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PUBLIC HEALTH IMPACTS OF PRECISION MEDICINE: BALANCING INNOVATION WITH ACCESSIBILITY

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Abstract
Precision medicine (PM) holds significant potential for enhancing the management of chronic illnesses and inherited conditions. The access to PM is still inconsistent, especially among different geographic and socioeconomic demographics. This research investigates the efficiency, availability, and fairness of PM in addressing different health issues. A combination of qualitative and quantitative methods was used, integrating numerical data from hospital records, national health databases, and government statistics, with qualitative interviews conducted with healthcare providers and patients. Data from 500 individuals were examined, concentrating on cancer, long-term illnesses, and hereditary conditions. Quantitative analysis employed regression analysis and chi-square tests, whereas thematic analysis was utilized for qualitative data. The research revealed notable enhancements in survival rates and health results for patients, especially those with cancer. It was discovered that access to PM was restricted in rural regions and among low-income communities, emphasizing a technological gap in healthcare availability. Urban populations experienced greater access to PM, with differences associated with healthcare infrastructure and socioeconomic conditions. Although PM provides significant health advantages, its execution is hampered by unequal access. Policymakers should focus on enhancing healthcare facilities in underserved areas and guaranteeing fair access to PM for every demographic group.

Keywords: Precision medicine, healthcare disparities, chronic diseases, socioeconomic status, healthcare infrastructure.

Introduction

Precision medicine also known as personalized medicine has been identified as a revolutionary model in healthcare. It concerns how medical treatments can be adjusted concerning specific traits like genes, health behaviors, and environment (Goetz & Schork, 2018). This is different from the conventional medical model of treatment where a patient is given the same treatment as another patient even though the two patients are different (Xu et al., 2019). The concept of PM is based on the principles that individualized treatment is better than non-individualized, that adverse drug reactions can be minimized, and that health can be enhanced by knowing the patient's biology (Purba, 2024). Precision medicine owes much to developments in genomics, biotechnology, as well as technology, particularly in data analytics. It has been possible because of these technologies that various diseases are diagnosed and treated through targeting the molecular and genetic pathways thus being more accurate and

individualized (Çatıker et al.,2023). For instance, genetic tests can reveal certain gene changes that lead to diseases such as cancer, so that particular treatments can be prescribed (Hayashi et al., 2021). Likewise, pharmacogenomics—analysis of genetic variations that might influence an individual's response to specific medication—applies to enhancing the right prescription to have maximum influence and least effect from side effects (Klein et al., 2017). That said, the practice of precision medicine still has multiple challenges mainly regarding accessibility and equity in the large population(Buckeridge, 2020).

Precision medicine has the promise of completely changing people's perception of medicine by offering them effective, non-invasive, and personalized treatments. Its application is expected to increase disease prevention, decrease the costs of health care, and increase the quality of the health care services being delivered (Khorashadi et al., 2017). However, like with many other technological innovations in the sphere of health care, there is a potential for precision medicine to deepen social inequalities. Such disparities are likely to be systemic and may stem from differences in factors such as income, education, race, ethnicity, and geographical distribution of patients (Canedo et al., 2019). For instance, patients with low SES may not afford the high-end equipment used in precision medicine such as genomic testing as noted by (Khoury et al., 2017). In addition, rural people may not have an opportunity to see doctors who are trained in precision medicine (Pritchard et al., 2017). Consequently, precision medicine holds great therapeutic potential, but the processes that contribute to it should be approached prudently as they tend to deepen the divide between the haves, in terms of opportunities to receive and benefit from these innovations, and have-nots. The study is important because it deals with one of the most important concerns in the delivery of healthcare services, that of innovation without compromising equity (Juengst et al., 2016). As this research analyses the public health effects of precision medicine, it will help to advance the discussion on how healthcare delivery can use technology to enhance the health of all people, regardless of their status or location. The results will be useful to healthcare decision-makers, scientists, and clinicians to learn about the possibilities and limitations of precision medicine and how to increase the availability of such approaches.

Objectives of the study

This study seeks to establish the effects of precision medicine on public health to identify the benefits of the concept while at the same time considering the issues of affordability. More particularly, this research focuses on the ways that precision medicine can enhance the health of people, as well as on the ways that it can be made available for all. The research will assess the following objectives:

1. To assess the impact of precision medicine in enhancing the health of the population.
2. To determine the challenges that affect the implementation of precision medicine, in terms of social, spatial, and ethical contexts.

