ISSN 1840-4855
e-ISSN 2233-0046

Original scientific article
http://dx.doi.org/10.70102/afts.2025.1834.1215

MANUFACTURING FEASIBILITY AND INDUSTRY READINESS FOR INDIGENOUS AUTO-RETRACTABLE SINGLE-USE SYRINGES IN INDIA: AN EMPIRICAL STUDY TO PREVENT NEEDLESTICK INJURIES AND BLOOD-BORNE INFECTIONS

Girish Kumar Kuppireddy[1*], Dr. Kamineni Saradhi[2]

[1]Research Scholar, School of Commerce & Management, Mohan Babu University, Tirupati, Andhra Pradesh, India. e-mail:girish7h@gmail.com,*
orcid: https://orcid.org/0009-0007-7249-7094
[2]Professor, School of Commerce & Management, Mohan Babu University, Tirupati, Andhra Pradesh, India. e-mail:saradhi@vidyanikethan.edu,
orcid: https://orcid.org/0009-0004-6381-1246

Received: October 11, 2025; Revised: November 15, 2025; Accepted: December 15, 2025; Published: December 30, 2025

SUMMARY

Needlestick injuries (NSIs) are an ongoing workplace risk associated with healthcare facilities and this risk is even more pronounced in the developing economies where the traditional disposable syringes are still in use as a method of therapy. Even though the use of safety-engineered syringes has been globally endorsed to minimize the occupational exposure to blood-borne infections, their use in India has not been widespread. Auto-disable syringes have enhanced safety in terms of preventing re use but does not remove the possibility of post-injection exposure to the needle hence subjecting healthcare workers to injuries. This paper explores the technical feasibility, industry preparedness and relevance of safety of production of indigenous auto-retractable single-use syringes in India. It was a structured survey over the manufacturers of syringes in India, which covered a near-census of the industry. Among the 64 manufacturers who were identified, 59 gave valid responses, which is a response rate of 92.2 percent. The article is a statistical study that incorporates design-feasibility and economic factors, determining the perception of manufacturers and the obstacles to the introduction of advanced safety technologies in the healthcare industry. The results of the research indicate that there is high awareness of the auto-retractable syringe technology, but the capacity to produce these syringes in-country is low. Majority of the manufactures still concentrate on traditional disposable or auto-disable syringes due to sensitivity of costs, complexity in design and uncertainty of demand in the market. Nevertheless, there is a strong relationship between the perceived risk of needle-stick injuries and acceptance of safer designs of syringes. Moreover, the more simplified retraction mechanisms that can be used with current production infrastructure prove more willingness to pilot adoption among manufacturers. The research concludes that indigenous auto-retractable syringe technology is technically viable and possibly economically viable in the Indian manufacturing ecosystem given that design simplicity, policy support and procurement incentives are coordinated. The findings also give useful information regarding the role of innovation and manufacturing capacities in enhancing safety and decreasing occupational hazards in the healthcare system in India.

Key words: *auto-retractable syringe, needlestick injury, injection safety, medical device manufacturing, industry readiness, india.*

INTRODUCTION

One of the most commonly carried medical operations in healthcare delivery is injection. There are billions of injections done every year as estimated by the World Health Organization of which a considerable percentage are done in treatment but not immunization related [1]. Although injections are highly essential in the treatment and prevention of diseases, unsafe injection behaviours are of high health and occupational safety concern mostly in the low- and middle-income nations. Among the other risks of injection practices, needlestick injuries (NSIs) are one of the most profound and irreducible occupational risks that healthcare workers and biomedical waste disposers experience [2]. The needlestick injuries are associated with the accidental puncture of skin by a needle or a sharp medical device, which alters the person who receives the piercing to blood-borne pathogens, including hepatitis B virus (HBV), hepatitis C virus (HCV), and human immunodeficiency virus (HIV). Empirical research in various health care facilities has always indicated that the incidence of NSIs go unreported, with the true incidence rate being far more significant when compared to the registered records.

