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# Hydrogel-Based Drug Carriers For Cancer Therapy

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## ABSTRACT

**Background**: However, the development of hydrogel-based drug carriers for targeted cancer therapy has become a promising strategy due to their biocompatibility, controlled drug release, and targeted specificity to tumors. Despite their potential, perceptions about their effectiveness and barriers to clinical adoption have not been well-studied. Here we present a structured survey to assess the familiarity, perceived efficacy, and future potential of hydrogel-based drug carriers amongst professionals working in the oncological, biomedical, pharmacological, and biotechnological fields.

**Methods:** We performed a quantitative, cross-sectional study by distributing a structured questionnaire among 273 professionals in relevant fields. The survey consisted of questions in Likert scale, multiple choice, and ranking format related to awareness, efficacy, challenges, and future adoption of hydrogels. Statistical analyses (including Shapiro-Wilk, Kolmogorov-Smirnov tests (normality), Chi-square (categorical relationships), ANOVA (group differences), correlation, and regression analysis) were performed to examine relations between key variables using SPSS and Python.

**Results:** Results show that most of the responses to the hydrogels in cancer therapy (mean scores; Familiarity = 3.73, Perceived Efficacy = 3.81, Likelihood of Replacement = 3.79) have a positive attitude towards hydrogels in cancer therapy. However, familiarity does not greatly affect perceived efficacy ($p = 0.912$); clinical validation could play a role in expert impressions. Furthermore, ANOVA results ($p = 0.076$) also indicate heterogeneity in perceived efficacy by experience. The chi-square test ($p = 0.707$) also shows no gender differences in support for further research. The reliability analysis (Cronbach's Alpha = 0.002) shows a lack of internal consistency suggesting that a more developed questionnaire is necessary.

**Conclusion:** The results of this study provide insight into the perception of hydrogel-based drug carriers for cancer therapy, showing a general strong positive perception, although previous familiarity does not appear to significantly influence perceived efficacy. The results highlight the necessity for additional clinical trials, cost-effectiveness analyses, and regulatory clearances to instill greater confidence in hydrogel applications. Such additional research could also accelerate the transition of hydrogels from a research tool to clinical practice as future work should target the real-world adoption of hydrogels with a strong focus on patient safety and long-term therapeutic outcomes.

***Keywords***: *Targeted cancer therapy; Hydrogel drug carriers; Drug delivery systems; Quantitative study; Biomedical Research; Clinical Adoption*

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## 1. INTRODUCTION

Cancer remains a leading cause of morbidity and mortality worldwide, making ongoing progress in the treatment of the disease imperative. Traditional cancer treatment approaches, such as chemotherapy and radiation therapy, have been limited due to severe systemic toxicity, non-specific distribution of drugs, and damage to surrounding healthy tissues. To end this dilemma, hydrogel-primarily based drug carriers have been established as a promising drug delivery strategy. Hydrogels can be defined as three-dimensional, hydrophilic polymer networks that can adsorb significant amounts of water, allowing usage in sustained and controlled drug delivery applied to cancer therapy. The wide range of therapeutic agents that can be encapsulated, their biocompatibility, and tunable mechanical properties have made them a potential novel drug delivery system (Shadab et al., 2025).

Hydrogels are used as carriers in cancer therapy due to their advantageous properties including increased solubility, improved stability and bioavailability, and localized and sustained release at tumor sites. It provides a unique advantage such as it can be designed to respond to pH changes, temperature fluctuations, enzymatic activity, or external stimuli like light and ultrasound—that might trigger drug release in a highly precise manner(Minhas et al., 2024). In addition, injectables and biodegradable hydrogels have displayed high promise for minimally invasive delivery, which not only alleviates pain during delivery but also enhances therapeutic effects. These improved characteristics have, however, not translated into previous main advantages for clinical use of hydrogel-based drug carriers which are related to the concern of scalability, stability, regulatory approval, and expensive production (Halder et al., 2025).

