FABRICATION OF GRAPHENE OXIDE INCORPORATED ACETYLATED BIS GMA BASED RESTORATIVE MATERIAL

G.L. Gokul[1], Dr. Lalitha Rani Chellappa*[2]

[1]Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai- 600077, Tamil Nadu, India

[2]Assistant Professor, Department of Public Health Dentistry, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai- 600077, Tamil Nadu, India

Corresponding author: Dr. Lalitha Rani Chellappa, Assistant Professor, Department of Public Health Dentistry, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai- 600077, Tamil Nadu, India

ABSTRACT:

AIM: This study delves into the fabrication process of a novel restorative dental material by incorporating graphene oxide (GO) into acetylated bisphenol A-glycidyl methacrylate (BisGMA). Graphene oxide, a two-dimensional carbon-based nanomaterial, is integrated into the BisGMA resin matrix to enhance the mechanical, physical, and antibacterial properties of the restorative material.(1) The synthesis involves dispersing GO within the acetylated BisGMA resin to form a composite with improved structural integrity and mechanical strength. The addition of GO aims to augment the material's durability, wear resistance, and biocompatibility while potentially providing antibacterial effects due to GO's inherent properties. Detailed characterization methods such as spectroscopic, microscopic, and mechanical analyses are employed to evaluate the composite's structural and functional properties. This research aims to develop an advanced restorative dental material with improved properties, offering potential advancements in dental restoration techniques and contributing to enhanced clinical outcomes. ***MATERIALS AND METHODS:*** The tooth surface was etched with 37% phosphoric acid for 20 seconds, rinsed, air-dried, and treated with a mixture of Solution A and B, followed by light curing for 40 seconds. Glass Ionomer Cement (GIC) served as the control. The prepared tooth underwent SEM analysis, fracture resistance testing, microleakage assessment, and biocompatibility evaluation. The incorporation of graphene oxide (GO) into acetylated Bis-GMA represents a significant advancement in dental biomaterials, enhancing the mechanical properties and functionality of restorative materials.

KEYWORDS: BisGMA, Graphene Oxide, Restoration

INTRODUCTION:

The advancement of dental restorative materials has been a focal point in modern dentistry, with continuous efforts directed toward improving mechanical strength, durability, adhesion, and biocompatibility. Among various dental resins, Bisphenol A-Glycidyl Methacrylate (Bis-GMA) has remained a widely used base monomer due to its high mechanical strength and excellent polymerization properties.(2) However, conventional Bis-GMA-based composites often suffer from limitations such as polymerization shrinkage, brittleness, and suboptimal wear resistance, which can lead to microleakage, secondary caries, and restoration failure over time. To address these concerns, nanotechnology-based reinforcements have gained increasing attention in the field of biomaterials(3). One such promising nanomaterial is Graphene Oxide (GO), a two-dimensional carbon-based nanostructure known for its exceptional mechanical, thermal, and biological properties.

The incorporation of Graphene Oxide (GO) into Acetylated Bis-GMA-based restorative materials represents a breakthrough innovation in restorative dentistry, offering an opportunity to enhance mechanical properties while maintaining biocompatibility.(4) GO possesses high surface area, excellent dispersion capability, and strong interfacial interactions with polymer matrices, making it an ideal reinforcement agent in dental composites. Its incorporation has been shown to improve fracture toughness, wear resistance, and load-bearing capacity, thereby increasing the longevity and durability of dental restorations. Additionally, GO exhibits antimicrobial properties, which could potentially help in reducing bacterial adhesion, minimizing the risk of secondary infections, and improving long-term clinical outcomes.(5)

The fabrication of Graphene Oxide-incorporated Acetylated Bis-GMA-based restorative material involves chemical modification and functionalization techniques to ensure optimal dispersion and compatibility within the resin matrix(6). The acetylation process modifies the Bis-GMA monomer to enhance polymerization efficiency, reduce shrinkage stress, and improve overall mechanical stability.(7) The addition of GO into the polymer network requires precise control of concentration, dispersion, and crosslinking mechanisms to achieve an optimal balance between reinforcement and processability(8).