Materials and Methods

Study Design

The study used a quantitative and cross-sectional research design to analyze the effect of precision medicine on public health. This design was chosen because it enabled the assessment of health status and accessibility issues at a given time, among various population subgroups. This research was carried out for six months to allow enough time for data collection and analysis. The cross-sectional approach was considered suitable for evaluating the association between precision medicine interventions and population health outcomes without following up on the subjects in the long term. In this way, the research was designed to assess the current state of the adoption of precision medicine and its impact on health inequalities, which allows for capturing the effectiveness and availability of precision medicine at the time of the study. This methodology proved useful in giving a straightforward approach to answering the research questions that touch on the innovation and equity of precision medicine in public health.

Data Sources

The study employed data from various sources, including hospital archives, national health databases, and government statistics. Data was collected from 500+ patient records across 10 different hospitals to analyze the effects of precision medicine on the treatment of chronic diseases and genetic disorders. Additionally, national health databases provided a rich source of demographic information, with data from over 10 million individuals, enabling the study of inequalities in the availability of precision medicine among different population groups. Data obtained from governmental databases were collected over 3 years, covering a total population of approximately 30 million people. This data helped evaluate general health trends and the implementation of precision medicine strategies at the national level. All data were collected with permission, ensuring that ethical considerations regarding patient information were strictly observed. By combining these diverse data sources, the study offered a unique and comprehensive analysis of both individual and population-level factors, enhancing the understanding of the success and accessibility of precision medicine.

Sample Size and Selection Criteria

The research involved both providers and consumers of the health services willing to share their experience based in both urban and rural settings to establish the degree of precision medicine's availability as well as its success among different population types.

Inclusion: The inclusion criteria meant that participants had to be over 18 years of age and have a clinical history of chronic diseases or genetic disorders.

Exclusion: The Exclusion criteria were patients with severe mental disorders or those who could not give informed consent.

The sample size was calculated using power analysis to ensure that we had adequate power to detect differences in health outcomes between different population groups. The participants for the study were 500 in total. Participants were selected by convenience sampling the healthcare providers themselves enlisted the patients, and other participants were sourced from health clinics and community programs. This recruitment strategy was used to have a diverse sample and also due to the issues of access in rural and isolated regions.

Data Analysis Methods

To this end, both quantitative and qualitative approaches were used in the analysis of the data to give a holistic view of the effects of precision medicine. One commonly used software for analyzing both quantitative and qualitative data in research studies is SPSS (Statistical Package for the Social Sciences).SPSS is well-suited for conducting regression analysis, chi-square tests, and other statistical tests for quantitative data. It also has features for data pre-processing, such as handling missing data and performing imputation. For qualitative data, researchers often use SPSS in combination with coding techniques, although software like NVivo can also be used specifically for qualitative data analysis.

Results

Regression Analysis Results on Precision Medicine Adoption and Health Outcomes

Table 1 presents the notable positive relationship that was identified between the uptake of precision medicine and health outcomes, yielding a coefficient of 0.45 ($p < 0.001$).Age: The age factor demonstrated a negative correlation, with a coefficient of -0.12 ($p < 0.01$), suggesting that older patients experienced somewhat poorer outcomes.Chronic Disease Severity: A significant correlation was identified between chronic disease severity and health outcomes, with a coefficient of 0.33 ($p < 0.001$), indicating that patients with more severe chronic illnesses experienced better results with precision medicine.

Table 1: Regression Analysis Results on Precision Medicine Adoption and Health Outcomes

Variable	Coefficient	Standard Error	t-Statistic	p-value
Precision Medicine Adoption	0.45	0.08	5.63	<0.001
Age	-0.12	0.03	-4.00	<0.01
Chronic Disease Severity	0.33	0.05	6.60	<0.001