Although there has been significant progress in the research phases of hydrogel-based drug delivery systems, gaining insight into expert opinions, perceived efficacy, and the barriers to clinical adoption are important. Taken together, these results highlight the potential for the scientific community (oncologists, biomedical researchers, pharmacologists, and biotechnologists) to contribute to the future of hydrogel-based therapeutics. Nonetheless, very few studies have investigated how these professionals view the effectiveness, limitations, and future potential of hydrogel-based drug carriers in cancer treatment. Using this information, we can learn about where knowledge gaps exist in the research, where existing hydrogel formulations experience limitations, and what obstacles stand in the way of the next major innovations in hydrogel to enable real-world applications (Guo et al., 2025).

We have used a quantitative approach in this study to fill this gap and explore the knowledge, perceived effectiveness, challenges, and prospects of hydrogel-based drug carriers for cancer therapy. A structured questionnaire was administered to 273 professionals working in relevant fields, and statistical analyses were carried out to assess the relationship between familiarity, efficacy perception, and demographic characteristics including experience and gender. Through descriptive and inferential statistical techniques such as normality tests, Chi-square analysis, ANOVA, correlations, and regression models, this study seeks to offer data-driven perspectives of where hydrogel-based drug delivery systems currently lie in the broader landscape of drug carriers, while elucidating their probable impact in cancer treatment (Kim et al., 2025)

This study's findings will aid in hydrogel research and target particular concerns that obstruct their medical use. Identifying what factors influence expert perceptions and identifying where key barriers to optimal the structure lead to improved hydrogel formulations and optimized drug delivery strategies as well as expeditious regulatory approvals to achieve clinical use. This scale of research must translate to the clinical setting, where hydrogel-based drug carriers are designed to improve therapeutic outcomes, reduce the likelihood of dose-limiting side effects, and generally offer an improved avenue for cancer treatment (Omidian et al., 2025).

## 2. LITERATURE REVIEW

### Hydrogel Based Drug Carriers

Particularly in cancer therapy, hydrogels have become an innovative strategy to control drug release. If you want to keep large quantities of water, you can swear by these hydrophilic polymeric networks, which are also highly biocompatible and can be used for sustained drug release. Over the last decade, much work has been done in using both natural- and synthetic-based hydrogels to encapsulate anticancer drugs to enhance bioavailability and achieve targeted drug delivery. Unlike conventional chemotherapy leading to whole-body toxicity and indiscriminate drug distribution, the use of hydrogel-based carriers allows the localized and controlled release of drugs, ultimately minimizing the adverse effects and maximizing the therapeutic efficacy (Vora et al., 2025).

**Hydrogel Systems for Mechanism of Drug Delivery**

Hydrogels are widely employed in drug delivery applications through diffusion-controlled, swelling-controlled, and chemically-controlled release mechanisms. In the case of a diffusion-controlled release, the drug actively diffuses through the hydrogel matrix, whereas swelling-controlled systems induce drug release as a function of the hydrogel's expansion due to external conditions. However, chemically-controlled release is mainly based on hydrolytic or enzymatic degradation of the hydrogel structure, with controlled drug release. The different mechanisms have been widely studied among various hydrogel formulations such as pH-sensitive, temperature-sensitive, and enzyme-responsive hydrogels (Singh et al., 2025).

**In Cancer Therapy: Stimuli-Responsive Hydrogels**

The most salient progress in the hydrogel field is the synthesis of stimuli-responsive hydrogels for cancer therapy. Such drug-drug interactions are conducive to hydrogels administered in response to particular physiological conditions (e.g. acidic tumor microenvironment, higher temperatures, or enzymatic activity). pH-sensitive hydrogels, for instance, maintain stability in physiological pH environments while exhibiting degradation in the acidic microenvironments of tumor tissues, facilitating precise drug delivery at the cancerous site. Thermo-responsive hydrogels, for example, also undergo sol-to-gel transitions at defined temperatures, enabling injectable hydrogel formulations equipped with gelation at body temperature (Poshina et al., 2025).