The professional and psychological impacts of NSIs go beyond the immediate trauma, and include long-term health hazards, emotional anxiety, and financial cost of post-exposure prophylaxis, diagnostic testing, and follow-up treatment. This paper examines the technological feasibility, the industry preparedness, and safety applicability of the production of indigenous auto-retractable syringes in India [3]. Although standard syringes hold the largest market, there is an increased demand of devices that are highly safe and engineered such as the retractable syringes [4]. This interest is in line with the central aspects of the research which comprise the innovation of medical equipment, production facilities and the barriers encountered in implementing these high-tech safety measures in the Indian healthcare system. There is a considerable potential of domestic production where India is having an established industry of syringes, yet the constraints in designing, manufacturing processes, and costs models pose a serious constraint. In a bid to control unsafe injection practices, the international health bodies have more frequently encouraged the employment of safety-engineered injection devices [5]. Auto-disable (AD) syringes are one type of intervention that has been extensively integrated into immunization programs to avoid syringe sharing and cross-infection of patients. Although AD syringes enhance patient safety, they do not negate the use of post-injection needles, which means that have minimal protection against needlestick injuries.

In turn, AD syringes are also known as the incomplete safety measure that fails to resolve the occupational exposure risks. Auto-retractable syringes are also a new type of safety-designed equipment that aims to automatically retract the needle into the syringe barrel once the injection has been made. These syringes permanently seal the needle inside the barrel and therefore, avoid reuse and expose the sharps at the same time, thus providing complete safety to the patients and health care personnel. According to the empirical data of international studies, auto-retractable syringes are linked with significant decrease in the incidence of NSI in comparison to conventional and auto- disable syringes. Although these are recorded safety benefits, auto-retractable syringes usage has not been widely adopted, especially in developing economies [6].

The syringe production business in India is quite old and contributes to the local market and the worldwide shipment of the disposable medical devices. However, the industry is still dominated by the traditional disposable and auto-disable syringes. The production of 100 percent auto retractable syringes by natives is very low and most of the market supply relies on imports or semi-retractable types. The current literature is indicating that this has been caused by a combination of factors, such as increased unit costs, more complicated designs, manufacturing limitations as well as procurement practices that focus more on the price of the initial purchase, rather than on the long-term safety benefits. Although some of the studies have dealt with injection safety and needlestick injuries concerning the clinical or epidemiological view, there is a significant gap in the existing empirical studies regarding the industry preparedness, manufacturing viability, and economic aspects associated with the implementation of the advanced safety-engineered syringes in India. Specifically, the views of syringe manufacturers that are key participants in the development of the technology, setting costs, and mass availability are underrepresented in the available literature. Moreover, limited literature combines statistical examination of views of the manufacturers with design viability and cost-effectiveness of the research

in the same analytical method. It is on this basis that the current study aims at showing empirically the viability and preparedness of the indigenous auto-retractable single-use syringe technology in India [7]. Through the use of first-hand data gathered through survey of syringe manufacturers in the nation and extensive statistical analysis, the study will evaluate the perceived safety lapses, adoption barriers, and the possibility of simplified retractable designs that can be fitted in the current manufacturing facilities. The paper goes further to identify the economic and policy response of switching to engineering-based injection safety solutions with emphasis on preventing needlestick injuries and the related risks of blood-borne infections.

Key Contribution

- The study evaluates the technical and logistical challenges involved in manufacturing indigenous auto-retractable single-use syringes in India, highlighting the industry's readiness to adopt this advanced safety technology.
- It examines the financial barriers to producing auto-retractable syringes, considering factors such as production costs, the need for specialized equipment, and the availability of skilled labor, offering insights into how to reduce costs and make these syringes more affordable.
- The research emphasizes the potential of auto-retractable syringes in reducing needlestick injuries and preventing blood-borne infections, contributing to enhanced healthcare safety standards and improving occupational health for healthcare workers in India.

Paper structure

The paper is structured as follows: Abstract, providing an overview of the study's objectives, methodology, and findings; Introduction, highlighting the significance of the problem and the need for auto-retractable syringes; Literature Review, discussing existing research on syringe safety and technology; Research Gap, Objectives, and Hypotheses, identifying the study's focus and hypotheses; Methodology, outlining the research design, population, and data collection approach; Results, presenting key findings on NSI risk perception and adoption readiness; Discussion, interpreting results in the context of current literature and industry feasibility; Economic and Policy Implications, discussing the cost and policy considerations for adopting safety-engineered syringes; and Conclusion, summarizing the study's contributions and suggesting future research directions.

