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Contact Lens History, Contact Lens Types and Future of Contact Lens

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ABSTRACT

With the rapid development of technology, the use of different materials and device production for sharp vision has accelerated. One of the areas that benefits from developing technology is contact lens technology. In this study, the production-development stages of contact lenses, contact lens types, and materials used in production were investigated. The advantages and disadvantages of using lenses as opposed to glasses have been outlined. In addition, the advantages and disadvantages of the production types of contact lenses compared to each other were examined. In the last stage, studies and expectations for the future of contact lenses are discussed.

Keywords: Contact lenses; hard contact lens; contact lens use; production technology; soft contact lens.

Kontakt Lens Tarihçesi, Kontakt Lens Çeşitleri ve Kontakt Lensin Geleceği

ÖZ

Teknolojinin hızlı gelişimi ile keskin görüş için farklı malzemelerin kullanımı ve cihaz üretimi hızlanmıştır. Gelişen teknolojinin faydalanan alanlardan biri de kontak lens teknolojisidir. Bu çalışmada, kontak lenslerin üretim-geliştirme aşamaları, kontak lens çeşitleri, üretimde kullanılan malzemeler araştırılmıştır. Gözlüklere kıyasla lens kullanmanın avantajları ve dezavantajları belirtilmiştir. Ayrıca, kontak lenslerin üretim türlerinin birbirlerine göre avantaj ve dezavantajları incelenmiştir. Son aşamada, kontak lenslerin geleceğine yönelik çalışmalar ve beklentiler tartışılmıştır.

Anahtar Kelimeler: Kontak Lensler; sert kontakt lens; kontakt lens kullanımı; üretim teknolojisi; yumuşak kontakt lens.

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1. INTRODUCTION

Opticians are eye care health professionals who are trained to fit eyeglass lenses which are prescribed by ophthalmologists to frames and can advise patients to find contact lenses by patients' needs to correct vision problems. They adjust, modify, or align frames with vision-correcting lenses to the face of the customer or patient. Besides being a health care profession, opticianry involves the wholesale and retail trade of eyewear products, including the import and export of items such as frames, contact lenses, solutions for contact lenses, eyeglass lenses, and sunglasses.

Eyeglasses are two parts of special glass or plastic placed in a frame worn in front of the eyes to improve vision. Contact lenses are artificial lenses that are attached to the front of the cornea, which is the outermost region of the eye, allowing people who have refractive errors to see clearly. Contact lenses hold on the cornea owing to the surface tension of the tear film. The tear film is made up of various cells such as conjunctival, corneal, epithelial cells, etc.

The invention of eyeglasses dates back to the 13th century, while contact lenses date back to the 16th century, as we will see in the following section. Production of contact lenses changed drastically from the 15th century up to today. Initially, fluid-filled bowls and/or cups have been utilized then came an era of glass, afterward organic materials have been used, which form the basis of modern wearable contact lenses.

2. HISTORY OF CONTACT LENSES

The history of contact lens development begins in the 15th century with the Codex of the Eye, written in 1508 by Leonardo da Vinci. Da Vinci devised a method that alters corneal power via submerging the eye in a round container that is full of water (Figure 1). However, he did not intend to correct vision — he was concerned about how the accommodation of the eye was achieved (Heitz & Enoch, 1987).

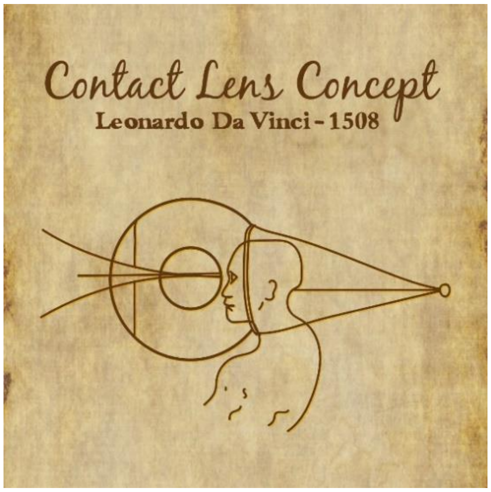

Figure 1: Da Vinci's Contact Lens Concept (Aslan, 2021).

