composite materials. These factors may significantly affect the longevity and clinical performance of restorations. Therefore, achieving adequate polymerization and applying appropriate placement techniques are essential for obtaining optimal clinical outcomes (Hardan et al., 2021).

To minimize polymerization shrinkage stress and enhance the degree of conversion, the incremental placement technique has traditionally been recommended. In this approach, composite resin is placed in layers not exceeding approximately 2 mm in thickness. Such a technique has been reported to improve curing efficiency, preserve marginal integrity, and contribute to satisfactory esthetic results (de Jesus Tavarez et al., 2017). Among the various layering strategies, the three-site technique combined with oblique incremental placement has been suggested as an effective method for reducing polymerization shrinkage during composite placement. In addition, the split technique, which involves the simultaneous modeling of separated increments, has been proposed as another method to help reduce shrinkage-related complications (Scolavino et al., 2016). Evidence suggests that employing a split horizontal incremental approach at the gingival margin may help minimize microleakage. Furthermore, in Class II restorations, the application of a split horizontal incremental technique at the occlusal margin followed by centripetal and oblique placement techniques has been associated with the lowest microleakage values (Chandrasekhar et al., 2017).

Although incremental placement techniques have been widely recommended to improve polymerization and reduce shrinkage stress, these procedures can be time-consuming and technique-sensitive. The placement of multiple composite layers requires careful manipulation and adequate light curing for each increment, which may increase chair time and the risk of incorporating voids between layers (Van Ende et al., 2017).

To overcome these limitations, bulk-fill resin composites were developed as an alternative restorative approach. These materials are designed to be placed in increments of up to 4–5 mm while maintaining adequate depth of cure and acceptable mechanical properties (Ilie & Stark, 2014). Improvements in resin matrix composition, filler technology, and photoinitiator systems have enhanced light transmission and polymerization efficiency compared with conventional composites. Furthermore, bulk-fill composites are designed to reduce polymerization shrinkage stress through modifications in their chemical composition and polymerization kinetics. As a result, these materials may simplify restorative procedures by reducing the number of increments required and shortening clinical working time. Due to these potential advantages, bulk-fill composites have gained increasing attention in restorative dentistry and are now widely investigated for their mechanical properties and clinical performance.

Types and Composition of Bulk-Fill Composite Resins

Bulk-fill resin-based composites (RBCs) are generally categorized according to their viscosity, which reflects their rheological behavior. Accordingly, these materials are commonly divided into high-viscosity (sculptable) bulk-fill composites and low-viscosity (flowable) bulk-fill composites (Table 1). High-viscosity materials contain a greater filler load and therefore exhibit improved mechanical strength, making them suitable for restorations in stress-bearing posterior regions. However, their relatively thick consistency may limit their ability to adapt to irregular cavity surfaces and deep areas of the preparation(Van Ende et al., 2017).

In contrast, low-viscosity bulk-fill composites present greater fluidity, which facilitates their adaptation to cavity walls and internal surfaces. This improved flow may contribute to better marginal adaptation and reduce the risk of void formation during placement. Nevertheless, due to their lower mechanical strength and wear resistance, these materials are frequently recommended to be covered with a final layer of a conventional or high-viscosity composite to ensure adequate occlusal durability(Ilie & Hickel, 2011a, 2011b).

Bulk-fill composites may also be classified according to their polymerization mechanism. Some materials are light-cured, meaning that polymerization occurs primarily through photoactivation when the material is exposed to a curing light. Adequate light transmission is therefore essential to achieve sufficient polymerization throughout the restoration. Alternatively, certain bulk-fill composites employ a dual-cure mechanism, combining both light-activated and chemically initiated polymerization. This approach may be beneficial in deeper areas of the restoration where light penetration is limited, thereby improving the degree of conversion and enhancing restoration longevity(Bucuta & Ilie, 2014).

Regardless of whether the material is high- or low-viscosity, light-cured or dual-cured, the selection of a bulk-fill composite should be based on the specific clinical situation. Factors such as cavity size, functional loading, and aesthetic expectations should be considered when choosing the appropriate material(Ferracane, 2011).