LITERATURE REVIEW

The issue of injection safety has been recognized as a major element of quality and safety of healthcare. Several international studies indicate that needlestick injuries still constitute one of the most common occupational risks among the healthcare personnel, especially nurses, laboratory technicians and waste handlers [8]. The literature has always suggested that a significant percentage of NSIs takes place not at the time of injection, but at the time of handling, recapping and the disposal of used syringes. According to epidemiological research, a single needlestick injury would pose a quantifiable risk of transmission of blood-borne pathogens, and probabilities of hepatitis B, hepatitis C and HIV exposure have been documented. In addition to the risk of infections, NSIs cause psychological pressure, absenteeism and financial expenses associated with diagnostic tests and post-exposure prophylaxis. Notably, a number of studies note that the incidence of NSI is widely underreported, and the actual occupational burden is therefore much steeper than the postulated statistics [9]. The overcrowding of patients, time constraint and the lack of access to superior safety machines contribute to further cases of unsafe injection practices in developing countries such as India. Such systemic reasons minimize the efficacy of behavior-based safety measures, which strengthens the importance of implementing risk control measures at the device level.

Weaknesses of Traditional Disposable Syringes.

Traditional types of disposable syringes are made with single-use manufacture in order to prevent reuse, but lack features to deal with post-use needle exposures. The literature has cited this as a core design weakness, because security performance is sensitive to user behaviour, such as not recapping, and proper

disposal procedures. A number of observational studies show that despite proper training, adherence to safe handling practices is not constant especially in the highly work environment. Consequently, traditional syringes will still remain linked to the presence of a high rate of occupational sharps injury [10]. The training programs do not seem to be able to produce consistent safety norms because the persistence of NSIs is an indication that even behavioural controls do not help.

Auto-Disable Syringes: Achievement and Limitations.

Auto-disable (AD) syringes are a new public health intervention to stop syringe reuse and decrease the spread of infections among patients. Their successful implementation in immunization programs is recorded in the literature where have achieved a lot in reducing the reuse related infections. Nevertheless, the common limitation mentioned in the literature is that AD syringes are not able to prevent the needlestick injuries because the needle is not covered after injection [11]. Therefore, AD syringes are safe to patients but have minimal protection to health care workers. Comparative literature tends to categorize AD syringes as a partial safety measure, i.e. good to prevent reuse, but not to provide a complete occupational safety measure. This is an essential difference between patient safety and worker safety that is often underestimated in the literature of the policy [12].

Safety-Engineered Syringe and Engineering Control Theory

Theoretical models on occupational safety identify engineering measures as better than administrative and behavioural measures in a hierarchy of hazard control. Safety-engineered syringes fit into this model because put the mechanisms of risk prevention into the device design. SIP syringes are syringes that have shields or covers that cover the needle after usage [13]. Although the literature indicates that moderate NSIs reduction is achieved with SIP syringes, their usage is mostly constrained by the dependency of the user, as must be manually activated. Inability to activate safety features has been cited as one of the major causes of residual injuries. These results support the fact that entirely automatic safety measures are more effective than those operated by humans.

Auto-Retractable Syringes

Design Ideas and Safety Performance. Auto retractable Syringes are the safest type of injection development. are characterized by the automatic withdrawal of the needle into the barrel after the injection that renders the exposed sharps permanently inaccessible and avoids reuse. The conclusion regarding auto-retractable syringes is a consistent occurrence in international studies where are reported to have the greatest decrease in the occurrence of NSI in comparison to conventional, AD and SIP syringes [14]. These devices are able to remove the exposure at the post-use of needles, the most frequent phases at which NSIs happen. Although are safer to operate than their counterparts, there are also extensive adoption barriers, such as additional parts, design complexity, higher costs of production, and difficulty in adapting retractable mechanisms to large-volume production approaches in the literature [15][16].

Feasibility of Manufacturing and Industry Preparedness

Innovation in medical devices has been studied to show that clinical efficacy in itself is not sufficient to be adopted. The issues that determine whether a technology can scale or not are manufacturing feasibility, cost structure and supply-chain compatibility. The research on disposable medical equipment accentuates the significance of a design simplicity, fewer tooling shifts, and the ability to match the equipment with the current production lines. Manufacturers are more resistant to innovations that necessitate significant retooling or present some complexity in their assembly [17][18]. In the Indian environment, the literature recognizes robustness in manufacturing in plastic melding and disposable medical equipment but mentions a reserved approach to the acquisition of sophisticated safety technologies because of the uncertainty in the market and price-directed purchasing behaviours [19].

