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A Review: Aesthetic element in prosthetic's cosmetic design for lower limb physical amputees

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Abstract
This systematic study aims to establish the key aesthetic elements in prosthetic cosmetic design. The increasing number of amputated individuals from congenital and traumatic causes implies the need for effective prosthetic design. It is crucial to note that most past research is not artistic and design-oriented. Therefore, utilizing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), this study reviewed articles from 2018 to 2024; sourced from Google Scholar. The review found seven major clusters leading to several sub-themes. The author states some ideas for future studies at the end of this article.

Keywords: Aesthetic ; Prosthetic ; Amputees ; Cosmetic

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1.0 Introduction

Prosthetic design for amputees is a critical area that has seen increased attention in recent years. This increased focus is closely related to the global increase in the number of individuals requiring prosthetic limbs due to congenital anomalies and traumatic injuries (McDonald, 2020). The main objective of this systematic review is to identify and analyze key features of prosthetic design for lower limb physical amputations. This need arises from the annual increase in amputees and the need for functional, comfortable, and adaptive prosthetic solutions that significantly improve the user's quality of life. According to an earlier study on upper limbs, people discontinue using prosthetics because they are less useful for daily activities (Datta, 2004).

Prosthetic limbs are broadly categorized into two types: upper limb prosthetics, which replace parts of the arm, such as the hand, forearm, or entire arm, and lower limb prosthetics, which substitute for the foot, leg, or entire lower extremity. In the past, research in prosthetic design was usually conducted from a clinical or engineering perspective, with limited consideration for art and design principles. These resulted in prosthetics that, while functional, may not fully meet the user's aesthetic and ergonomic needs. Prosthetics should both restore function and address the psychological and social aspects of limb loss. Therefore, there is a critical need to incorporate a design-centered approach in prosthetics research, emphasizing user-centered design principles that consider aesthetics, comfort, and usability (Khalid, 2023). This area of study coincides with the recommendations issued by the Malaysian Standard Users Association, which is to increase research in assistive devices for disabled and ergonomic individuals. The current study undertakes a

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comprehensive literature review to bridge this gap, focusing on integrating art and design perspectives in prosthetic development. Utilizing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, this review systematically examines the existing body of knowledge sourced from Google Scholar (PRISMA, 2021). The selection criteria yielded 200 articles published between 2018 and 2024, which were then analyzed to identify key trends and themes in prosthetic design.

2.0 Literature Review

In Malaysia, physically disabled individuals has been increasing annually, and therefore there is a pressing need for improved prosthetic solutions. According to Nooranida (2017), there remains limited knowledge regarding the production of high-quality prostheses and the process of enhancing device quality and services. Past research focused on clinical and engineering disciplines, placing much emphasis on function at the expense of user satisfaction. Nevertheless, there is more recent evidence indicating a paradigm shift to more comprehensive orientations. Leite (2019) emphasizes the role of future technologies, materials, artificial intelligence, and individualized medicine in shaping the prosthetic design of the future. Shaorong Ji (2022) also highlights the role of emotionally stable visual communication tactics like fun, utility, symbolism, and interactivity, which can be effective in driving customer behaviour and supporting product adoption. Khalid Alluhydan (2023) supports this by highlighting the need for user preference, functionality, and experiential feedback during the design process.

Additionally, aesthetic considerations are being recognized gradually for their psychological impact. Designers collaborate with artists and fashion experts to develop prostheses that are not just functional but expressive and a representation of individual identity (Ibanez-Arricivita, 2024). This emerging research is demonstrated herein to evidence a clear transition from traditional utilitarian models, towards user-focused, interdisciplinary design culture capable of meeting functional plus affective prosthetic users' requirements. It shows how the design elements of prostheses are getting more attention, acknowledging how important good looks are to amputees' psychological health.

3.0 Methodology

There are three primary subsections presented in this section, namely resources, Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), and data analysis.