Thomas Young, in 1801, constructed a cup which was filled with a liquid that fitted into the orbital rim, but he also did not intend for this device to be used to correct refractive errors, instead he tried to enumerate some dioptrical propositions and described an instrument for calculating the focal length of the eye (Young, 1801).

In the late 1880s, many research activities have been carried out. Physicist Eugene Fick was the first to describe how to fabricate and fit contact lenses to the eye. He manufactured a spherical glass segment for the correction of refractive errors. This glass lens was made from heavy brown glass and was 18-21 mm in diameter (Efron & Pearson, 1988).

The first powered contact lens was produced by August Müller. He reported the alteration of his 14.00 dioptres myopia using a scleral contact lens in 1889. The inability to wear this lens for more than 30 minutes was likely because of limbal pressure, given that the primary optic diameter being too small (Pearson & Efron, 1989).

50 years passed without much improvement regarding contact lens development, Carl Zeiss proposed the production of contact lenses from a plastic material called cellon (cellulose acetate) Manufacturing process was by the process of moulding. The primary advantage of plastic over glass was that they would be unbreakable and maintain ocular protection. Unfortunately, after being used by patients, it was observed that the contact lens made from cellon had many disadvantages (Pearson, 2015):

- It did not have the grade of polish of glass lenses
- It was not stable because of humidity and temperature effects
- It caused extensive corneal erosion

In 1936, Room and Haas Company invented polymethyl methacrylate (PMMA) which is transparent plastic, and also in 1936, Feinbloom devised a scleral lens that includes an opaque plastic touchable part and a pure glass centre. Following that, scleral lenses began to be manufactured from PMMA. These lenses were lighter than glass lenses, quicker to manufacture, and shatterproof. While these lenses were comfortable and didn't cause irritation, they required a polish of their optical zone every six months (Pearson & Efron, 1989).

Optical technician Kevin Tuohy separated haptic portion and corneal portion when lathing a PMMA scleral lens unintentionally. After that, he wondered even if the corneal portion could be worn, so he brightened the edge, placed it in his eye, and observed that the lens could be used. He filed for a patent for his invention in 1948 (Braff, 1983).

In 1960, Wichterle and Lim published that hydrophilic gels could be used in manufacturing contact lenses, and arteries (Wichterle & Lim, 1960). After that, Wichterle began initial attempts to produce soft lenses fabricated from hydroxyethyl methacrylate (HEMA), and manufactured the initial suitable soft contact lenses in the past few days of 1961 (Wichterle, 1978). Based on the results of this study, companies began to utilize Wichterle’s results, and Bausch & Lomb Company of Canada (formerly the USA) acquired a patent to manufacture soft contact lenses. Later, it introduced soft lenses to the world market.

Early HEMA lenses produced by Bausch & Lomb were thick and not comfortable to wear. So much of the research in contact lens technology afterward has been related to the invention of materials and innovative lens construction that aims to increase adaptability, mostly by improving corneal oxygenation and curtailing the absorption of lipids, proteins, and tear components (McMahon & Zadnik, 2000).

After the invention of soft lenses, patients continued to wear the same set of lenses until they caused significant discomfort and serious eye reactions. In 1985, Holden proved the advantages of replacing lenses regularly (Holden et al., 1985). However, there was a big challenge: soft lenses were costly; therefore, not all patients could afford to change these lenses regularly. To solve the cost problem, clinicians and engineers began to work and a group led by Michael Bay developed a molding process to manufacture multiple individual lens packs at a considerable cost. Afterward, Johnson and Johnson Company reworked the polymer formulation and utilized Stabilized Soft Moulding technology to eliminate the shortcomings of Michael Bay’s lens and introduced Acuvue lenses (Mertz, 1997).

2.1. Categories Of Contact Lenses And Materials Used

2.1.1. Soft Contact Lenses

Soft contact lenses are produced from flexible plastics, their materials can be divided into two groups:

- Hydrogel materials
- Silicone hydrogel materials

As for hydrogel materials poly (hydroxyethyl methacrylate) or pHEMA was invented in 1952 by Drahoslav Lim and Otto Wichterle for biological use (Grant et al., 2022). It was synthesized by polymerization using 2-hydroxyethyl methacrylate as raw material and triethylene glycol dimethacrylate as a cross-linking additive, and the hydrophilic behavior of HEMA is due to the presence of the hydroxyl group at the end of the monomer (Wichterle & Lim, 1960).

