Review

Strategies for Sustainability and Cost Optimization in Corneal Transplantation: From Surgeons' Perspective

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Abstract

The main purpose of this review is to provide an overview of surgical strategies that can be implemented in keratoplasty to maximize resource utilization and enhance sustainability. To achieve this, we conducted a thorough search of PubMed to identify articles on sustainability and cost-effectiveness in surgical settings, as well as studies comparing the cost-effectiveness of different keratoplasty techniques. Our review shows that both penetrating keratoplasty and lamellar techniques are cost-effective. However, lamellar techniques offer greater long-term sustainability and cost efficiency in addition to improving patient vision. For corneal transplantation surgeries, strategies such as reducing operating room time, properly educating the surgical team, reusing instruments like trephines and punches, using surgical materials economically, and selecting the appropriate surgical technique are recommended to enhance sustainability and reduce costs. The strategies outlined could contribute to more sustainable practices in keratoplasty procedures. In conclusion, although ensuring the economical use of surgical materials is beneficial for improving sustainability and reducing costs during surgery, utmost care should be taken to preserve safety and effectiveness while taking measures to reduce costs, and a balance should be achieved between sustainability and patient safety.

Keywords: Cornea, keratoplasty, sustainability

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Introduction

"The life of every child born today will be profoundly affected by climate change. Without accelerated intervention, this new era will come to define the health of people at every stage of their lives." -Lancet Countdown 2019 report.[1]

Climate change is recognized as one of the greatest threats to global health in the 21st century.[2] The health sector is known to contribute significantly to the production of greenhouse gas emissions, with a report published in 2019 stating that health sector-related emissions accounted for at least 4.4-5.0% of all global greenhouse gas emissions.[3] To highlight the significant contribution of the health sector to carbon emissions, it has been emphasized that if global health care were a country, it would be the fifth largest contributor to carbon emissions.[4] Ophthalmology, which differs from other branches in that it has rapid patient circulation and the highest number of surgeries in the health system, may constitute a substantial part of this burden.

Penetrating keratoplasty has been regarded as the most commonly used procedure in corneal transplant surgery since it was first performed by Eduard Zirm in 1905.[5] This technique is successful, safe, and effective, and many innovations and advances have been achieved in this field in recent years. Worldwide, the demand for corneal transplantation has been reported as approximately 12.7 million patients. However, it is estimated that this number may be even higher due to problems such as underreporting and limited access to health care in developing countries.[6]

The main cost drivers in penetrating keratoplasty are often the length of hospital stay, recurrent outpatient visits, and visual rehabilitation procedures.[6] Additional costs arise from the preparation, proper storage, and transportation of donor corneas. In addition, the choice of surgical technique can also play an important role in reducing costs and ensuring sustainability. To date, however, there has been no publication in the literature

evaluating from the surgical perspective with the aim of reducing keratoplasty costs and contributing to sustainability.

Careful planning and precautions are necessary ensure a sustainable future and the appropriate allocation of resources. Therefore, the main objective of this review is to provide an overview of surgical strategies that can be implemented in keratoplasty surgeries to maximize resource utilization and increase sustainability.

Penetrating Keratoplasty: Is it a Cost-effective Surgical Procedure?

In many publications in the literature, it has been clearly demonstrated that penetrating keratoplasty is considered a cost-effective surgical procedure and complies with the threshold value found in the World Health Organization's definition of cost-effective interventions.[5,6,7] Hirneiss et al.[5] evaluated the cost-effectiveness of penetrating keratoplasty in patients with poor binocular visual acuity and reported that penetrating keratoplasty was cost-effective, despite being an expensive procedure during the operation. Considering graft survival in the 10-year postoperative period, they determined a cost utility of 11,557 United States dollars (USD) per quality-adjusted life year. As visual acuity is the main criterion considered when determining the ophthalmological benefit, it can be assumed that a patient with poor visual acuity in one eye and good visual acuity in the other eye will benefit less from penetrating keratoplasty than a patient with poor binocular visual acuity. However, Hirneiss et al.[5] emphasized that despite good visual acuity in the fellow eye in preoperative assessment, performing penetrating keratoplasty in the treatment of the eye requiring transplantation surgery is still quite cost-effective.