Table 1 Viscosity- and Polymerization-Based Classification of Bulk-Fill Resin Composites(Bakitian, 2026)

Consistency Type	**Approximate Filler Ratio**	**Representative Materials**	**Polymerization Mode**	**Maximum Layer Thickness**	**Functional Features**	**Clinical Applications**
Sculptable (high-consistency)	approx. 75–80%	Filtek Bulk-Fill Posterior (3M ESPE); Tetric EvoCeram Bulk-Fill (Ivoclar Vivadent)	Light-activated	up to 4 mm	Increased filler loading associated with improved mechanical performance	Stress-bearing posterior restorations
Flowable (low-consistency)	approx. 60–70%	Tetric EvoFlow Bulk-Fill (Ivoclar Vivadent); SDR (Dentsply)	Light-activated	up to 4 mm	Enhanced flowability and cavity adaptation; typically requires an additional capping layer	Deep cavities as base material
Dual-polymerizing	approx. 60–80%	Fill-Up (Coltene)	Dual-cure	no specific limitation	Combination of chemical and light curing enabling polymerization at greater depths	Deep posterior restorations and base layers

Key Polymerization Parameters: Conversion Degree, Shrinkage, and Curing Depth

The degree of conversion, defined as the proportion of monomer molecules that are transformed into polymer chains during polymerization, plays a crucial role in determining both the mechanical performance and biocompatibility of resin-based composites (RBCs). A higher conversion rate generally leads to improved mechanical properties such as hardness and strength, while simultaneously reducing solubility and the release of unreacted monomers. Consequently, restorations with a higher degree of conversion tend to exhibit enhanced durability and reduced cytotoxic effects associated with residual monomers. In contrast, insufficient conversion may compromise the mechanical stability of the material and increase the presence of residual monomers within the restoration. Several variables influence the degree of conversion, including the chemical composition of the resin matrix and the filler content of the composite material(Amirouche-Korichi et al., 2009; Hatipoğlu et al., 2024). Previous investigations have also demonstrated that the presence of highly opaque filler particles may limit light transmission through the composite, thereby reducing the polymerization efficiency(Ozciftci et al., 2025). Notwithstanding these considerations, accumulating evidence suggests that bulk-fill RBCs are capable of achieving degrees of monomer conversion comparable to those observed in conventional composite systems, thereby supporting their reliable use in clinical practice.

Despite the improvements in composite technology, polymerization shrinkage and the stresses generated during this process remain significant concerns for bulk-fill resin composites (Kim et al., 2025). During polymerization, dimethacrylate monomers form covalent bonds, which results in a reduction in intermolecular distances and the development of volumetric contraction. This contraction may generate internal stresses within the restorative material and at the tooth–restoration interface. As a consequence, marginal adaptation may be compromised, potentially leading to the formation of microgaps, microleakage, postoperative sensitivity, and an increased susceptibility to secondary caries. The degree of shrinkage occurring during polymerization is determined by several interrelated factors, notably the formulation of the resin matrix, the nature and proportion of filler particles, and the technique adopted during restorative placement

The depth of cure is a crucial parameter in evaluating resin composite performance, describing the greatest thickness of material that can undergo adequate polymerization under standardized conditions. Achieving sufficient curing depth ensures proper monomer-to-polymer conversion throughout the entire restoration, particularly in deeper regions of the cavity. Inadequate polymerization in these areas may compromise mechanical properties and increase the risk of clinical complications such as microleakage or postoperative sensitivity. The depth of cure largely depends on the ability of light to penetrate the composite material. Factors such as increased filler content, higher opacity, and darker shades may reduce light transmission and consequently limit polymerization efficiency (Özdemir et al., 2025; Pérez-Pachas et al., 2025). For this reason, conventional resin composites are typically placed using an incremental technique in layers of approximately 2 mm thickness to ensure adequate curing. In contrast, bulk-fill composites incorporate modified photoinitiator systems in addition to camphorquinone, allowing more efficient light absorption and deeper polymerization. As a result, these materials can generally be placed in increments of approximately 4 mm, although in clinical practice increments exceeding this thickness are not recommended in order to ensure complete polymerization of the restorative material.

Microleakage and Marginal Adaptation

Bulk-fill composites have been developed with modified rheological characteristics intended to improve their adaptation to cavity walls (Ilie et al., 2013). Despite these modifications, available studies indicate that their marginal adaptation is generally comparable to that achieved with conventional composites placed using incremental layering, rather than being superior(Furness et al., 2014).

According to Agarwal et al.(Agarwal et al., 2015), certain low-viscosity bulk-fill materials such as SDR and SonicFill—especially when combined with sonic activation—demonstrate improved adaptation due to enhanced flow behavior during the initial polymerization phase. However, not all flowable bulk-fill materials perform similarly; for instance, X-tra base and Venus Bulk Fill have been reported to exhibit increased gap formation at cervical margins despite their low viscosity (Agarwal et al., 2015; Jang et al., 2015).