As already mentioned in the second section, pHEMA lenses were first produced by the Bausch and Lomb Company and proved to have caused hypoxia and lens spoliation. To increase oxygen transmission to the eye, manufacturers decided to develop thin lenses, and soon O3 series lenses were manufactured by Bausch & Lomb. O3 series soft lenses were less than half the thickness of the original thick lenses.

The second type of soft contact lenses is the ones that are made up of silicone hydrogel materials. Silicone hydrogel materials have a major advantage over hydrogel materials in that they have higher oxygen permeability, so that they can be worn for longer periods.

One of the main methods used to manufacture silicone hydrogel materials is using macromers. A macromonomer is a polymer or oligomer with one end-group that acts as a monomer. There are also different methods of obtaining silicone with hydrogel monomers, but they are out of the scope of this article.

2.1.2. Hard (Rigid Gas Permeable) Contact Lenses

A hard (RGP) contact lens is manufactured from a material that allows carbon dioxide and oxygen gas but contains no water. The first hard contact lenses were manufactured from glass. After 1950, plastic materials were selected for replacement of glass lenses. PMMA was a favorite material because it had a glass-like look and was easy to fabricate. However, its largest failure as a contact lens material is its lack of oxygen permeability (Harvey et al., 1990).

In the mid-1960s, scientists began to develop silicone rubber, which is much more permeable to oxygen than PMMA, and they proved clinically that it had little harmful outcome on corneal breathing (Hill & Schoessler, 1967). Nevertheless, the question of how to maintain satisfactory surface properties has never been solved. To address this problem, several flexible thermoplastic materials were studied, best results were achieved with poly(4-methyl-1-pentene), commercially called TPX, and also with cellulose acetate butyrate (CAB). The oxygen permeability of TPX and CAB is approximately 20 times larger than that of PMMA (Refojo et al., 1977).

To further increase oxygen permeability, contact lenses were fabricated using polymers derived from perfluoroalkyl ethyl methacrylates (Tighe, 1997). After the invention of perfluoroalkyl ethyl methacrylates, it became possible to adjust oxygen penetrability and rigidity, which increases processability and wettability. To enhance oxygen penetrability and material strength, original siloxanylstyrene monomers were introduced into the polymer backbone. Menicon Z material was produced. Menicon Z utilizes tris silyl styrene. Menicon Z has outstanding mechanical specifications, permitting the lens to be much slimmer than an ordinary rigid lens which relies on silicone-encompassing methacrylate compounds (Szczotka, 2004). Due to its excellent mechanical properties, it is possible to wear lenses made from Menicon Z for 30 days.

2.1.3. Advantages and Disadvantages

Soft contact lenses are easier to adapt to the eye since they drape over the cornea, and that maintains increased comfort because they do not feel much when wearers blink. Soft contact lenses are wider in diameter, which makes them much more comfortable to wear.

Disadvantages of soft lenses include the risk of tearing and damaging the lens more easily and less oxygen transportation to the cornea than with rigid gas-permeable contact lenses. Soft contact lenses cannot effectively correct astigmatism satisfactorily. Hydrogel absorbs tear fluid and therefore requires sufficient tear production, so patients who do not have sufficient tear production may need to use lubricant eye drops. Proteins and dirt particles may get deposited in the hydrogel of soft contact lenses, which have sponge-like structures.

As for RGPs, they allow more oxygen transportation to the cornea by tear. RGP provides a very clear vision. Nevertheless, RGP is smaller in diameter than soft contact lenses and that makes them vulnerable to being dislocated easily and pushed off to the side more easily than SCL.

2.1.4. Lens Care Systems

Regardless of type, all contact lenses must be subjected to a maintenance routine after each use. Maintenance routine includes cleaning, disinfection, and safe storage in a suitable environment.

There are three types of sediment deposits on contact lenses: organic, inorganic, and environmental. Major sources of organic deposits are proteins such as lysozyme, lactoferrin, and albumen, lipids, and carbohydrates. Lipids are observed in minor quantities on hydrophilic lenses, but they can deposit on rigid gas permeable lenses, which encompass silicone. This leads to a hydrophobic contact lens. The most observed types of inorganic deposits are jelly bumps which are round, circular deposits made up of cholesterol and calcium. They occur commonly because of long-term wearing of contact lenses. Common environmental deposits are particles from cosmetics (Ghanem, C., & Bailey, M. D., 2004).