Reducing Costs and Contributing to Sustainability in the Operating Room

The basic strategy for sustainability can be summarized as the 5R rule (reduce, reuse, recycle, rethink, and research). All of these principles can be applied to keratoplasty procedures.

1. Reduce

Reducing Operative Time

It is a well-known fact that longer operative times lead to higher costs. A review published by Wu et al.[8] examined the importance of a surgical team consisting of well-trained personnel. The authors emphasized that an experienced team could significantly reduce operative times, thereby lowering costs. Another study analyzed the effect of preparing a preoperative checklist on operating room turnover time and costs.[9] It was determined that preoperative checklists resulted in the faster provision of necessary surgical instruments in the operating room and reduced operating room usage time and surgical costs.

Reducing Energy Consumption and Plastic Waste

Energy consumption can be reduced by turning off lights when the operating room is not in use and turning off devices when not needed. With current technology, timers and motion detector systems can also help save energy in the operating room.[10]

One of the most important sources of waste is the plastic packaging used to store surgical instruments and devices (Figure 1). In addition to being harmful to the environment, such disposable plastic packaging incurs serious costs.[11] Instead of packing single-use surgical equipment individually, packing in batches containing appropriate gloves and disposable gowns may be a useful way to reduce waste associated with plastic packaging. In addition, single-use sterile packs often contain unnecessary items not used in the surgical procedure. Revising these packs and reducing unnecessary items can contribute to improving sustainability.

Cunningham et al.[12] evaluated 113 surgical procedures in their 12-day pilot study and determined that 46 items were unnecessarily included in surgical packs. In the same study, the results of a 3-week follow-up and evaluation of 359 surgical procedures indicated potential savings of 1,111.88 USD by eliminating unnecessary items from surgical packs. In the continuation of the study, removing unnecessary items from surgical packs over the course of 1 year resulted in savings of 27,503 USD.[12]

The "do not open what you will not use" principle should be the main viewpoint for ophthalmological surgeons.

Single Cornea, Multiple Surgeries

Another option to both solve the high demand for keratoplasty and increase sustainability may be to use a single donor corneal tissue for multiple lamellar surgeries such as deep anterior lamellar keratoplasty (DALK) and Descemet membrane endothelial keratoplasty (DMEK). In a study by Siddharthan et al.[13], this method was reported to be successful and safe, and may allow corneal surgeons in developing countries to more sustainably meet the demand for keratoplasties without the need for expensive tools such as a microkeratome. Opting to use a single donor cornea for multiple lamellar procedures, such as both DALK and DMEK, may be a sensible way to meet the high demand for keratoplasty as well as improve sustainability.

2. Reuse

In keratoplasty procedures, many surgical instruments such as trephines and corneal punches that are marketed by manufacturers as single-use can be reused in corneal transplantation. In addition, studies have reported that sterile marking pens and rulers provided in plastic packaging can be reused with a negligible risk of infection.[14]

There is no study examining the reuse of disposable products made for single use in various ophthalmological surgeries. However, in a study evaluating gynecological operations, the reuse of disposable devices was reported to yield similar efficacy and safety when compared to single use.[15]