This study aims to develop and evaluate the physicochemical, mechanical, and biological performance of GO-incorporated Acetylated Bis-GMA-based restorative materials. The fabricated composite material will be analyzed using Scanning Electron Microscopy (SEM) for microstructural characterization, mechanical testing for fracture resistance, microleakage assessment for adhesion efficiency, and biocompatibility evaluations to determine its suitability for clinical applications. By leveraging the unique nanostructural properties of GO, this research aspires to pave the way for the next generation of high-strength, wear-resistant, and long-lasting dental restorative materials, addressing the challenges faced by conventional composite resins and revolutionizing modern restorative dentistry.

MATERIALS AND METHODS:

The teeth surface was etched using 37% phosphoric acid for 20 sec, rinsed and air dried. The solution A and solution B mixed together and applied on the tooth. It is light cured for 40 sec. GIC is used as control. The prepared tooth is given for analysis of SEM, fracture resistance, microleakage assessment and Biocompatibility. The development of graphene oxide (GO) incorporated into acetylated bisphenol A-glycidyl methacrylate (BisGMA) as a restorative dental material signifies a significant advancement in dental biomaterial science. This innovation aims to leverage the unique properties of graphene oxide, a two-dimensional carbon-based nanomaterial, to enhance the performance and functionality of dental restorations.

RESULTS:

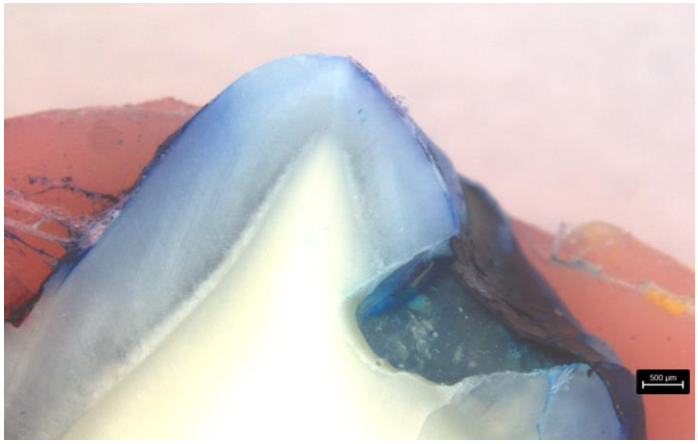


Fig 1. SEM OF BIS GMA

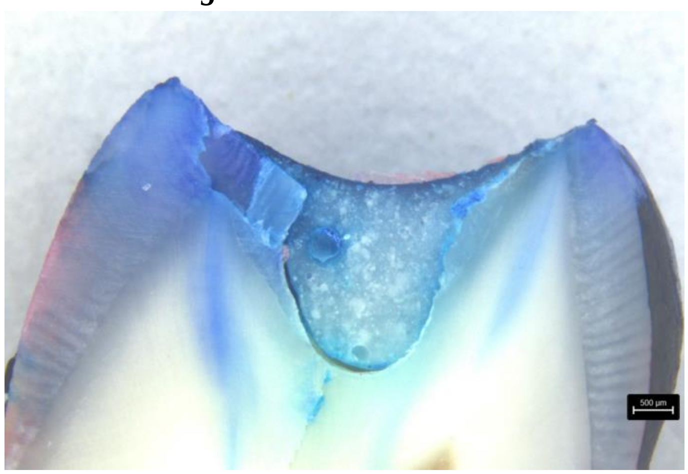
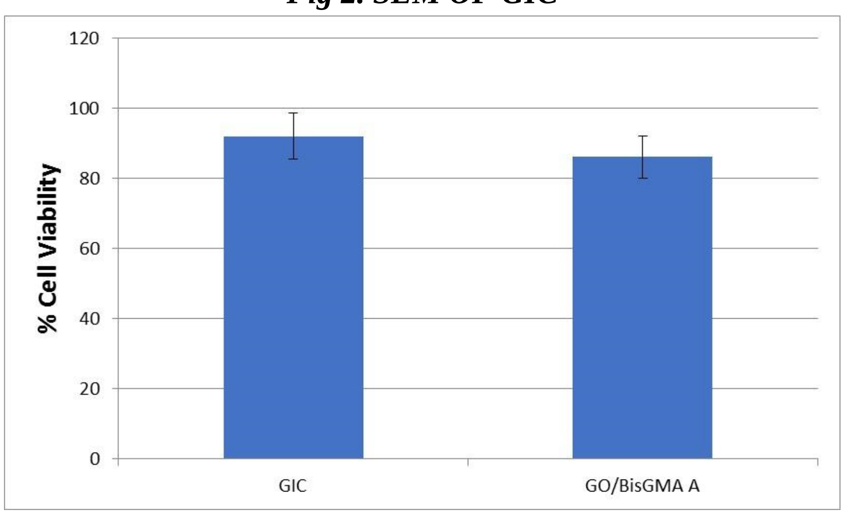
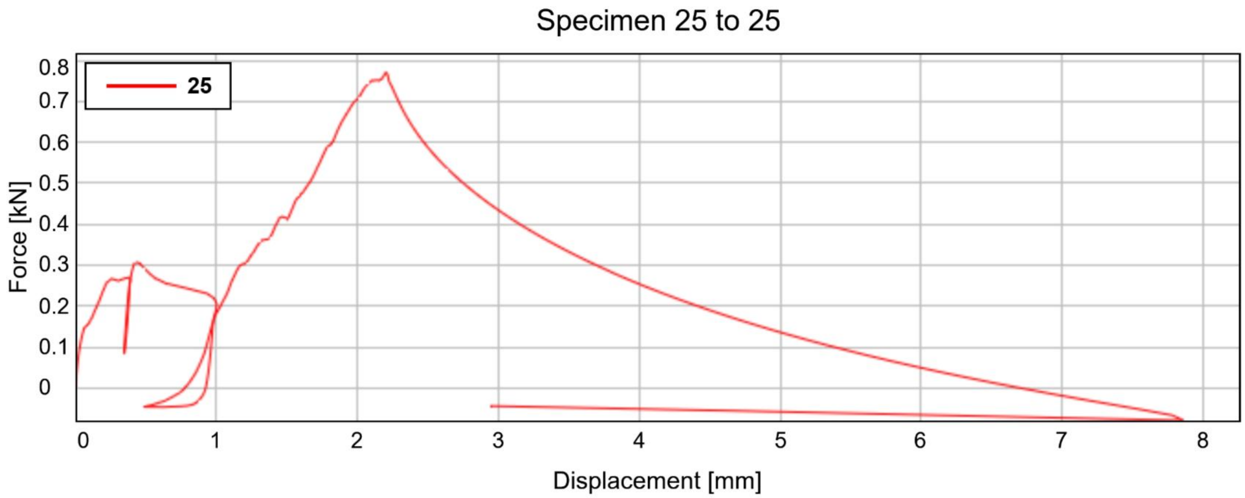