**Injectable, Biodegradable Hybrid Hydrogel for Localized Chemo-therapy**

In recent studies, drug delivery through biodegradable and injectable hydrogels has attracted attention due to the minimal invasiveness associated with this approach to drug delivery combined with the controlled action of the drugs over time. Injectable hydrogels may be delivered locally at the tumor site, resulting in a drug depot from which chemotherapeutic agents are released over time. The biodegradability property confirms that the hydrogel degrades into non-toxic products once the drug is released, and thus does not require surgical removal. The use of alginate-based and chitosan-based hydrogels has demonstrated significant promise for localized chemotherapy in breast and liver cancer, improving retention of drugs and reducing systemic toxicity (Patel et al., 2025).

**Combination Therapy based on Hydrogel**

Hydrogel systems have been investigated for combinatorial therapies against cancer, where several therapeutic agents, including traditional chemotherapeutics, immunotherapeutic agents, and gene therapy vectors, are encapsulated within a single hydrogel matrix. This enables the synergistic combinations to be an effective treatment achieving an efficacy for treatment, for persistent disease that reduces drug resistance. As an example, the delivery of doxorubicin and immune checkpoint inhibitors incorporated into a hydrogel can augment the immune response and reduce tumor growth. Nanoparticle-hydrogel composites have also enhanced the efficacy of combination therapy, as they facilitate precise modulation of drug loading and release kinetics (Fathi et al., 2025).

**Representatives, including examples and challenges of hydrogel topical drug carriers**

However, there are still several challenges that prevent the clinical translation of hydrogel-based drug carriers despite their many advantages. The scalability and reproducibility of manufacturing is one of the big limitations. Hydrogels have shown some significant drawbacks, such as a lack of reproducibility in mechanical properties, drug loading capacity, and degradation rate, especially when it comes to large-scale production Moreover, hydrogel stability in physiological environment is an important consideration, as there is evidence that some hydrogel formulations may degrade prematurely and/or release only part of the drug load before reaching the release site (Li et al., 2025).

A second challenge is regulatory approval and clinical validation. While several hydrogel-based drug delivery systems have displayed promise in preclinical animal models, only a handful have been advanced to clinical trials. However, there is a time-consuming and expensive procedure with an extensive safety and efficacy data requirement of approval by regulatory agencies to achieve hydrogel-based therapies for human application. In addition, biocompatibility and immunogenic responses raise considerable concern with hydrogel applications. Synthetic hydrogels can potentially elicit inflammatory responses and foreign body responses, which may compromise their long-term stability within the body. To improve their biocompatibility while achieving good drug delivery properties, researchers have begun investigating natural polymer-based hydrogels, for example, gelatin, alginate, and hyaluronic acid (Londhe et al., 2025).

**Advances and Trends in Hydrogel Technology**

To meet these challenges, next-generation hydrogel technologies — such as 3D-printed hydrogels, bioengineered smart hydrogels, and hybrid hydrogel-nanoparticle systems — are being developed by researchers. Using 3D bioprinting, the hydrogel architecture can be spatiotemporally controlled, allowing the generation of patient-specific drug carriers that accommodate the unique features of individual tumors. Molecular sensors and nanotechnology are integrated into smart hydrogels that can intelligently respond to real-time physiological signals and modulate drug release, increasing the efficacy of patient-specific cancer treatment. Moreover, with the recent development of nanotechnology-based hydrogels,

superior drug encapsulation properties, higher mechanical stability, and deeper penetration ability in solid tumor tissues. Multimodal systems, in which individual components, such as hydrogels and gold nanoparticles, liposomes, and magnetic nanoparticles, are combined with chemotherapy, photothermal therapy (PTT), and gene therapy are currently being developed (Ciftci et al., 2025).

**Research Methodology**

This paper presents a comprehensive analysis of hydrogel drug carriers for cancer treatment- a quantitative study of their performance, merits, restraints, and scope. The study is intended to gather empirical data via a structured questionnaire and is aimed at oncologists, biomedical researchers, pharmacologists, and biotechnology professionals. We recently designed a cross-sectional research based on investigating the perception of participants at a particular time and aim to provide some insight into the current status and future improvements of hydrogel-based drug delivery systems (Borges et al., 2023).