3.1 Resources

To gain resources, the researchers have chosen to use a publish-and-perish software application known as Google Scholar database to conduct this research. Researching prosthetic cosmetic design features via Google Scholar has many benefits that can increase the scope and complexity of the social science study. A more comprehensive and expansive database is provided by Google Scholar, which includes theses, books, conference papers, patents, and peer-reviewed journal articles. Prosthetic design research has benefited from the domain's multidisciplinary approaches to social sciences, engineering, materials science, and medicine (ergonomics). Google Scholar can index material from multiple sources like institutional repositories and open-access publications which gives it a large variety of viewpoints and developments (Ebrahim, 2017). In addition, Google Scholar returns stats about the number of citations specific to prosthesis design articles that have accumulated over time up, until pretty recently, and how many critical studies influenced future research. This can be especially useful for identifying emerging technologies and design paradigms gaining traction in the academic and clinical communities. Thus, Google Scholar's more inclusive, multidisciplinary scope makes it possible to include an extensive array of studies and viewpoints.

3.2 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is a standardized framework that is particularly useful for systematically reviewing and synthesizing research findings on a specific topic. PRISMA has several advantages which include providing a framework for conducting literature reviews that minimizes the possibility of bias in selecting studies and synthesizing data; promoting rigorous study selection methods through at least two independent researchers using strict inclusion criteria calibrated by all included members of the research team; supporting comprehensive synthesis to enable patterns across each search to emerge while encouraging links between different conceptual or theoretical frameworks. Ultimately, PRISMA establishes a clear and transparent methodology that can be reproduced which helps to improve review quality by providing helpful and culturally relevant prosthetic solutions.

3.3 Data analysis

This systematic review employed an inclusion and exclusion criteria, selecting published journals (2018–2024) on lower limb prosthetic design focusing on functionality, aesthetics, or cosmetic aspects. Only full-text English articles were included, while theses, books, conferences, reviews, unrelated topics, duplicates, and incomplete records were excluded to ensure research relevance and quality.

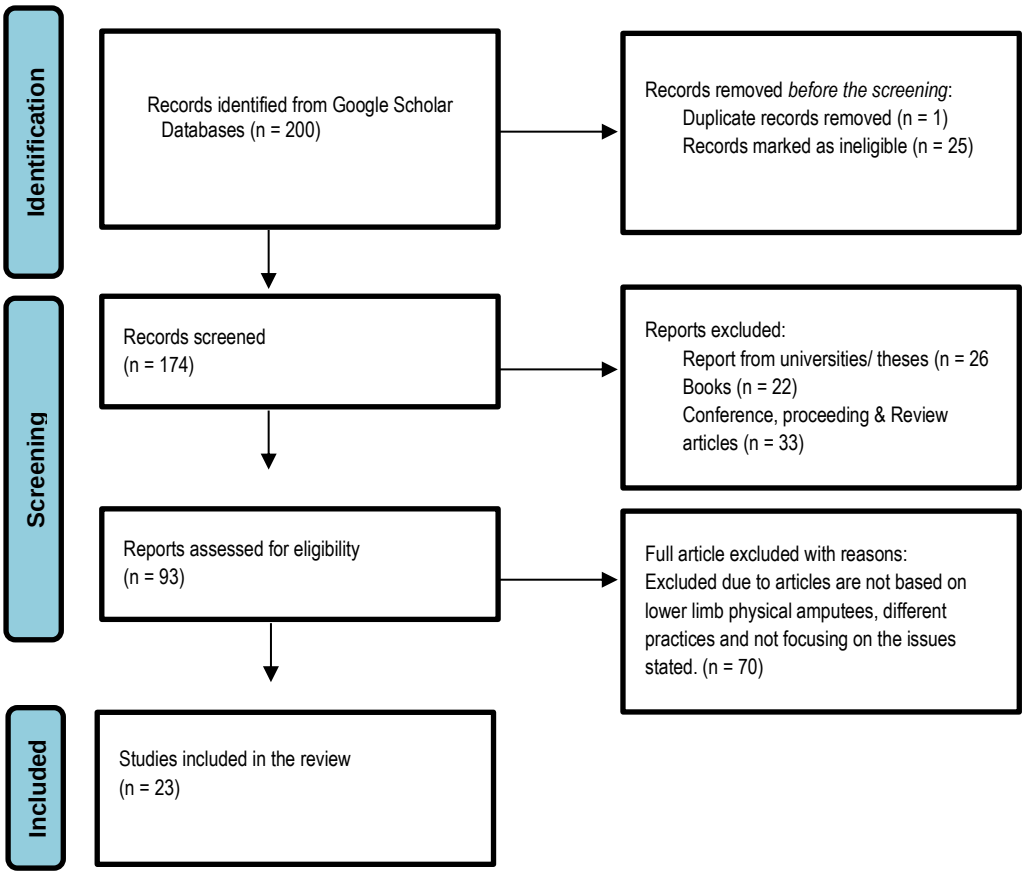

Fig. 1: PRISMA Statement
(Source:) Adapted from (Moher, 2009)