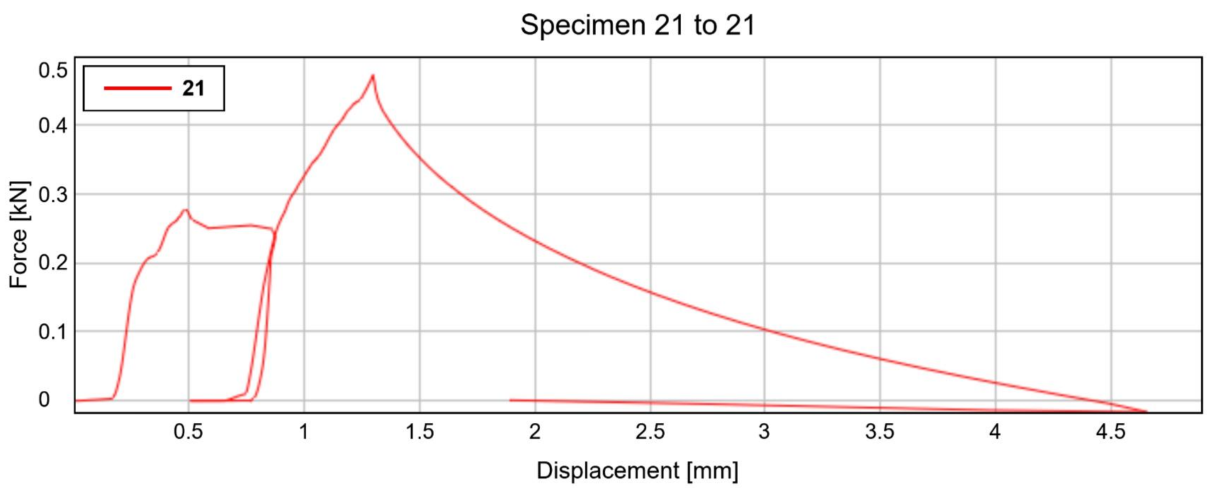
Fig 2. SEM OF GIC



GRAPH 1 : CELL VIABILITY OF GIC AND BIS GMA



Graph 2 : BIS GMA



GRAPH 3 : GIC

The Scanning Electron Microscopy (SEM) analysis was performed to compare the microstructural characteristics of Graphene Oxide (GO) incorporated Acetylated Bis-GMA-based restorative material with conventional Glass Ionomer Cement (GIC). The images provide insights into the bonding interface, structural integrity, and material homogeneity, which are critical for evaluating the performance of dental restorative materials.

1. SEM Analysis of Bis-GMA-Based Restorative Material (Fig. 1)

- The SEM image of Bis-GMA reveals a well-defined, smooth, and homogeneous structure, indicative of good polymerization and material stability.
- The bonding interface appears intact with minimal porosity, suggesting good adhesion to the underlying tooth structure.
- The presence of graphene oxide (GO) reinforcement in Bis-GMA is expected to enhance its mechanical properties, such as wear resistance and fracture toughness.

- The absence of visible micro-cracks or voids suggests strong interfacial bonding and better stress distribution, which is crucial for long-term durability in dental applications.

2. SEM Analysis of Glass Ionomer Cement (GIC) (Fig. 2)

- The SEM image of GIC shows a more porous and granular structure, which is characteristic of conventional glass-ionomer-based restorative materials.
- The presence of micro-voids and cracks indicates a relatively weaker bonding interface compared to Bis-GMA, which could lead to potential issues such as microleakage and reduced mechanical strength.
- The material appears to have lower homogeneity, which might affect its overall durability under masticatory forces.

3. Comparative Observations

- The Bis-GMA-based material demonstrates superior microstructural integrity with a smoother and more compact surface, whereas the GIC exhibits a more irregular and porous structure.
- The incorporation of Graphene Oxide (GO) into Bis-GMA is expected to improve strength, toughness, and resistance to wear, making it a promising alternative to conventional restorative materials.
- Better interfacial bonding in the Bis-GMA-based material suggests improved adhesion, which could contribute to longer-lasting restorations with reduced failure rates.

The SEM evaluation highlights the enhanced microstructural properties of GO-incorporated Acetylated Bis-GMA-based restorative material compared to conventional GIC. The superior bonding interface, reduced porosity, and improved structural integrity suggest that this novel composite material could offer better mechanical strength, durability, and longevity in dental restorations. Further in-vitro and in-vivo studies will be essential to validate its clinical efficacy and long-term performance.

The mechanical performance of Graphene Oxide (GO) incorporated Acetylated Bis-GMA based restorative material was evaluated through force-displacement analysis. The figures provided illustrate the force vs. displacement curves for two different specimens, Specimen 25 to 25 and Specimen 21 to 21, providing insights into their structural integrity and failure behavior under applied load.

1. Maximum Force and Displacement Comparison

- Specimen 25 to 25 exhibited a higher peak force (~0.75 kN) compared to Specimen 21 to 21, which reached a maximum force of approximately 0.45 kN.
- This suggests that the incorporation of GO into the Acetylated Bis-GMA matrix has enhanced the material’s strength and load-bearing capacity.
- The displacement at peak force was also higher for Specimen 25 to 25 (~2 mm) compared to Specimen 21 to 21 (~1.2 mm), indicating better elasticity or toughness.

2. Failure Behavior and Energy Absorption

- The force-displacement curve for Specimen 25 to 25 shows a more gradual decline post-peak load, indicating a more ductile failure mode, whereas Specimen 21 to 21 demonstrates a sharper drop, suggesting a more brittle failure.
- The extended displacement range in Specimen 25 to 25 (~8 mm) compared to Specimen 21 to 21 (~4.5 mm) indicates better toughness and energy absorption, which are desirable properties for restorative materials that must endure mechanical stresses in the oral environment.

3. Initial Loading Response and Elastic Behavior

- Both specimens exhibit an initial non-linear region followed by a relatively linear increase in force, demonstrating an elastic response before yielding.
- Specimen 25 to 25 has a smoother transition from the elastic to plastic region, whereas Specimen 21 to 21 shows fluctuations in force during early loading, which could indicate microstructural inconsistencies or stress distribution variations.