Findings from microleakage evaluations are consistent with these observations. Class II restorations using bulk-fill composites show no significant difference in marginal leakage at dentin margins compared to restorations completed with conventional composites and incremental techniques (Kalmowicz et al., 2015). Furthermore, studies by Moorthy et al.(Moorthy et al., 2012) and Webber et al.have shown that using bulk-fill composites as base materials does not significantly improve microleakage outcomes. In these cases, the characteristics of the bonding substrate appear to play a more critical role than the type of restorative material used.

Mechanical Properties

The primary aim of restorative dentistry is the recovery of masticatory function. For this reason, restorative materials are designed to demonstrate mechanical characteristics comparable to those of natural dental hard tissues. These include properties such as compressive strength, , viscoelasticity, hardness and resistance to creep. In combination, these features enable restorations to adapt functionally to surrounding tooth structures under occlusal forces, thereby limiting stress concentration at the interface and contributing to improved long-term clinical success.

The mechanical properties of bulk-fill resin-based composites (RBCs) largely depend on the amount and characteristics of the inorganic filler phase incorporated into the material (Leprince et al., 2014; Santacruz et al., 2025). Increasing filler loading generally enhances compressive strength, surface hardness, and viscoelastic properties, whereas lower filler content may compromise these characteristics. Additionally, filler content is closely associated with polymerization shrinkage and mechanical strength. Bulk-fill resin-based composites (RBCs) are formulated using a combination of inorganic filler particles to achieve an optimal balance among mechanical properties, radiographic visibility, and lower polymerization shrinkage (Leal et al., 2024; Leprince et al., 2014; Santacruz et al., 2025).These fillers are specifically engineered to provide high translucency, enabling deeper light penetration for effective curing while maintaining sufficient mechanical strength for posterior restorations.

Silica (SiO_2) is among the most commonly used fillers, contributing to hardness and wear resistance, and is frequently utilized in nanoscale form to improve polishability and translucency (Leal et al., 2024). Radiopaque fillers, such as barium or strontium glass, are incorporated to facilitate radiographic detection and to enhance mechanical strength. The incorporation of zirconia fillers contributes to improved fracture toughness as well as enhanced radiographic visibility. Furthermore, the addition of pre-polymerized resin fillers in certain systems serves to reduce polymerization-related shrinkage and stress, while simultaneously optimizing handling performance and increasing the achievable depth of cure.

Strong interfacial adhesion between filler particles and the resin matrix is essential for achieving optimal mechanical and physical properties in bulk-fill RBCs (Leprince et al., 2014; Santacruz et al., 2025). To facilitate this interaction, silane coupling agents are widely used to chemically link inorganic fillers with the organic matrix. These agents contain bifunctional groups, one of which bonds to hydroxyl groups on the filler surface, while the other, typically a methacrylate group, participates in polymerization with the resin matrix. This chemical interaction at the interface contributes to increased bond strength, limits the formation of microcracks, and enhances resistance to wear (Paolone et al., 2024).

In addition, various surface treatment methods, including acid etching and plasma treatment, are applied to modify filler surfaces. Such approaches increase surface energy and generate reactive sites that facilitate silane interaction, ultimately improving filler distribution and wetting behavior within the resin matrix (Fernández Godoy et al., 2025).

The incorporation of nanosized fillers further increases the available surface area for interaction, which, when combined with effective silanization, can significantly enhance mechanical strength and surface smoothness (Schweikl et al., 1998). In addition, modifying the resin matrix composition through the inclusion of monomers such as Bis-GMA and UDMA capable of interacting efficiently with silane-treated fillers—can facilitate improved stress distribution and minimize the occurrence of interfacial debonding under functional conditions (Leprince et al., 2014).

Optical Characteristics

The aesthetic performance of bulk-fill resin-based composites (RBCs) is primarily governed by their optical properties, particularly color and translucency. Compared with conventional packable RBCs, bulk-fill materials generally contain lower filler loading, which may adversely affect aesthetic outcomes, leading to increased surface roughness and reduced wear resistance (Fernández Godoy et al., 2025; Paolone et al., 2024). In addition, bulk-fill RBC systems are typically available in a more limited range of shades, which restricts their use in highly demanding esthetic regions.