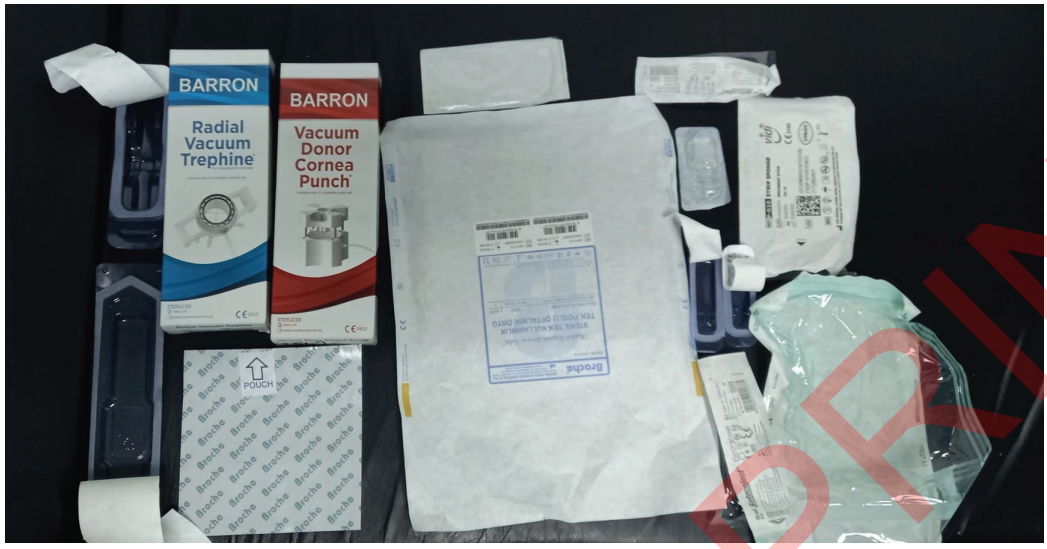

Figure 1. Plastic and paper waste generated during preparation for keratoplasty

Manatakis and Georgopoulos[16] evaluated the impact of reusing instruments in laparoscopic patients compared to single-use products and determined that costs were 9 times higher with single-use products. The authors emphasized that in urology or gynecology departments, choosing to reuse would allow an additional 50-100 procedures per year to be performed for the same cost. In addition to significantly reducing costs, no safety-related issues were reported with reusable laparoscopic instruments. Moreover, the maintenance costs arising from reusable devices and tools were found to be acceptable. In another study, Kwakye et al.[17] reported that using reusable surgical gowns instead of disposable gowns reduced carbon-producing waste by 23,000 kg and saved 60,000 USD per year.

Although there are conflicting views on the energy and water costs of cleaning and sterilizing reusable products, many studies have shown that reusable devices have a lower carbon footprint than single-use devices, and the sustainability benefits of choosing reusable products have been reported in various publications.[18,19] Tool reuse might be expected to cause more technical problems compared to single-use tools. However, these problems can be overcome with technological advances, new and more durable designs, and appropriate staff training. For example, both trephines and corneal punches can be reused several times without sharpening and can be replaced after several surgeries. On the other hand, scissors can be used longer and may require sharpening after 60 to 80 surgeries.

3. Recycle

Waste separation and recycling is another important way to improve sustainability as well as benefit economically.[20] McGain et al.[21] reported that recycling does not add any additional costs and that the impact might be greater if recycling were widely adopted by the global health system. Most operating room waste consists of recyclable material such as paper or plastic packaging, metal, or glass.[22,23] The positive impact of recycling on the economy or environment may seem low on an individual basis, but if implemented globally, recycling can be a very useful way to ensure sustainability in health care.

4. Rethink

Rethinking the Economical Use of Surgical Supplies

During surgery, there are several ways to reduce costs associated with surgical supplies as well as increase sustainability. For example, cutting the suture close to the knot while suturing can be an effective way to prevent suture waste and complete the surgery using half of the suture material in a package. Using the remaining suture in the next corneal transplantation may be an effective way to reduce costs. Using both sides of the absorbent cotton swabs frequently used during surgery, increasing the number of surfaces by cutting the sticks into smaller pieces, and trying to use less viscoelastic material are other useful ways to contribute to sustainability and reduce costs. Optimizing cleaning and sterilization methods is essential to make the sterilization of reusable devices cost-effective and sustainable. Unnecessary sterilization procedures should also be avoided.[24]

Education and Awareness

Standardization of surgical training in ophthalmology is another way to improve sustainability and cost-effectiveness. A recent study indicated that experienced surgeons had better outcomes in terms of surgical success and were more cost-effective than less experienced ones.[25] Greater surgical experience may reduce the complication rate, resulting in a decrease in

complication costs. Training programs related to ophthalmology should also provide information on invoicing processes, effective and equitable distribution of resources, and cost reduction strategies. A study by Ross et al.[26] showed that simple education such as cost awareness posters for surgeons in operating rooms resulted in a significant increase in the reuse of single-use surgical instruments.