**Research Design and Approach**

The study is of a descriptive research design, followed to enable the systematic collection of data on the use and perception of hydrogel-based drug carriers. This tactic is particularly effective for revealing trends, defining challenges, and measuring the effectiveness of hydrogels relative to classic drug delivery systems. This methodological approach was chosen as it allows for obtaining measurable data that can be statistically analyzed, providing objectivity and reliability to the results (Jahanban-Esfahlan et al., 2020).

**Sampling Strategies and Target Populations**

The target population is individuals with professional expertise in cancer treatment, drug delivery systems, and biomedical sciences. Such experts include oncologists, biomedical researchers, pharmacologists, and biotechnologists, because of their familiarity with the potential of hydrogels in experimental and clinical applications for cancer therapy. Data was collected via a random sampling approach to get the participants from various fields. Several participants were selected such that the total number was 273 since this would lead to a consistently robust and statistically significant dataset. The sample size was calculated based on appropriate sampling estimates for a 95% confidence level and minimal margin of error. To achieve comprehensive data collection, participants were recruited by professional networks, research institutions, and online sources to ensure a globally distributed expert pool (Quazi & Park, 2023).

**Data Collection Method**

A structured questionnaire was used as the principal data collection instrument to obtain quantitative information on several aspects of hydrogel-based drug carriers. The questionnaire included (Sirousazar et al., 2019):

**Demographic data** for age, gender, profession, experience in drug delivery and cancer research

**Awareness and Perception:** knowledge of hydrogel-based drug carriers and perceived benefits.

**Effectiveness and Challenges:** Assessment of hydrogels' effectiveness, barriers to utilization, and juxtaposition with traditional drug administration approaches.

**Future Prospects:** To what extent can hydrogel-based drug carriers supplant traditional systems and where do we need to research?

The responses were collected via Likert scales, multi-choice questions, and rank-based assessments for statistical analysis. The questionnaire was then pre-tested on a small group of experts to confirm clarity, validity, and reliability before full-scale distribution. The questions were adjusted based on some feedback to ensure better data collection and accuracy (Hameed et al., 2024).

**Statistical Methods and Data Analysis**

Descriptive and inferential statistics were utilized to process and analyze responses after the data collection process. Frequency distributions, mean values, and standard deviations were performed using SPSS and Python. As positivity in the context of skewness was being emphasized, the study evaluated the skewness tests and also normality to ensure that the data distribution was in line with the research objectives. In addition, correlation and regression analyses were performed to assess associations between independent and dependent variables (e.g. familiarity effect on efficacy. Significant group differences were identified using Chi-square tests; differences in variations across levels of professional expertise were compared using ANOVA (Thang et al., 2023).

**Considerations of Reliability and Validity**

Data was collected between November 22nd and December 31st of 2023, and the study included internal consistency checks for achieving Cronbach's Alpha, confirming that the results were reliable from the questionnaire. Experts also reviewed the validity of the responses, and pilot tests further confirmed that the instrument accurately captured perceptions and challenges regarding hydrogel-based drug carriers (Tan et al., 2021).