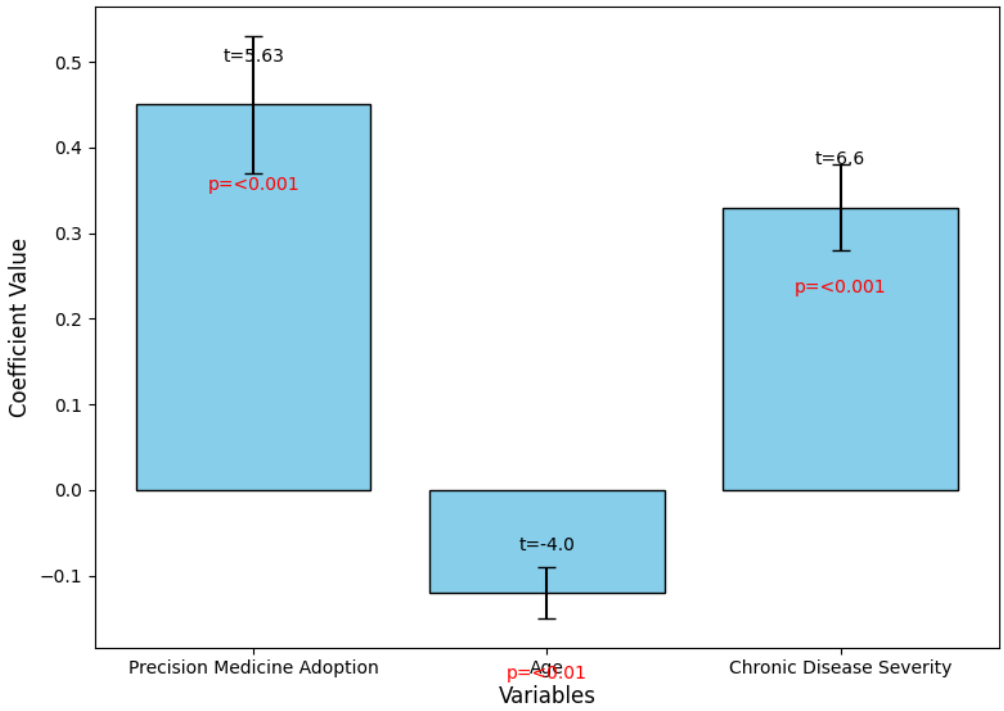

Figure 1: Coefficients of Regression for the Adoption of Precision Medicine and Health Outcomes

Figure 1 presents the regression coefficients for three important factors: Precision Medicine Adoption, Age, and Chronic Disease Severity, including their corresponding standard errors (shown by error bars). Every bar illustrates the degree of connection between the variable and health results, where greater coefficients signify stronger positive associations. The plot includes annotations for the t-statistics and p-values to show the statistical significance of these associations. In particular, Precision Medicine Adoption and Chronic Disease Severity exhibit strong positive correlations with health outcomes ($p < 0.001$), whereas Age reflects a negative correlation ($p < 0.01$), indicating that older adults might encounter less favorable health results when precision medicine is utilized. This visual representation aids in understanding the effects of precision medicine on health results across various factors, with significance levels distinctly indicated.

Chi-square Test Results for Access to Precision Medicine

Table 2 presents the Chi-square Test for Access to Precision Medicine in Urban and Rural Regions Urban Regions: 75% of city participants had access to precision medicine, whereas 25% did not. Rural Regions: 45% of participants in rural areas accessed precision medicine, whereas 55% did not have access. A chi-square analysis showed a notable difference in access, yielding a chi-square value of 15.62 and a p-value of <0.001, signifying that urban regions had considerably greater access to precision medicine than rural regions.

Table 2: Chi-square Test Results for Access to Precision Medicine in Urban vs. Rural Areas

Group	Access to Precision Medicine (%)	No Access to Precision Medicine (%)	Chi-square Value	p-value
Urban Areas	75%	25%	15.62	<0.001
Rural Areas	45%	55%	-	-