To summarize, rethinking involves educating and motivating ophthalmologists to minimize cost and improve sustainability. It can also be considered a reminder of the need to be careful about unnecessary sterilization procedures. Reducing operating room usage time for corneal transplantation procedures, properly educating ophthalmologists and the surgical team, reusing instruments such as trephines and corneal punches, attempting to use surgical supplies more economically, and choosing the appropriate surgical technique are all possible beneficial ways to improve sustainability and reduce costs during surgery.

5. Research

Further research should be conducted to understand the carbon footprint of various ophthalmological procedures, including keratoplasty, and to develop solutions. There is only one study evaluating the carbon footprint associated with keratoplasty surgeries, in which Borgia et al.[27] reported that endothelial keratoplasties involve a significant carbon footprint. However, more comprehensive supportive studies are needed.

Which Keratoplasty Technique Should Be Preferred?

Penetrating Keratoplasty versus DALK

Penetrating keratoplasty has been the standard surgical procedure of choice for corneal transplantation for many years.[28] It is a safe and effective procedure, although graft failure is a complication seen in 10-34% of patients.[29,30] The main causes of graft failure are endothelial rejection and endothelial failure. To overcome these complications, lamellar transplantation techniques have been developed. These surgeries involve transplantation of the anterior cornea only.

Without intervention to the endothelium, the risk of endothelial rejection or endothelial cell loss is reduced. In DALK, the corneal stroma is excised down to Descemet's membrane. However, the procedure is technically challenging.[27] A study conducted by van den Biggelaar et al.[31] showed that DALK was more costly than penetrating keratoplasty in the first postoperative year. As their study evaluated only the first postoperative year, it can be argued that long-term cost analyses may yield different results.

Cost differences in the comparison of DALK and penetrating keratoplasty may be related to the time-consuming "large bubble technique" in DALK, which increases operating room time compared to penetrating keratoplasty. However, the potential endothelial complications and need for retransplantation that may occur after penetrating keratoplasty may lead to higher costs in the long term compared to DALK. Therefore, the cost-effectiveness of DALK could increase over time, and longer follow-up studies are needed.

Penetrating Keratoplasty versus Descemet Stripping Automated Endothelial Keratoplasty

Although penetrating keratoplasty has long been the standard technique for endothelial corneal diseases, it has several disadvantages such as suture-related complications, wound healing problems, and longer visual rehabilitation time.[32] Therefore, endothelial keratoplasty procedures have increased in popularity in recent years. These procedures target endothelial transplantation only, with no intervention to the anterior of the healthy cornea. The main advantages of endothelial keratoplasty over penetrating keratoplasty include faster postoperative visual rehabilitation, lower-grade changes in astigmatism, better tectonic stability, and fewer suture-related complications.[33,34] Descemet stripping automated endothelial keratoplasty (DSAEK) is a technique in which the donor cornea is prepared using a microkeratome.[35]

There are several studies in the literature comparing DSAEK and penetrating keratoplasty in terms of cost-effectiveness. Short-term results in the literature have generally indicated that DSAEK is more costly. In the study by van den Biggelaar et al.[36], DSAEK was found to be more costly in the short term compared to penetrating keratoplasty. The two main sources of early costs of DSAEK are the preparation of donor tissue using a microkeratome and the use of an additional insertion apparatus when performing the surgery. In addition, procedure-specific complications such as graft detachment can require an additional operation, which further increases costs.[37] However, studies have shown that the frequency of graft detachment decreases rapidly with increasing surgeon experience.[38]

On the other hand, Bose et al.[7] evaluated the cost-effectiveness of both procedures based on values obtained 3 years postoperatively. Taking into account the initial fees for the surgical procedure and complication costs, the estimated average 3-year costs were 7476 USD for DSEK and 7236 USD for penetrating keratoplasty. Both penetrating keratoplasty and DSAEK were determined to be "very cost-effective" interventions according to the World Health Organization cost-effectiveness criteria. However, the authors clearly emphasized that although both surgeries meet the threshold set by the World Health Organization, DSAEK should be the preferred procedure if the goal is to increase health gains with stable resources.