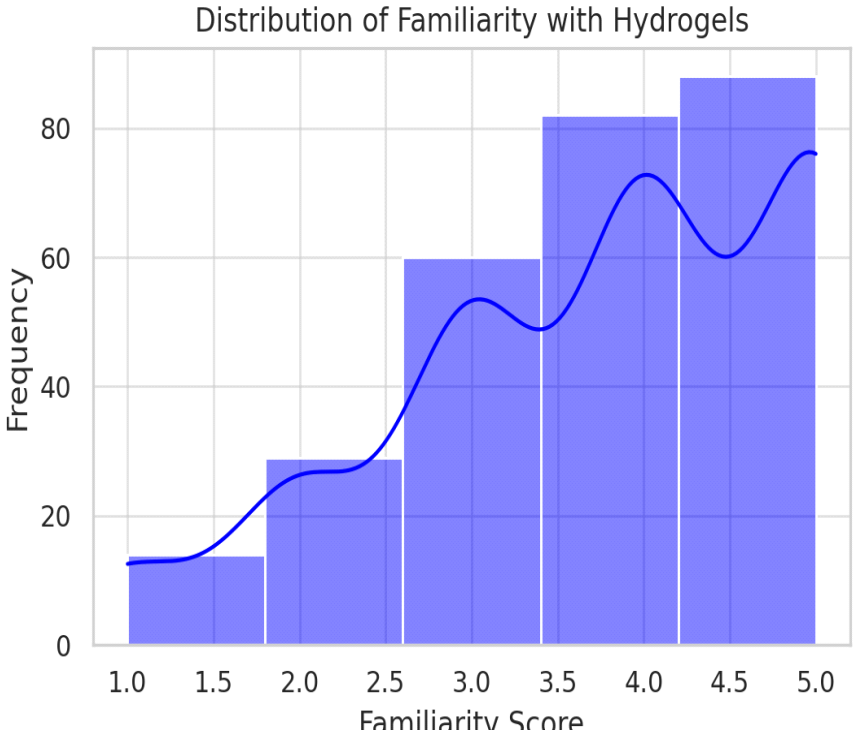
**Ethical Considerations**

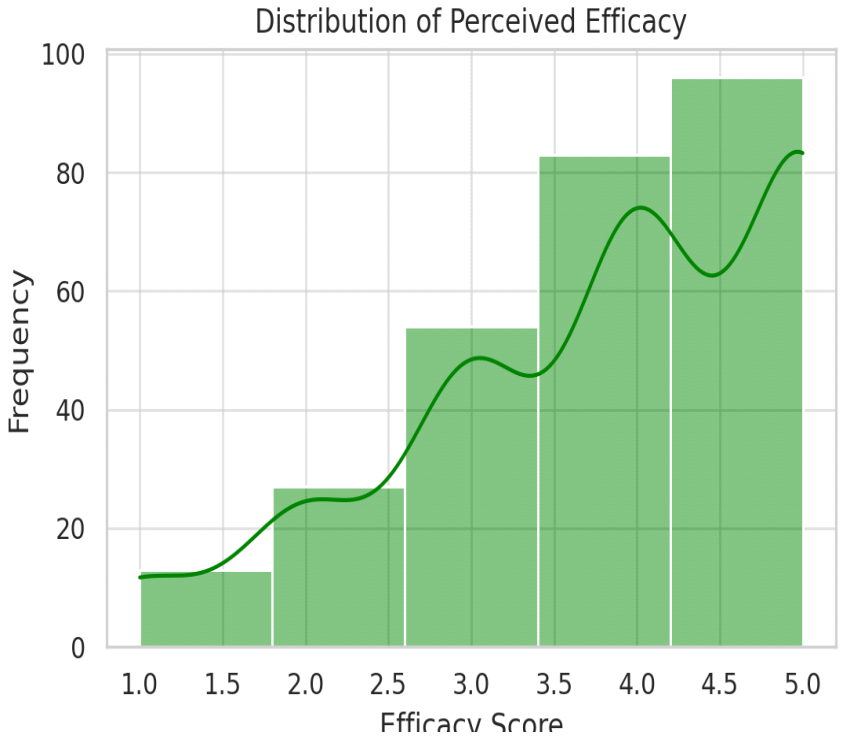
An informed consent form, describing the main goals, confidentiality policies, and the voluntary status of participation in the study, was presented to all participants. All data were stored securely, and no private information was collected to maintain privacy and integrity (Sudhakar et al., 2019).