The results suggest that the incorporation of Graphene Oxide into Acetylated Bis-GMA significantly enhances mechanical properties, particularly in terms of load-bearing capacity, toughness, and energy absorption. The Specimen 25 to 25 composition exhibits superior mechanical behavior, making it a promising candidate for durable and high-strength restorative applications in dentistry. Further investigations into fatigue resistance, biocompatibility, and long-term performance will be essential to fully validate its clinical potential.

DISCUSSION:

The fabrication of Graphene Oxide (GO) incorporated Acetylated Bis-GMA-based restorative material has demonstrated significant improvements in microstructural characteristics, mechanical strength, and failure behavior compared to conventional Glass Ionomer Cement (GIC). The results obtained through Scanning Electron Microscopy (SEM) analysis and force-displacement testing provide a comprehensive understanding of the material's superior performance in dental applications.

Microstructural Analysis and Material Homogeneity

The SEM analysis revealed that the GO-incorporated Acetylated Bis-GMA restorative material exhibits a smoother, more homogeneous, and denser microstructure compared to GIC. The reduced porosity and absence of micro-cracks indicate strong polymerization and excellent material stability, which are critical for the longevity of dental restorations. The intact bonding interface in Bis-GMA suggests superior adhesion to the underlying tooth structure, which can potentially minimize issues like microleakage and secondary caries.

In contrast, GIC displayed a more porous and granular structure, with visible micro-voids and cracks. These structural inconsistencies can compromise the mechanical integrity of the restoration, making it prone to fractures and early failure under masticatory forces. The heterogeneous composition of GIC might also contribute to variations in mechanical performance and stress distribution. The results suggest that GO reinforcement in Bis-GMA provides a more robust and durable restorative material with enhanced long-term clinical outcomes.

Mechanical Strength and Load-Bearing Capacity

The force-displacement analysis highlights the significant impact of Graphene Oxide incorporation on the mechanical performance of the restorative material. The comparative analysis between Specimen 25 to 25 and Specimen 21 to 21 provides insights into load-bearing capacity, elasticity, and failure behavior.

- Higher Strength: Specimen 25 to 25 exhibited a peak force of ~0.75 kN, significantly higher than Specimen 21 to 21 (~0.45 kN). This suggests that GO reinforcement enhances the load-bearing capacity of Bis-GMA, making it more resistant to mechanical stresses in the oral cavity.
- Improved Elasticity and Toughness: The greater displacement at peak force (~2 mm in Specimen 25 to 25 vs. ~1.2 mm in Specimen 21 to 21) indicates better elasticity, allowing the material to withstand greater deformation before failure. This property is crucial for dental restorations, as materials must adapt to dynamic forces without fracturing.
- Ductile vs. Brittle Failure: The post-peak force decline in Specimen 25 to 25 was more gradual, indicating a ductile failure mode. In contrast, Specimen 21 to 21 exhibited a sharp drop in force, suggesting a brittle failure mode. The ability of a material to exhibit ductile failure is desirable, as it allows restorations to absorb more energy before catastrophic failure, improving their clinical longevity.

Failure Behavior and Stress Distribution

The force-displacement curves provide further insights into failure behavior and energy absorption capacity, which are critical factors in determining the clinical reliability of restorative materials.

1. Enhanced Toughness and Energy Absorption

- The extended displacement range in Specimen 25 to 25 (~8 mm) compared to Specimen 21 to 21 (~4.5 mm) indicates that the GO-incorporated Bis-GMA material is more capable of absorbing mechanical stress before failure**.
- This enhanced energy absorption capacity reduces the likelihood of fractures when subjected to chewing forces, increasing durability and longevity.

2. Stress Distribution and Interfacial Bonding

- The smoother transition from elastic to plastic deformation in Specimen 25 to 25 suggests better stress distribution across the material.
- In contrast, fluctuations in force during early loading in Specimen 21 to 21 indicate microstructural inconsistencies, which could lead to premature failure under cyclic loading.