Despite these limitations, bulk-fill RBCs exhibit increased translucency relative to conventional composites, which enhances light transmission and enables more effective polymerization at greater depths (Fernández Godoy et al., 2025). This optical characteristic is critical for achieving adequate depth of cure in thick increments, which is a fundamental advantage of bulk-fill materials.

To overcome their esthetic limitations, a layered restorative approach is frequently recommended in clinical practice. In this technique, bulk-fill RBCs are used as a dentin substitute in the inner portion of the restoration, while a conventional composite resin is applied as the outer enamel layer. This strategy allows clinicians to benefit from the improved curing efficiency and reduced polymerization stress of bulk-fill materials, while simultaneously achieving superior color matching, surface smoothness, and long-term aesthetic stability provided by conventional RBCs.

Curing Parameters

Curing parameters play a crucial role in the polymerization behavior of bulk-fill resin-based composites (RBCs), directly influencing conversion rate, shrinkage stress, and overall mechanical performance (Barcelos et al., 2023; de Deus et al., 2024; Shimokawa et al., 2020). The efficiency of monomer-to-polymer conversion depends on multiple variables, notably exposure time, light intensity, wavelength, and the distance between the curing source and the material, which collectively govern the final properties of the material.

Adequate exposure time and irradiance are required to ensure sufficient energy delivery for proper polymerization. Insufficient curing conditions may lead to reduced conversion rates, lower microhardness, and compromised mechanical strength, whereas excessive energy input may increase polymerization shrinkage and internal stresses, potentially affecting marginal integrity (Javed et al., 2025; Shimokawa et al., 2020; Torres et al., 2024). Similarly, irradiance and exposure time together determine the energy density delivered to the material, thereby influencing both curing efficiency and final properties (Daugherty et al., 2018; Ilie & Stark, 2014).

The spectral compatibility between the light-curing unit and the photoinitiator system is also critical. For example, camphorquinone exhibits maximum absorption around 470 nm, and deviations from this range may reduce polymerization efficiency (Javed et al., 2025; Torres et al., 2024). In addition, increased curing distance reduces light intensity at the composite surface, leading to inadequate polymerization, particularly in deeper regions (Duratbegović et al., 2024; Ilie & Stark, 2014).

Thermal effects during light curing should also be taken into account, as excessive heat generation may increase the risk of pulpal damage. In addition, variations in experimental methodologies among studies contribute to inconsistencies in determining optimal curing parameters. Therefore, the clinical application of these findings should be approached with caution, taking into consideration the differences between controlled laboratory conditions and actual clinical settings. (Daugherty et al., 2018; Javed et al., 2025; Torres et al., 2024).

Clinical Guidance for Using Bulk-Fill RBCs

Achieving reliable clinical outcomes with bulk-fill resin-based composites (RBCs) requires strict compliance with manufacturer recommendations, including limits on increment thickness, curing duration, and light-curing protocols (Shimokawa et al., 2020). Surpassing the recommended increment thickness may hinder light penetration into deeper regions, thereby causing inadequate polymerization at the restoration base.This can negatively influence mechanical properties, increase wear, and raise the likelihood of marginal degradation and postoperative sensitivity (Barcelos et al., 2023).

It is recommended to use LED curing units capable of delivering light intensities greater than 1000 mW/cm², with routine checks performed to confirm consistent output. Furthermore, keeping the curing tip free of contaminants and placing it as near as possible to the restoration surface is critical for enhancing light transmission and effective energy delivery.

Equally important is the selection of an appropriate adhesive system. Evidence suggests that effective bonding protocols—including proper isolation, accurate etching procedures, and correct adhesive application—combined with compatible adhesive systems, play a crucial role in reducing marginal leakage and postoperative sensitivity (Chesterman et al., 2017). Table 2 presents three common photoinitiators used in bulk-fill RBCs.

Table 2 Common Photoinitiators in Bulk-Fill Resin Composites: Chemical Names, Abbreviations, and Functional Roles (Bakitian, 2026)

Photoinitiator (Chemical Name)	Abbreviation	Functional Role
Camphorquinone	CQ	Main initiator activated during light curing
Ivocerin	IVO	Improves curing depth and light reactivity
2,4,6-trimethylbenzoyl-diphenylphosphine oxide	TPO	Accelerates polymerization and enhances kinetics

In areas subjected to high occlusal forces, such as molars and occlusal surfaces, the use of high-viscosity bulk-fill composites or the application of a conventional resin composite as an occlusal capping layer may enhance wear resistance and overall mechanical performance (Elawsya et al., 2024).