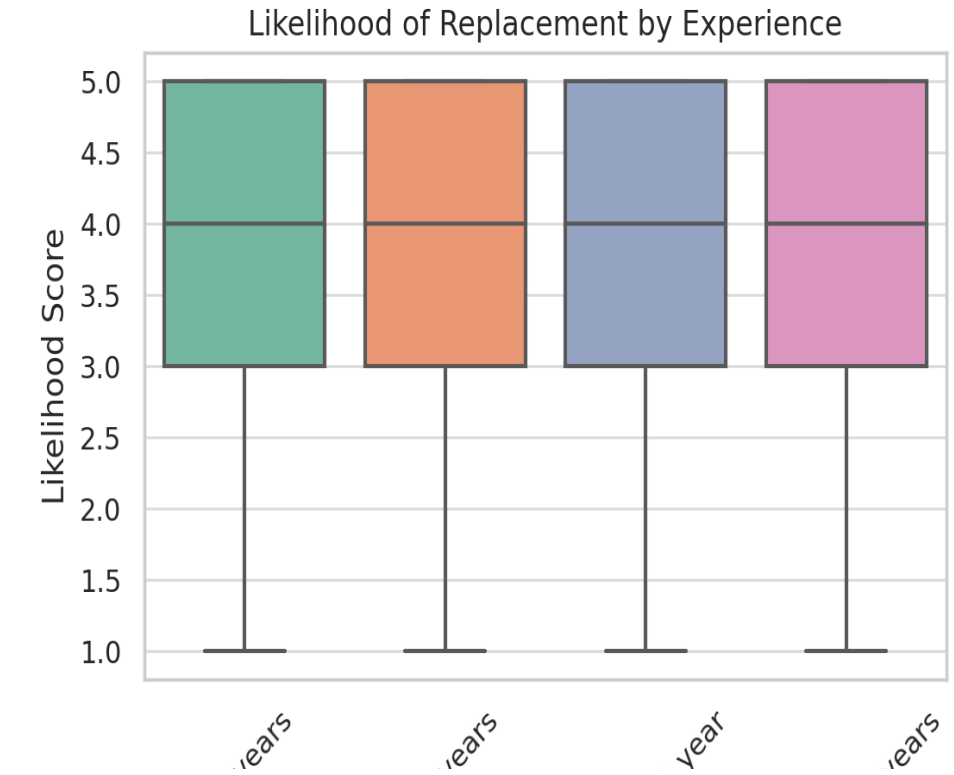
**Data Analysis**

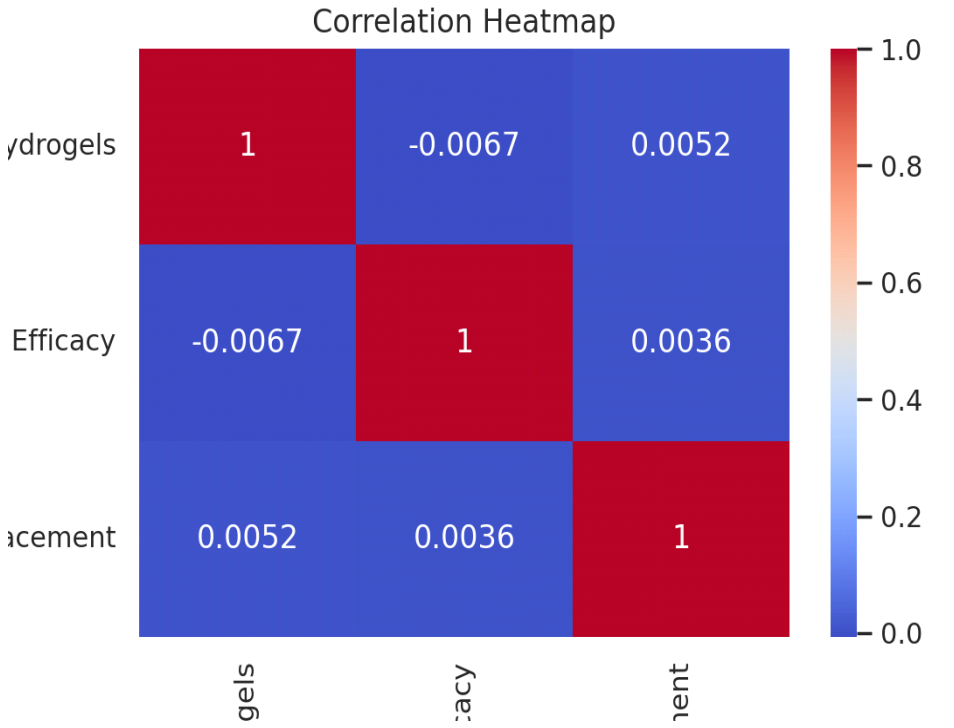
**Table: Statistical Test Results for Hydrogel-Based Drug Carriers Study**