To cope with deposits, mostly multipurpose solutions are used. The multipurpose solution is used to clean, sterilize, and store soft contact lenses. The advantage of these solutions lies in the fact that they don’t require the use of other auxiliary components. They account for nearly 90% of lens care systems in Australia, Europe, and Canada (Morgan et al., 2016).

Obey the below procedures for the appropriate use of multipurpose solutions:

- Wash your contact lenses and keep them in fresh solution whenever you use them.
- Do not mix a new solution with an old or used one.
- Drain all the remaining solution out of the case and dry it with a clean tissue.

Hydrogen peroxide-based systems can also be used to clean, sterilize, and store contact lenses. They are recommended to be used if the patient is allergic to constituents in a multipurpose solution that causes rubor or irritation of the eye. Hydrogen peroxide-based systems require the use of a customized container that comes with the solution. This customized container reacts with the hydrogen peroxide, converting it to a non-toxic salty solution over time. However, it is important to keep in mind that if the patient uses colored contact lenses, the color of them may fade. Fading happens when the dye of a colored contact lens is of a type that reacts with hydrogen peroxide. This is due to an oxidative reaction.

3. METHODS OF PRODUCTION

3.1. Soft Contact Lens Production

Three methods are employed to manufacture soft contact lenses:

- Spin casting
- Lathe cutting
- Injection molding

In the spin casting process, a spinning mold machine is used. Liquid contact lens monomer is injected into a concave spherical spinning mold. The contact lens front surface is created by the curvature of the Spinning Mould machine. Lens parameters are controlled by the following (Banko, 1976):

- Shape of mold
- Spin speed
- Amount of injected material
- Surface tension

After spinning, the liquid polymer is converted into a solid state by ultraviolet light. The periphery of the lens is edged and furbished to produce an even surface (Figure 2).

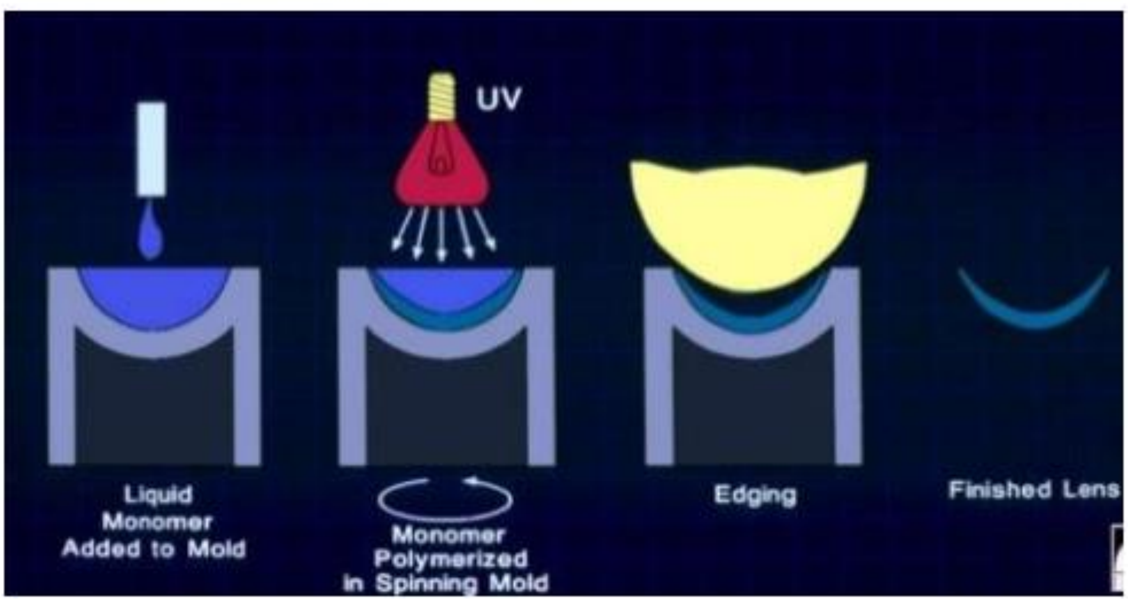

Figure 2: Spin Casting Process (Shah & Chowdhury, 2020).