4.0 Findings

Based on Figure 1 above, 200 papers were identified on Google Scholar's database from 2018 to 2024, with the keyword cosmetic design for prosthetic legs. A total of 26 papers were removed before screening due to duplicate records and marked as ineligible. Next, 174 records were screened, which excludes 26 universities' theses, 22 chapters from books, and 33 articles from conference proceedings. Following an eligibility assessment of the 93 reported papers, 70 records were deemed ineligible for numerous reasons, including publications that did not center on the issues raised or were not based on lower limb amputees. As a result, 23 studies were identified to be reviewed manually, as shown in Table 1 below.

Table 1. The list of reviewed papers

No.	Author	Title	Year	Abstract
1.	K Efstathiou, A McGarry	3D Printed Cosmetic Covers for Lower Limb Prosthetics	2023	In the past, the majority of prosthetists' utilized a Plastazote foam block, which was then shaped and matched to the patient's sound leg to provide the prosthesis a more appealing appearance.
2.	SP Lee, C Mitchell, K Repayo, M Tillitt, ...	Patient Engagement in Cosmetic Designing of Prostheses: Current Practice and Potential Outcome Benefits	2022	The aesthetic design of their prosthetic limbs. How patients presently participate in clinical settings when creating prosthesis appearances. "This is the patient's leg; it ought to appear as they …
3.	SM Mahajan	Design and Development of Prosthetic Legs	2019	This article's objective is to outline the advancements in prosthetic limbs. This study will highlight prosthetic legs by emphasizing the socket portion, which is frequent.
4.	A Manero, J Sparkman, M Dombrowski, P Smith, ...	Evolving 3D-Printing Strategies for Structural and Cosmetic Components in Upper Limb Prosthesis	2023	Numerous businesses have started using thermoforming for prosthetic sockets, including arms and legs. A positive mold is created from the geometry of a patient's severed limb.
5.	FG Ibrahim, AEN Abu El-Majd, ...	Using CAD–CAM Technology in The Design of Prosthetic Devices	2020	… Prosthetics vary in type and design; they are … prosthetic devices are nonfunctional, serving only cosmetic … He spent his recovery designing a prosthetic leg, and would go …
6.	AM Román-Casares, O García-Gómez, ...	Prosthetic Limb Design and Function: Latest Innovations and Functional Results	2018	… and functional results in prosthetic limb design and function. … , and adaptation of prosthesis to the particular conditions of … current advances in bioelectric