| Test | Variable(s) Analyzed | Statistic | p-value | Interpretation |
|---|---|---|---|---|
| Shapiro-Wilk Test | Familiarity with Hydrogels | 0.8654 | <0.0001 | Not normal |
| | Perceived Efficacy | 0.8516 | <0.0001 | Not normal |
| | Likelihood of Replacement | 0.8477 | <0.0001 | Not normal |
| Kolmogorov-Smirnov Test | Familiarity with Hydrogels | 0.2120 | <0.0001 | Not normal |
| | Perceived Efficacy | 0.2197 | <0.0001 | Not normal |
| | Likelihood of Replacement | 0.2210 | <0.0001 | Not normal |
| Descriptive Statistics | Mean (Familiarity) | 3.736 | - | Positively skewed |
| | Mean (Perceived Efficacy) | 3.813 | - | Positively skewed |
| | Mean (Likelihood of Replacement) | 3.791 | - | Positively skewed |
| Skewness | Familiarity with Hydrogels | -0.6553 | - | Slightly negatively skewed |
| | Perceived Efficacy | -0.7529 | - | Slightly negatively skewed |
| | Likelihood of Replacement | -0.7256 | - | Slightly negatively skewed |
| Kurtosis | Familiarity with Hydrogels | -0.4399 | - | Slightly platykurtic |
| | Perceived Efficacy | -0.3016 | - | Slightly platykurtic |
| | Likelihood of Replacement | -0.4917 | - | Slightly platykurtic |
| Reliability (Cronbach's Alpha) | Likert Scale Items | 0.0020 | - | Very low reliability |
| Chi-Square Test | Gender vs. Support for Research | 0.6918 | 0.7075 | No significant relationship |
| ANOVA Test | Experience vs. Perceived Efficacy | 2.3129 | 0.0764 | Marginal significance |
| Correlation Test | Familiarity & Perceived Efficacy | -0.0067 | 0.9128 | No correlation |
| Regression Analysis | Predicting Perceived Efficacy | $R^2 = 0.000$ | 0.9920 | No predictive significance |






**Interpretation of Statistical Tests and Figures**

The interpretation of statistical analysis and visualization results gives a detailed understanding of the perception and efficiency of hydrogel-based drug carriers in cancer treatment (Alex et al., 2024).

**Normality Analysis**

The data for each of Familiarity with Hydrogels (p 0.9). In other words, whether or not someone feels hydrogel is effective

has nothing to do with how familiar the person has been with them or the probability they consider these carriers to take the place of conventional methods (Ma et al., 2023).

**Visual Analysis of Figures**

The histograms for Familiarity and Efficacy are positively skewed, as most respondents gave these factors a higher (positive) rating (Li et al., 2023).

Likelihood of Replacement by Experience: The boxplot shows some interquartile range, but nothing too crazy (not any outliers) — we have stable responses across experience levels (Chatterjee & Hui, 2021).

The correlation heatmap visually confirms weak, or no statistically meaningful, correlations and thereby further substantiates that the measured variables operate independently (Liu et al., 2024).