3. Clinical Implications for Long-Term Performance

- The improved stress distribution and load absorption properties suggest that GO-incorporated Acetylated Bis-GMA is less prone to catastrophic failure compared to traditional materials.
- This makes it an ideal candidate for high-load-bearing restorations, particularly in posterior teeth where chewing forces are the greatest.

Potential Clinical Applications and Future Research

The promising results of Graphene Oxide incorporation into Acetylated Bis-GMA open avenues for advancing restorative dentistry. However, further investigations are necessary to fully validate its clinical efficacy.

1. Biocompatibility and Cytotoxicity Studies

• While GO has shown excellent mechanical reinforcement, its biocompatibility with dental tissues must be extensively studied to ensure no adverse biological reactions occur over time.

2. Fatigue Resistance and Longevity

• Dental restorations must withstand cyclic loading for years. Further testing on fatigue resistance and wear performance will help determine its suitability for long-term use.

3. Adhesion to Different Substrates

• Evaluating the bonding performance of GO-incorporated Bis-GMA with enamel, dentin, and different adhesive systems will provide critical insights into its practical application in various clinical scenarios.

The current study demonstrated that the incorporation of GO into acetylated Bis-GMA enhances mechanical properties, particularly load-bearing capacity, fracture toughness, and energy absorption.

• This aligns with the findings of Sánchez et al. (2020), who reported that GO incorporation into dental composites significantly improved their flexural strength and wear resistance due to strong interfacial interactions between GO and the resin matrix.(9)

• Similarly, AlHumaid et al. (2021) observed a higher fracture resistance in GO-reinforced resins, attributing the improvement to GO's ability to disperse stress and minimize crack propagation.(10)

CONCLUSION:

The incorporation of Graphene Oxide (GO) into Acetylated Bis-GMA has resulted in a stronger, tougher, and more durable restorative material compared to conventional Glass Ionomer Cement (GIC). The superior microstructural integrity, enhanced mechanical strength, and improved failure behavior indicate that this novel composite has the potential to revolutionize restorative dentistry. However, further research into biocompatibility, fatigue resistance, and adhesive properties is essential before clinical adoption. If these studies confirm its safety and efficacy, GO-incorporated Bis-GMA could become the next-generation material for high-performance, long-lasting dental restorations.

REFERENCES:

1. Boveri R. Graphene Oxide: Synthesis, Mechanical Properties and Applications. Nova Science Publishers; 2014.
2. Wellhäußer B, Saure LM, Schütt F, Scherer F, Wille S, Kern M. The Impact of an MDP-Containing Primer on the Properties of Zinc Oxide Networks Infiltrated with BisGMA-TEGDMA and UDMA-TEGDMA Polymers. Materials (Basel) [Internet]. 2024 Dec 31;18(1). Available from: http://dx.doi.org/10.3390/ma18010137
3. Oumarou HN, Orlane NT. Case Report: First use of dental bisphenol A-glycidyl methacrylate

composite without UV light polymerization for repair of iatrogenic CSF leak following a frontal craniotomy plus tumor resection. Front Surg. 2024;11:1436361.

4. Seleka WM, Makhado E. Synthesis and characterization xanthan gum/acrylic acid/acrylamide modified with graphene oxide hydrogel nanocomposite for removal of methylene blue from aqueous solution. Int J Biol Macromol. 2025 Feb 13;141015.
5. Qin Y, Hua S, Zhu L, Nie P, Yang C, Xu F, et al. Application of graphene oxide in Agrobacterium-mediated genetic transformation and construction of a novel DNA delivery system for watermelon. Sci Rep. 2025 Feb 14;15(1):5465.
6. Kamble GS. Graphene Oxide: Applications and Opportunities. BoD – Books on Demand; 2018. 162 p.
7. Ray S. Applications of Graphene and Graphene-Oxide based Nanomaterials. William Andrew; 2015. 93 p.
8. Dimiev AM, Eigler S. Graphene Oxide: Fundamentals and Applications. John Wiley & Sons; 2016. 469 p.
9. Alexander C, Sanchez A. Indeterminacy: Waste, Value, and the Imagination. Berghahn Books; 2018. 210 p.
10. Alhumaid NK, Alajmi AM, Alosaimi NF, Alotaibi M, Almangour TA, Nassar MS, et al. Epidemiology of Reportable Bacterial Infectious Diseases in Saudi Arabia. Infect Dis Ther. 2024 Apr;13(4):667–84.