				prostheses, their benefits and …
7.	JC Fernandes, M Silva, ...	Components of Prosthetic Lower Limbs for Transfemoral and Transtibial Amputations: General Prescription Recommendations and Literature Review.	2018	… day to day prosthesis for walking and for specialized activity. … prosthetic leg before going into the water. If the amputee wishes to use a prosthetic leg for bathing for cosmetic reasons …
8.	K Alluhydan, MIH Siddiqui, ...	Functionality and Comfort Design of Lower-Limb Prosthetics: A Review	2023	… emphasized the necessity of constant innovation and improvement to boost user happiness, mobility, and quality of life. An emphasis on user-centricity was placed. Two important issues that were brought up were accessibility and affordability...
9.	R Bekrater-Bodmann	Factors Associated with Prosthesis Embodiment and its Importance for Prosthetic Satisfaction in Lower Limb Amputees	2021	Most of the participants in the present study lost their leg by accidents, which is different to … In addition to cosmetic and functional aspects of the prosthesis, prosthesis embodiment has …
10.	S Manz, R Valette, F Damonte, L Avanci Gaudio, ...	A Review of User Needs to Drive the Development of Lower Limb Prostheses	2022	… is affected or missing (i.e., control of the leg and sensory feedback) [46,47,48,49]. The use and maintenance of a prosthetic leg involve several areas related to cognitive processes …
11.	MR Rosenberger	Utilizing 3D Printing for Prosthetic Limbs In Developing Nations and Conflict Zones	2020	… with a transfemoral 1 amputation will need a full leg prosthetic in a smaller size than a grown … myoelectric hand or if a transradial 3 amputee requires only a nonfunctional cosmetic hand. …
12.	N Cairns, J Corney, K Murray, ...	Rethinking The Foam Cosmesis for People with Lower Limb Absence	2018	Additionally, a full leg-length zip in the design allows for simple maintenance access with ... Increasing the durability and aesthetic appeal of cosmetic foam covers for individuals.
13.	EC Baars, E Schrier, PU Dijkstra, JHB Geertzen	Prosthesis Satisfaction in Lower Limb Amputees: A Systematic Review of Associated Factors and Questionnaires	2018	MEDLINE was designed: (leg OR lower limb) AND (prosthesis OR … designed questionnaire included three questions on factors affecting satisfaction with the cosmetic properties of prosthesis…
14.	A Vlachaki, AMJ Paterson, SC Porter, RJ Bibb	Exploring Users' Attitudes Towards Prosthesis Aesthetics in the UK And Greece	2020	… of the aesthetics of prostheses with users' psychology. Lucy … make it more acceptable for them to have a prosthetic leg. … a specific design to show that although it is a prosthetic limb.
15.	S Savsani, S Singh, HS Mali	Additive Manufacturing for Prostheses Development: State of the Art	2023	… He concocted the "Hanger Limb," a prosthesis leg made of barrel staves … Cosmetic prostheses are designed to aesthetically replace a missing body part, whereas functional prostheses …
16.	IA Satam	Review Studying of the Latest Development of Prosthetic Limbs Technologies	2021	… legs are considered as lower Limbs. The arms are connected at the shoulders to the Torso and the legs … The difference between the Cosmetic and Functional is that Cosmetic only.
17.	P Maroti, AT Schlegl, B Nagy, L Toth, P Bogar, ...	Additive Manufacturing in Limb Prosthetics And Orthotics: The Past, Present and Future of 3D Printing Orthopedic Assistive Devices	2024	… The earliest written evidence about prosthetics is probably the … in a battle and got a leg prosthetic, which helped her to return to … of cosmetic prosthetics with realistic, lifelike appearance. …
18.	T Taylor	A Qualitative Pilot Study Exploring Reasons for Prosthetic Preference in A Veteran Amputee Population	2020	Nine people responded about how the limb looked. But, in any case, it is crucial to be able to balance on a prosthetic leg, however, the methods by which this happens.
19.	R Holt, S Murray	Prosthesis and the Engineered Imagination: Reading Augmentation and Disability Across Cultural Theory, Representation and Product Design	2020	Many studies of the relationship between disability and technology, such as those involving novel advancements in smart prostheses, neural implants, exoskeletons, or cosmetic.
20.	WT Chan	Review Of The Complications In Prosthesis Making & Servicing	2022	As well as the prosthesis care. However, creating, implanting, and maintaining prostheses are not without difficulties.
21.	C Fanciullacci, Z McKinney, ...	Evaluation of Human Factors for the User Centered Design of Powered Robotic Transfemoral Prostheses: A Survey Of Transfemoral Amputee Experience and …	2020	… to single prosthesis characteristics such as cosmetic design (… relationships between TFP design features, functionality, and … -foot prosthesis normalizes walking gait for persons with leg …
22.	MJ Hall, DR Cummings, RI Welling Jr, MK Kaleta, ...	Essentials of Pediatric Prosthetics	2020	…designs featuring foam covers for cosmetic protection. Patients with limb prosthetics include knees, feet that clip into ski boots, and legs with carbon blades for exercising.
23.	H Gavette, CL McDonald, K Kostick-Quenet, ...	Advances in Prosthetic Technology: A Perspective on Ethical Considerations for Development and Clinical Translation	2024	… prosthetic devices and related technology. We present several ethical considerations for current advances in prosthetic … of those who can benefit from advances in prosthetic technology. …