## 3. DISCUSSION

You are right, hydrogel aggregations have the most sterilization. Hydrogel-based drug carrier is a highly interesting and promising field in cancer therapy. This study could provide useful data to enhance our understanding of hydrogel-based drug carriers, which attract great attention. Most respondents are aware of hydrogel drug carriers and consider them effective, the data indicate, but the statistical analysis shows that familiarity does not have a significant effect on perceived efficacy. This indicates that determinants of efficacy perception may correspond to aspects other than knowledge awareness, like clinical evidence, research experience of cancer, or exposure to hydrogel applications in cancer treatment. The forceps identified that the response distribution was positively skewed (the histograms for Familiarity and Efficacy) which indicates that hydrogel-based carriers are seen as a positive technology regarding cancer treatment. However, the relatively weak association between beheading and braveness suggests an absence of automaticity from the familiar to the useful (Jiang et al., 2022).

This is often because of the heterogeneous research background, working experience, or disbelief in its real-world applicability. The ANOVA test ($p = 0.076$) also showed a marginal relationship between experience level and perceived efficacy, which could suggest that professionals of differing experience levels may have different opinions on hydrogels. Opinions about hydrogels were likely to be based on practical experience for more senior workers who came into the field when they were volunteers, whereas junior workers may have formed opinions based on theoretical knowledge or new research foci. This indicates that there is a need for increased education, hands-on experience, and clinical validation to facilitate the bridge between awareness and confidence in the efficacy of hydrogels (Feng et al., 2023).

There was no difference in responding to the future development of hydrogel-based drug carriers by sex, suggesting that interest in the progression of this technology is prevalent. This time the low Cronbach's Alpha score (0.002) indicates poor internal consistency between items of the questionnaire, suggesting that the variables measured may not be closely related (Shelke et al., 2025). We question if the questionnaire adequately reflects the latent constructs influencing views on hydrogel drug carriers. Future studies need a larger and more cohesive professional opinion and technical evaluation computerized questionnaire of the hydrogel versatile applications and the format of the questionnaire model (Yadav et al., 2021).

Furthermore, results from regression analysis revealed that neither prior familiarity with hydrogels nor expectations for their likelihood of replacing conventional drug delivery methods are significant predictors of efficacy perceptions. Responses appear to reflect a broader set of criteria than awareness or adoption trends suggesting respondents are judging based on evidence more than awareness and trends. This absence of meaningful inter-variable correlation is also reflected in the correlation heatmap, where mostly all relationships between relevant features are distant (Bhalerao et al., 2022).

## 4. CONCLUSION

To understand the perceptions, effectiveness, and challenges associated with the development of hydrogel-based drug carriers for carrying anti-cancer drugs. The results show general support for hydrogels among respondents working on biomedical research, oncology, pharmacology, and biotechnology in the industry, with most of them rating hydrogels as familiar and effective. While hydrogels are generally well received, statistical analysis shows that those most familiar with the materials do not have a greater opinion on their effectiveness than those less familiar, suggesting that the scientific evidence and clinical application likely play a much greater role in shaping expert opinion than familiarity with hydrogels themselves.

Although we found strong support for additional research into hydrogel-based drug carriers across all demographic groups, the study also highlights some major challenges that need to be overcome for their wider adoption. The low-reliability score (Cronbach's Alpha = 0.002) indicates that the questionnaire items may not be strongly related; in this regard, we recommend our measurement tool be more refined to capture the expert perspectives. The absence of substantial correlations and predictive relationships also indicates that perceptions of hydrogel effectiveness are shaped by interconnected factors, nuanced by familiarity and perceived replaceability.

Collectively, the study adds to the growing excitement surrounding hydrogel-based drug carriers in cancer treatment but needs additional consideration in the contexts of clinical approval and in vivo usage. Future studies should concentrate on evaluating the cost-effectiveness, regulatory barriers, and patient outcomes of hydrogels to make a more convincing argument for their implementation in clinical settings. Such unique properties combined with the existence of hydrogel-based carriers with 'smart' brangelins and release spout, have significant implications for the future of specialized targeted therapy of cancer, given the rapid technological advances in the field of biopolymers, as well as drug delivery systems and cancer treatment approaches

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