In the lathe-cutting process, hard disks of contact lens substance are attached on a rotating shaft that revolves 100 revolutions per second and is formed with a cutting tool (Figure 3). It is then polished and hydrated. Even though this process maintains more symmetry and bigger lens accuracy, it requires more advanced technology, more time, and more resources in proportion to cast molding (Shah & Chowdhury, 2020).

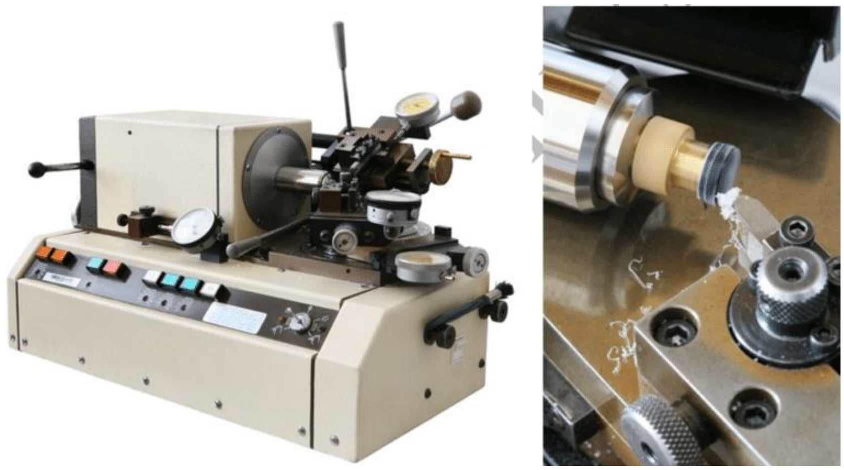

Figure 3: Lathe Cutting Tool (Michalek et al., 2022).

In the injection molding process, soft contact material (monomer) is warmed up until it gets into the liquid state, and then it's injected into precise, pressurized molds (Figure 4). After they are shaped, they undergo polishing, hydrating, and quality control testing. Injection molds are prone to thousands of pounds of pressure every cycle. To stand this pressure, these molds should be made from very durable materials that can withstand recurrent use without distorting. While injection molding has a high upfront cost for the molds, at a certain production volume, injected contact lens are cheaper than lathe-cut contact lenses.

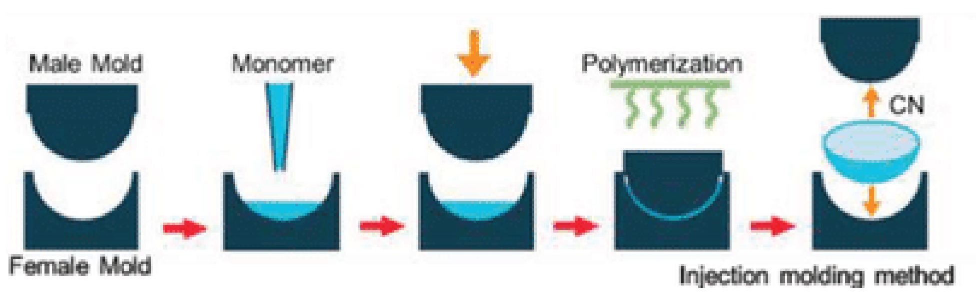

Figure 4: Injection Moulding Process (Zhu et al., 2022).

3.2. Hard Contact Lens Production

Conventional lathes cut the back and front lens surfaces from buttons. The buttons are made up of a mixture of approximately 10 liquid monomers, which add a bunch of peculiarities such as oxygen permeability, stability, etc. This mixture is injected into molds and polymerized, using heat, turning the liquid into hard polymer. The hardened material is removed from the mold and annealed. Annealing is a heating process that allows the molded material to relax and reduce stresses which have occurred from being trapped inside the molded rod. Buttons look very bright in color, but after lathe cutting, most of the material is cut away, and the final product will typically have a soft color at the end. The advantages and disadvantages of the three methods in the contact lens manufacturing process are summarized (Table 1).

Table 1: Pros and Cons of Contact Lens Manufacturing Processes.