(Source:) Sorted by the author

5.0 Discussion

Seven clusters were identified from the selected research papers. The connection between the focus of the researchers was recognized and presented in the following mind map (Fig. 2). Based on these clusters, the most dominant trend is the integration of technological

advancements and innovative materials in prosthetic limb design. The increasing use of 3D printing, CAD-CAM technologies, and advanced materials reflects a significant shift toward enhancing both the functionality and aesthetic appeal of prosthetic devices. These innovations not only streamline manufacturing processes but also offer greater customization and accessibility, especially in low-resource settings. This trend signifies a broader movement toward more efficient, user-responsive, and inclusive prosthetic solutions, aligning technological progress with the practical and psychosocial needs of diverse user populations.

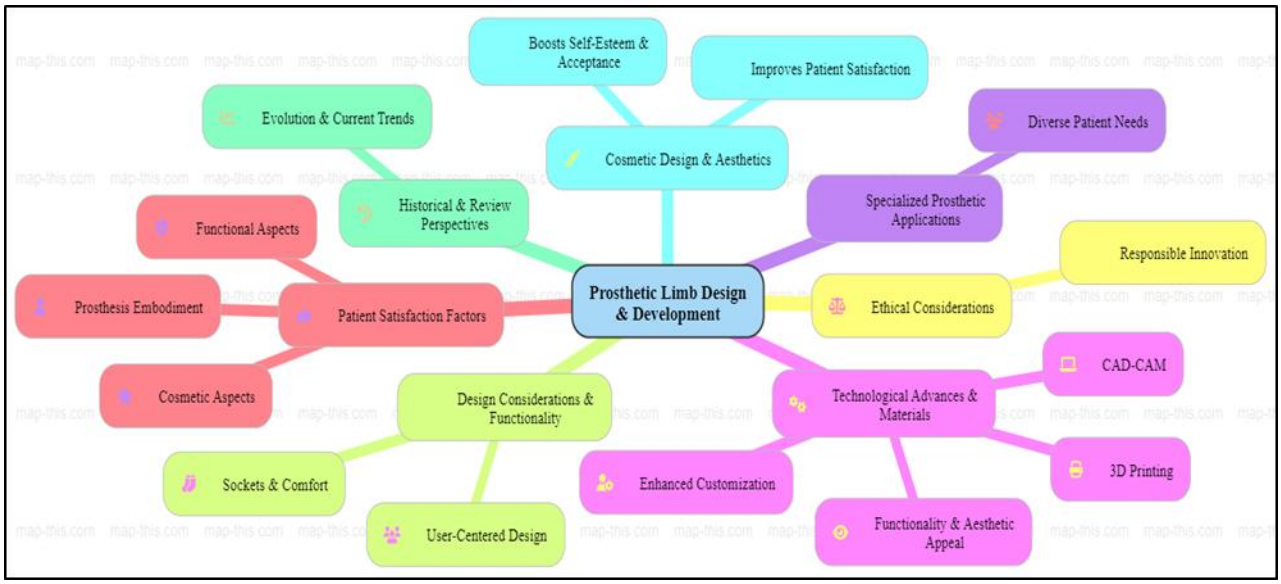

Fig. 2: The clusters of prosthetic design and development
(Source:) Sorted by the author

The first cluster is Technological Advances and Materials. Several research papers have focused on the use of new technologies such as the use of 3D printing and CAD-CAM in the design and development of prosthetic limbs. This technological advancement is to provide functionality and a better aesthetic appeal to prosthetic designs. The studies mentioning this were carried out by Efstathiou & McGarry (2023); Manero, Sparkman, Dombrowski & Smith (2023); Ibrahim & Abu El-Majd, (2020); Savsani, Singh & Mali (2023); Maroti, Schlegl, Nagy, Toth & Bogar, (2024); Rosenberger (2020). The results of their study indicate a shift towards more innovative and efficient manufacturing processes, which may lead to more accessible and suitable prosthetic solutions, especially in resource-constrained settings. The second cluster is Cosmetic Design and Aesthetics. Most of the research papers emphasized the importance of cosmetic design in prosthetics, including the patient's involvement in the design process and the psychological effects of prosthetic aesthetics. These research papers consisted of studies done by Lee, Mitchell, Repayo & Tillitt (2022); Cairns, Corney & Murray (2018); VIachaki, Paterson, Porter & Bibb (2020); Holt & Murray (2020); Taylor (2020). The role of aesthetics is emphasized in increasing patient satisfaction, self-esteem, and acceptance of prosthetic devices, showing that prosthetics not only function as aids but also provide personal identity. The third cluster is Patient Satisfaction and Factors. Studies from Bekrater-Bodmann (2021); Baars, Schrier, Dijkstra & Geertzen (2018); Gavette, McDonald & Kostick-Quenet (2024) not only explored the factors that influence patient satisfaction with the use of prosthetics but also focused on its functional and cosmetic aspects as well as the concept of acceptance of the prosthesis as part of the body. They have found that user perception is important to understand how design features may affect the overall user experience and psychological integration of their image.