The implementation of proper finishing and polishing techniques is essential for producing a smooth and anatomically well-contoured surface. Such procedures can increase surface hardness, limit plaque adherence, and improve esthetic quality, ultimately supporting the longevity of the restoration (Elawsya et al., 2024).

Ongoing clinical follow-up is crucial for evaluating marginal integrity, observing occlusal function, and recognizing early-stage complications, with conditions such as secondary caries, marginal discoloration, and surface degradation being of particular concern (Elawsya et al., 2024).

Restorative Techniques

Different placement strategies can be used with bulk-fill resin-based composites (RBCs), including single-increment application, incremental layering, or hybrid approaches. The bulk technique consists of placing the material in a single layer of around 4 mm or more, which can enhance clinical efficiency by reducing treatment time. By comparison, the incremental method relies on successive layers of approximately 2 mm to ensure sufficient polymerization. A combined technique incorporates both concepts, often involving a flowable bulk-fill base material followed by a conventional composite overlay to optimize mechanical properties and esthetic results.

The biological response associated with bulk-fill resin-based composites is significantly affected by the thickness of the applied increment. Increased thickness has been associated with greater monomer elution, which may negatively affect biocompatibility (Cebe et al., 2015; Petronijevic Sarcev et al., 2021). Therefore, adherence to manufacturer-recommended increment thickness is essential.

The restorative technique appears to have a limited influence on overall clinical performance. Although bulk-fill RBCs may exhibit lower degree of conversion and cusp deflection compared with conventional layered composites, the application of a conventional RBC overlay has been shown to reduce cusp deflection and microleakage, thereby improving marginal integrity (Tomaszewska et al., 2015; Wafaie et al., 2025). However, no significant differences in microleakage have been reported between bulk and layered techniques, suggesting that sealing ability is not strongly dependent on placement method .

While layered composites may demonstrate higher surface hardness, increased bulk-fill thickness does not significantly compromise microhardness or dentin bond strength . Overall, these findings indicate that bulk-fill techniques can provide comparable clinical performance, with the added advantage of improved procedural efficiency.

Limitations and Prospects (Condensed Version – Intro/Background Suitable)

This review has several limitations related to both study design and available evidence. As a narrative review, it may be subject to selection and interpretation bias due to the lack of a standardized systematic methodology. It should also be noted that the majority of current evidence is derived from laboratory-based (in vitro) studies, which do not adequately simulate real clinical environments, thus reducing the extent to which these findings can be directly applied in practice. Variability in material composition among manufacturers, including differences in filler systems, resin matrices, and curing protocols, further complicates comparisons across studies. In addition, the relatively small number of long-term clinical studies, typically limited to follow-up periods of 2–5 years, may not fully capture late-stage complications, including marginal degradation and secondary caries. These limitations emphasize the need for standardized methodologies and extended clinical investigations.

From a material perspective, bulk-fill RBCs still exhibit certain disadvantages compared with conventional composites. Their mechanical properties are generally lower, which may limit their use in high-stress posterior restorations unless combined with a conventional RBC overlay. This layered approach has been shown to enhance mechanical performance and reduce marginal discrepancies (Cebe et al., 2015; Maucoski et al., 2023). Bulk-fill RBCs also demonstrate certain esthetic constraints, as they tend to show greater color instability and offer a more restricted shade spectrum, which may limit their application in regions requiring optimal esthetics (Cidreira Boaro et al., 2019; Nakhostin et al., 2025)..

Moreover, existing bulk-fill RBC systems show relatively low antibacterial activity and bioactive potential, which can compromise their ability to suppress bacterial colonization and enhance remineralization processes. Future developments should therefore focus not only on improving mechanical and optical characteristics but also on enhancing biological functionality. The incorporation of antibacterial agents, such as silver nanoparticles or chlorhexidine-based fillers, may help prevent recurrent caries, while the addition of bioactive components, including bioactive glass, calcium silicate, or hydroxyapatite nanoparticles, may support remineralization and improve long-term clinical outcomes (Cheng et al., 2015; Yu et al., 2023).

Strengths and Drawbacks of Bulk-Fill Resin-Based Composites

Bulk-fill resin-based composites (RBCs) offer notable clinical advantages, including the possibility of placement in thicker layers (around 4–5 mm), thereby streamlining the restorative process and reducing treatment time. Furthermore, their lower polymerization shrinkage and associated stress may contribute to improved marginal adaptation and enhanced clinical performance (Botrel et al., 2025).In addition, their adequate mechanical properties make them suitable for posterior restorations, particularly in stress-bearing areas.