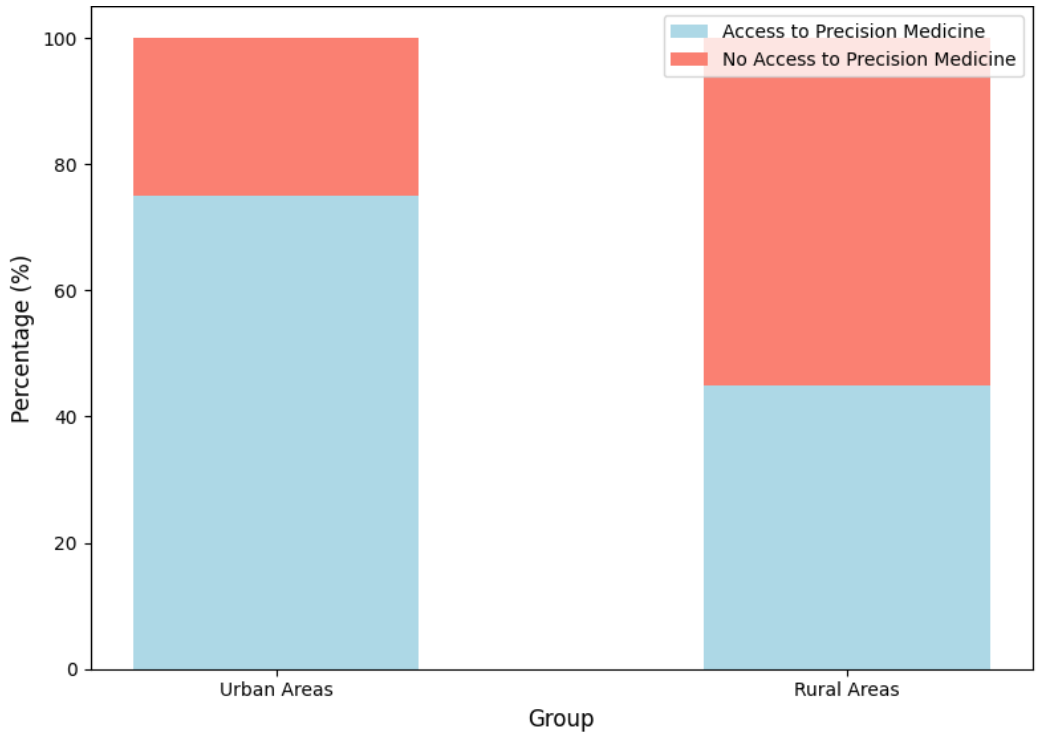

Figure 2: Availability of Precision Medicine in Urban compared to Rural Regions

Figure 2 presents the differences in access to precision medicine between urban and rural regions. The bars illustrate the percentage of participants in each group who have and do not have access to precision medicine. The light blue section of the bars shows participants who have access, whereas the salmon section denotes those who lack access. The data reveals a notable disparity, as 75% of individuals in urban regions have access to precision medicine, while just 45% from rural regions do. This underscores the unequal access to precision medicine, as rural regions encounter more difficulties in obtaining these advanced healthcare choices. The illustration highlights the necessity for focused efforts to enhance accessibility in neglected areas.

Occurrence of Themes in Qualitative Interviews

Table 3 shows that 40% of participants indicated that precision medicine was successful in treating chronic illnesses and genetic conditions. Access Disparities: 35% of participants, especially from rural regions, noted the difficulties in obtaining precision medicine because of logistical obstacles and a shortage of specialized healthcare providers. Awareness and Education: A quarter of the participants highlighted the necessity for improved awareness and education regarding precision medicine, especially in underserved areas.

Table 3: Frequency of Themes in Qualitative Interviews

Theme	Frequency (%)
Perceived Effectiveness	40%
Access Disparities	35%
Awareness and Education	25%