In another study conducted in India, it was reported that DSAEK was significantly more costly than penetrating keratoplasty at postoperative 6 months.[39] However, analysis at postoperative 1 year showed that penetrating keratoplasty more costly than DSAEK, and DSAEK emerged as significantly more cost-effective at postoperative 2 years.

When comparing DSAEK and penetrating keratoplasty in terms of long-term cost-effectiveness, it should be noted that high astigmatism contributes substantially to the increase in

costs associated with penetrating keratoplasty. Contact lenses or glasses may be used for visual rehabilitation in patients, while additional surgery may be planned to reduce astigmatism in some cases. As postoperative astigmatism is expected to be significantly lower after DSAEK, lower costs related to astigmatism correction can also be expected. In addition, faster recovery after DSAEK accelerates patients' return to productivity, possibly contributing to the reduction of DSAEK-related costs in the long term. Moreover, the lower incidence of complications such as suture-associated infectious keratitis, shorter postoperative drug use, and the need for fewer outpatient visits may also contribute to reducing the cost of DSAEK procedures in the long term.

DSAEK versus DMEK

DMEK is an endothelial keratoplasty technique that enables transplantation of Descemet's membrane and endothelium without involving the posterior stroma. As this technique is performed through a smaller incision, more successful results are obtained both in terms of refraction and the increase in visual acuity. In addition, lower rates of endothelial rejection have been reported compared to DSAEK and penetrating keratoplasty.[40] The main disadvantage of this method is the long learning curve.[41] Many studies in the literature have reported that the DMEK procedure more effectively preserves endothelial cell function and can yield more successful visual results. Furthermore, endothelial rejection rates were found to be lower compared to DSAEK.[42,43]

In terms of cost-effectiveness, a study by Simons et al.[44] showed that DMEK was more costly compared to DSAEK in the short term (1 year). However, the increase in visual acuity was observed to be higher in the DMEK group. In contrast, Gibbons et al.[45] compared the long-term cost-effectiveness of DMEK and DSAEK and reported that DMEK was less costly than DSAEK.

In the study by Simons et al.[44], the long learning curve required for DMEK surgery may have been a contributor to the higher short-term cost, as the main source of the cost in the procedure was determined to be the need for additional rebubbling and graft placement due to lack of experience. On the other hand, studies based on longer-term results reveal that the cost difference decreases as the surgeon's experience with the DMEK technique increases. Revisions and precautions in DMEK surgery such as choosing SF_6 gas instead of air, creating a larger descemetorhexis, marking the graft to prevent orientation problems, and improving grafting techniques may reduce the rate of additional rebubbling.[46]

Complications that may develop in DSAEK, such as late graft failure or graft rejection, may affect the results in short-term cost-effectiveness analyses. Price et al.[47] evaluated 5-year graft survival rates in their study and found that graft rejection rates were higher in DSAEK patients than in the DMEK group.

In conclusion, when DSAEK and DMEK are compared, the long learning curve required for DMEK surgery may be a contributing factor to its higher cost in short-term analyses, because rebubbling and regrafting due to lack of experience were found to be the main sources of cost. However, higher graft rejection and lower graft survival rates in DSAEK patients may play a role in its higher costs compared to DMEK in the long term.

Conclusion

Reducing unnecessary costs is an important part of improving health system quality. However, the utmost care should be taken to preserve safety and effectiveness when implementing cost-reduction measures. In corneal transplantation surgeries, reducing operating room time, properly educating ophthalmologists and the surgical team, reusing instruments such as trephines and punches, striving for the economical use of surgical supplies, and choosing the appropriate surgical technique are all potential ways to improve sustainability and reduce costs during surgery. Further research is needed to improve this area of medicine and increase sustainability, and the tips and strategies presented in this review may contribute to a more sustainable world.

Declarations

Authorship Contributions

Surgical and Medical Practices: M.P., Concept: M.P., P.K., Design: P.K., Data Collection or Processing: P.K., Analysis or Interpretation: M.P., P.K., Literature Search: P.K., Writing: P.K.

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