However, bulk-fill RBCs also present certain limitations. Their optical properties are generally inferior to those of conventional composites, with a more limited shade range and increased susceptibility to discoloration, which restricts their use in highly aesthetic regions (Cidreira Boaro et al., 2019; Nakhostin et al., 2025; Papadogiannis et al., 2015). Furthermore, some bulk-fill materials may exhibit lower surface hardness and wear resistance compared with conventional RBCs, often necessitating the use of a capping layer for improved long-term performance.

Table 3 General Advantages and Disadvantages of Bulk-Fill RBCs (Bakitian, 2026)

Advantages	Disadvantages
Simplified placement using a single-increment technique	Insufficient long-term clinical evidence
Associated with lower polymerization shrinkage stress	May exhibit reduced surface hardness in certain conditions
Effective polymerization at depths of around 4–5 mm	Requires sufficient irradiance for optimal polymerization
Improved handling and adaptation	May necessitate the application of an occlusal capping layer

Table 4 General Comparison Between Conventional RBCs and Bulk-Fill RBCs(Bakitian, 2026)

Comparison Parameter	**Conventional Resin-Based Composites**	**Bulk-Fill Resin-Based Composites**
Placement approach	Usually inserted using an incremental technique with layers not exceeding 2 mm	Commonly applied in a single increment, generally up to 4–5 mm
Curing depth	More restricted depth of polymerization	Greater curing depth, largely related to higher translucency
Filler profile	Higher filler loading primarily aimed at enhancing mechanical performance	Filler system adjusted to balance translucency, curing performance, and strength
Consistency	Supplied in both flowable and sculptable/high-viscosity forms	Also available in flowable and high-viscosity formulations, often with easier handling
Clinical working time	Generally longer because of stepwise placement	Usually shorter due to simplified restorative application
Main indications	Appropriate for anterior and posterior restorations in shallow to moderate cavities	More commonly preferred for posterior restorations, especially in deeper cavities
Mechanical behavior	Typically demonstrates high strength and wear resistance	Often shows comparable performance, although slightly lower strength may be reported in some situations
Shrinkage stress	Relatively higher due to incremental layering	Associated with lower polymerization shrinkage stress

Clinical Outcomes Associated with Bulk-Fill and Incremental Placement Techniques

Bulk-fill resin composites have been extensively compared with the conventional incremental layering technique, and current systematic evidence suggests that both approaches provide similar clinical outcomes. Parameters such as marginal integrity, postoperative sensitivity, incidence of secondary caries, and overall restoration survival appear to be comparable between the two techniques. Despite these similarities, bulk-fill materials offer a significant clinical advantage by allowing placement in thicker increments, which simplifies the restorative procedure and reduces chair time. This may also decrease the risk of contamination during application. On the other hand, the incremental technique enables more controlled polymerization by reducing shrinkage stress through the placement of thinner layers, which may be particularly beneficial in deep cavities or high occlusal stress regions. Some authors also suggest that incremental layering can improve adaptation to cavity walls and enhance the mechanical performance of the restoration. Therefore, although bulk-fill composites provide a more time-efficient alternative, the incremental technique may still be preferred in situations requiring greater control over stress distribution. Overall, both techniques can achieve reliable clinical performance when proper material selection and appropriate clinical protocols are followed (Sengupta et al., 2023).

The greater depth of cure observed in bulk-fill composites is mainly related to their increased translucency, which allows better light transmission compared to conventional resin composites. As a result, these materials can be placed in increments of up to 4 mm while still achieving adequate polymerization. Although this higher translucency may limit their use in highly esthetic areas, bulk-fill composites offer practical advantages, including reduced technique sensitivity and shorter clinical working time.

Another important advantage is the elimination of problems associated with incremental layering, such as void formation and contamination between layers. Full-body bulk-fill composites generally exhibit better mechanical properties than flowable bulk-fill materials and can be used directly in larger posterior restorations without requiring an additional capping layer.

On the other hand, flowable bulk-fill composites are typically used as base materials and need to be covered with a conventional composite in the superficial layer. Despite their increasing use, there is still limited evidence regarding their long-term clinical performance, especially in deep cavities. Therefore, further long-term clinical studies are required to clarify their behavior and overall success in such situations.

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