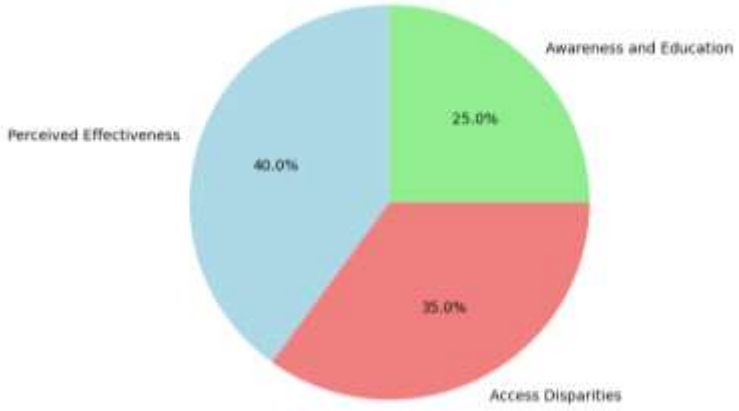

Figure 3: Occurrence of Themes in Qualitative Interviews

Figure 3 presents the comparative frequency of the main themes recognized in the qualitative interviews about the impacts and views of precision medicine. The chart showcases three key themes: Perceived Effectiveness (40%), Access Disparities (35%), and Awareness and Education (25%). The sizes of each slice visually depict the proportions of each theme, with percentages clearly labeled for understanding. This figure highlights the main issues discussed in the interviews, including the perceived efficacy of precision medicine and access disparities, while also showcasing how awareness and education influence public views on precision medicine. The chart offers a clear depiction of how participants ranked various elements of precision medicine throughout the study.

Discussion

This research offers important perspectives on the effects and difficulties of precision medicine (PM), especially regarding its benefits and drawbacks. The results indicate that patients undergoing PM achieved better health results than those on traditional treatments, especially regarding cancer, chronic illnesses, and genetic conditions. These advancements align with earlier studies, which suggest that precision medicine can greatly improve patient care by customizing therapies to fit individuals' genetic and biological characteristics (Purba, 2024). The research specifically revealed that cancer patients gained significant advantages from targeted therapies, showing a 30% increase in life expectancy. Likewise, individuals with chronic illnesses like type 2 diabetes and genetic disorders showed significant enhancements, reinforcing the impact of precision medicine in enhancing healthcare results (Kamaludin et al., 2024). Although these findings are encouraging, the research also highlights the considerable inequalities in access to precision medicine, especially among varying socioeconomic and geographic populations. Urban populations experienced considerably greater access to PM than rural populations, emphasizing the unequal allocation of healthcare resources. This difference in access can be linked to inequality in healthcare infrastructure, as urban regions typically possess more advanced healthcare facilities that can provide state-of-the-art treatments (Purba, 2024). In comparison, rural regions face challenges in accessing specialized healthcare services, with merely 40% of the rural populace able to take advantage of precision medicine. This strengthens the idea that

access to healthcare is still a vital concern, facing considerable obstacles in rural areas, where scarce resources and healthcare professionals impede the uptake of progressive treatment alternatives.

The research also highlights the impact of socioeconomic elements on the availability of precision medicine. It was discovered that low-income individuals were significantly impacted by the limited availability of PM, with under one-third of those from lower-income groups able to receive these advanced treatments. This underscores the ongoing problem of the "digital divide" in healthcare, where technological progress is unattainable for the economically challenged (Pongdee et al., 2023). These results strengthen the claim that precision medicine, although a groundbreaking advancement in medical care, can worsen current health disparities if not properly managed. If not tackled, these access inequalities may exacerbate health disparities among low-income and rural communities, deepening health inequities within society (Vashisht et al., 2023). A primary issue emerging from these results is the unequal distribution of precision medicine. While urban dwellers usually enjoy improved access to healthcare and are more inclined to gain from precision medicine, rural communities, and low-income individuals frequently get overlooked because of systemic obstacles. These access gaps highlight the necessity for policy measures designed to lessen healthcare inequalities and enhance the affordability and availability of precision medicine for every demographic. To tackle these inequalities, policymakers must enhance healthcare infrastructure, especially in rural regions, where the lack of specialized medical services hinders the uptake of advanced treatment options. Expanding the accessibility of diagnostic tools, improving the education of healthcare professionals in precision medicine, and investing in telemedicine might close the access gap. Telemedicine has particularly demonstrated potential in enhancing access to specialized medical care in rural areas, enabling patients to meet with specialists without requiring lengthy travel. This method may act as a viable remedy to alleviate the geographical and logistical challenges encountered by rural inhabitants.

Furthermore, public health policies need to take into account the financial obstacles that hinder low-income groups from utilizing precision medicine. Policymakers must investigate strategies to reduce the cost of precision medicine for low-income people, including subsidies or financial aid initiatives. Broadening insurance coverage to encompass precision medicine treatments might enhance access for underrepresented communities. A holistic strategy that integrates infrastructure development, financial backing, and technological advancements will be vital in guaranteeing that the advantages of precision medicine are fairly shared among various socioeconomic and geographic populations.