Process	Advantages	Disadvantages
Lathe Cutting	Can be used to cut a wide range of materials	Labour intensive
	Can be used to manufacture soft contact lenses and rigid contact lenses	Cleaning and polishing are needed
	More precise dimensioning	Not cost-effective
	Applicable to wide range of designs	Slow to manufacture
Spin Casting	More suitable for mass production	Parameters are few in comparison with lathe-cutting
Injection Moulding	Thinner	Waste
	No need to polish	Parameters are few in comparison with lathe-cutting
	Lowest cost	
	Most suitable for mass production because of the speed of production	
	Highest quality	

4. FUTURE OF CONTACT LENSES

Besides visual enhancement with ordinary contact lenses, there are also smart contact lenses that are enhanced by technology. They have advanced technology designed to enhance human possibilities. Recently, smart contact lenses have been studied and produced for a diversity of purposes, from applications including the substitution of conventional glasses to biomedical applications. Especially smart contact lenses manufactured using pHEMA hydrogels have been widespread for biomedical applications. For example, Ulu manufactured an antibacterial contact lens made up of pHEMA hydrogel loaded with boric acid to treat eye infections (Ulu et al., 2018). Smart contact lenses with integrated circuits have started changing traditional devices to succeed non-invasive and easy physiological measurements. For example, a prototype smart contact lens produced by Google Company of the USA can measure glucose levels from tear fluid (Figure 5). That said, it is wise to predict that non-invasive observation of the wearer's biomarkers and health indicators could be a big market in the future.

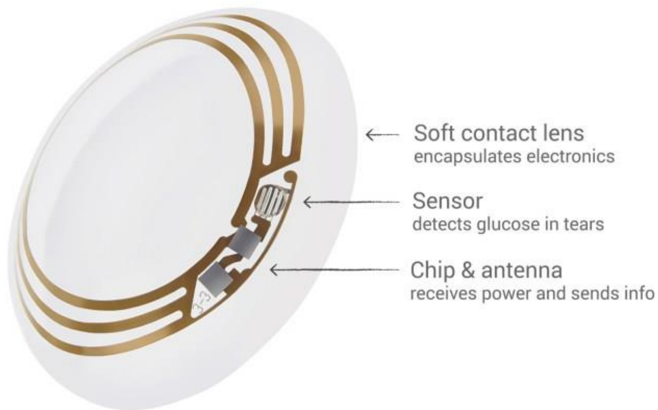

Figure 5: Google’s Smart Contact Lens (Lardinois, 2014).

The concept of contact lens technology extending beyond its basic use can be seen in Augmented Reality applications. Augmented reality, which allows monitoring the real world complemented with computer-generated content, is getting popular. The technology developed by EP Global Communications in the USA revolves around the production and integration of electronics into modern silicone hydrogel lenses. This innovative technology permits the incorporation of flexible electronics into the contact lens throughout the fabrication process, supplying solutions in the areas of autofocus and optics for augmented reality ("Smartphone Controlled Vision is Coming", 2017).

Mojo Vision, a company in the USA, is in the process of manufacturing a contact lens that offers AR. In January 2022, the company teamed with Adidas and other fitness companies to bring data-tracking eye lenses to market (Heater, 2022).

5. CONCLUSION

The purpose of this review article is to raise awareness by providing information about contact lenses to opticianry students, academicians, contact lens wearers, and the general public. Briefly, the purpose of the review article is to raise awareness by providing information about contact lenses. The evolution of contact lenses was a gradual process, initially beginning in Europe and eventually achieving global reach. Both the materials used to produce contact lenses and the methods of manufacturing have changed considerably from the early days of the contact lens era. Initially, contact lenses were made from glass and later from PMMA.

However, these materials had limited oxygen permeability. Advancements in chemistry have enabled the development of hydrogel lenses, which have higher oxygen permeability and improved comfort.

The future of contact lenses is looking bright, especially considering advancements in smart contact lens technology. Smart contact lenses can be among the most popular wearable technologies, enabling important advantages in people's lives. While the potential usage areas for the future of smart contact lenses are not completely realized, it is deemed limitless. In the future, smart lens technology could let the wearer take photographs with their eyes or watch various body parameters to support the early detection and treatment of diseases. There is inspiring and developing potential for this future technology.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

CONTRIBUTIONS OF AUTHORS

Formal analysis, research, resources, writing-original draft preparation, writing-review and editing HKM, formal analysis, research, resources, writing, writing-review and editing MK, formal analysis, research, resources, writing-original draft preparation, writing-review and editing were done by AK.

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