The fourth cluster is Design Considerations and Functionality. Mahajan (2019), Fernandes and Silva (2018), Alluhydan and Siddiqui (2023), and Fanciullacci and McKinney (2020) have all discussed the design and functionality of prosthetic limbs. The focus is on socket components, comfort, and a user-centered design approach. Their papers have highlighted the importance of practical design elements that improve the usability, comfort, and adaptability of prostheses for users' daily activities. The fifth cluster is Ethical Considerations. The central discussions are how to provide guidance and ensure that technological progress does not widen the access gap to users. This is because the technology used should make it easier for users to get healthcare help. In particular, Gavette, McDonald, and Kostick-Quenet (2024) and Holt and Murray (2020) highlighted ethical issues in the development of prosthetics, particularly regarding the implications of new designs on users. The sixth cluster is Specialized Prosthetic Applications. Some papers have focused on specific applications of prosthetic technology, such as prosthetics for pediatrics, and conflict zones, or prosthetics for particular activities such as waterproofing for sporting purposes. Studies from Hall, Cummings, Welling Jr., and Kaleta (2020) and Chan (2022) emphasized the need for diverse patient populations and their importance in meeting these unique needs. The final seventh cluster is Historical and Review Perspectives. Several review papers provided historical overviews, literature reviews, or recent summaries of the field that offer a broader context for understanding the evolution and current trends in prosthetic limb design. For example, Mahajan (2019), Savsani, Singh & Mali (2023). Their research papers are significant because they have identified research gaps and have outlined the direction for innovation, technology, and prosthetic design in the future.

6.0 Conclusion and Recommendation

The study shows that selected prior studies applied a multidisciplinary approach to studying products for individuals with lower-limb physical amputees. Half of the studies combined (Engineering + Design) + Psychology and Ethics. Therefore, the focus on both functional and aesthetic matters is an indication of a maturing mindset. Prosthetics are no longer solely a medical device but an essential component of one's identity and everyday living. New-generation manufacturing technologies like 3D printing, and CAD-CAM are also playing their part in providing prosthetic solutions at a much faster rate signaling replacement cues for more user-friendly and accessible alternatives. The ongoing improvement of user satisfaction underlines the importance of prosthesis design and specification which closely regard those various needs or preferences. Hence, this study is in line with the calls from the Malaysian Standard Users Association to expand research in assistive devices for persons living with disability and ergonomics. Despite the systematic methodology employed, this review acknowledges certain limitations. Primarily, the exclusive reliance on Google Scholar may have constrained the comprehensiveness of the literature search. While these databases are widely utilized, they may not encompass all pertinent studies, particularly those published in specialized or regional databases. This limitation could potentially introduce selection bias, thereby affecting the generalizability of the findings. Additionally, the review's temporal scope was confined to publications from 2018 to 2024. Although this timeframe captures recent advancements, it may exclude seminal works published before 2018 that could provide foundational insights into prosthetic design. Applying such date restrictions, if not adequately justified, can influence the outcomes of systematic reviews and should be approached with caution.

Furthermore, no language restrictions were applied, the reliance on English dominant databases introduced implicit bias, potentially excluding relevant non-English studies. Future research should broaden database selection, include regional and subject-specific sources, and extend the publication period to enhance diversity, reduce language bias, and improve the review's comprehensiveness.

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Paper Contribution to Related Field of Study

This study will bring the user, academician, industry, government, or NGO to discuss current issues on enhancing prosthetic designs in Malaysia.

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