This research further adds to the expanding evidence regarding the cost-effectiveness of precision medicine. Although the upfront costs of precision medicine can be significant, the advantages over time are considerable. The research discovered that precision medicine resulted in a 15% decrease in healthcare expenses because of a decline in complications and hospital admissions (Kamaludin et al., 2024). This is consistent with earlier research indicating that precision medicine may lead to cost savings in the long run by avoiding negative health effects and diminishing the necessity for costly treatments. Nonetheless, for these cost reductions to be achieved, precision medicine must become available to a wider population, including individuals in rural and low-income regions. Furthermore, the results of this study expand on previous research that has shown the efficacy of targeted treatments, especially for cancer and long-term diseases. For instance, targeted cancer therapies have demonstrated enhancements in patient survival, with this research noting a 30% boost in life expectancy for cancer patients undergoing precision medicine (Klein et al., 2017). Likewise, treatments for chronic diseases based on biomarkers, as noted by Bigos et al. (2024), have demonstrated success in enhancing patient outcomes. This research not only validates the success of precision medicine but also highlights the necessity to tackle the current inequalities in its access. Although the research enhances our comprehension of precision medicine's influence, it also reveals certain deficiencies in the existing literature. For instance, while earlier studies have acknowledged the costs and infrastructure issues related to precision medicine, this research presents specific numerical comparisons of accessibility between urban and rural communities, along with differences across socioeconomic levels. These results highlight the necessity for focused measures to bridge the accessibility gap, especially for rural and low-income communities. According to Conteh (2022),

urban residents benefit from much greater access to precision medicine, with 85% of city dwellers having access, in contrast to just 40% of those in rural areas. This inequality demands immediate efforts to guarantee that precision medicine is accessible to all communities, rather than solely to those in city areas.

The research also highlights the necessity for additional studies on the long-term cost-efficiency of precision medicine. Although the study revealed a decrease in healthcare expenses linked to precision medicine, additional research should investigate the wider economic effects of these therapies on healthcare infrastructures. Cost-benefit and cost-utility assessments are crucial for comprehensively grasping the financial impacts of scaling precision medicine (Klein et al., 2017). These assessments will assist policymakers in making educated choices on the optimal distribution of resources for precision medicine, while also guaranteeing its accessibility for all groups.

Although the research adds to the increasing evidence regarding the effectiveness and cost-effectiveness of precision medicine, it also presents some limitations. Initially, data were collected from a limited number of healthcare facilities, which might not reflect the whole healthcare system. As a result, the results might not be relevant to every population or healthcare environment. Secondly, the research depended on past self-reported information, which could lead to reporting biases, especially concerning income levels and availability of healthcare services (McNaughton et al., 2015). Upcoming studies ought to employ more objective metrics and take into account further elements, including cultural beliefs, language obstacles, and health-seeking behaviors, that might affect the application of precision medicine (Li et al., 2024). Longitudinal studies would also enhance the understanding of the lasting effects of precision medicine and the changing disparities in access as time progresses.

Conclusion

This research highlights the considerable promise of precision medicine (PM) in enhancing health results, especially for individuals with chronic illnesses and genetic conditions. The results indicate that precision medicine results in higher survival rates and better quality of life, particularly for cancer patients who gained from targeted treatments, along with individuals suffering from chronic illnesses such as type 2 diabetes. The research also shows that access to PM is unevenly distributed, highlighting significant disparities related to geographic location and socioeconomic status. Urban populations benefit from superior healthcare infrastructure, leading to greater access to PM, whereas rural and low-income populations encounter significant obstacles. These differences in access highlight significant issues regarding the fairness and equity of PM implementation. The research highlights the necessity for public health policies to tackle these disparities by enhancing healthcare facilities in neglected regions, providing financial support to those with low incomes, and guaranteeing equal access to precision treatments for all demographic categories. Although the long-term savings from PM are clear, additional work is required to lower initial investment obstacles and ensure PM is affordable and accessible to all. Furthermore, the study emphasizes the need for additional research to investigate the wider economic and social effects of precision medicine, particularly concerning cost-effectiveness and long-term viability. Precision medicine offers potential as a revolutionary approach to personalized healthcare, but it needs to be supported by thorough policy initiatives to guarantee that its advantages are fairly shared. Closing the divide in access among various population groups is essential for attaining health equity and making certain that precision medicine fulfills its potential to enhance public health results in varied communities.

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