Economic Analysis of Safety- Engineered Syringes

Economic analyses of safety-engineered syringes usually consider increased initial costs of a device against improved savings due to lower NSIs [20]. These reviews prove that safety syringes could be cost-efficient in the long-term costs that are based on occupational exposure. Nevertheless, majority of the existing economic models are founded on the data of high-income countries and may fail to represent the cost-structure, wage-level and healthcare-financing mechanisms in India [21]. There is a literature consensus on the fact that there is a gap in India-based specific economic assessments that include manufacturing cost viewpoints and healthcare system savings.

Research Gap Identification

Based on the reviewed literature, the following gaps are identified:

1. There are few empirical studies exploring manufacturer perspectives on the adoption of auto-retractable syringes in India.
2. Limited alignment among design feasibility, industry preparedness, and economic assessment.
3. Heavy dependence on clinical and epidemiological studies, with little emphasis on manufacturing realities.
4. Insufficient statistically supported, industry-specific evidence to guide policy and procurement choices.

Positioning of the Present Study

This study fills those gaps through a near-census survey of Indian syringe manufacturers and uses thorough statistical analysis to assess the readiness, feasibility, and safety significance of locally developed auto-retractable syringe technology. By combining industry data with engineering and economic factors, it provides original empirical evidence on injection safety literature.

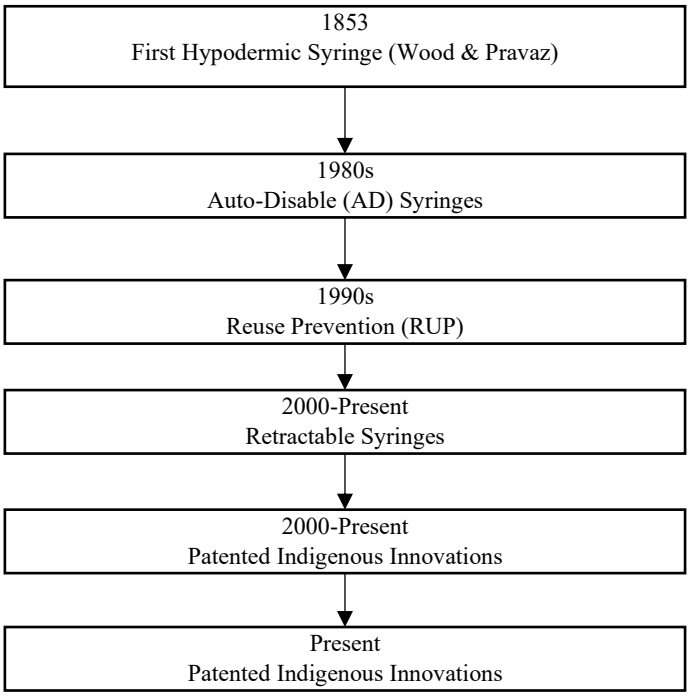

Figure 1. Evolution of syringe design for injection safety

Figure 1 illustrates the evolution of syringe technologies from reusable models to auto-retractable systems, emphasizing the gradual move toward engineering-focused solutions for improved injection methods safety.

RESEARCH GAP, OBJECTIVES, AND HYPOTHESES

Research Gap

A review of current literature shows a strong agreement on the public health and occupational hazards linked to unsafe injection practices and needlestick injuries. Many studies have measured the clinical impact of NSIs and highlighted the better safety record of auto-retractable syringe systems. Nonetheless, despite this expanding knowledge base, key gaps persist, especially in developing economies like India. First, most studies focus mainly on clinical, epidemiological, or policy viewpoints, with less emphasis on the manufacturing ecosystem that influences the widespread availability and affordability of safety devices. The insights of syringe manufacturers—who are vital in design choices, cost management, and scaling production—are largely missing from existing research.

Second, while auto-retractable syringes are widely acknowledged as the most effective safety solution, the literature provides insufficient empirical evidence on industry readiness and feasibility for indigenous production in India. Available studies often focus on imported devices There is a tendency to focus on conceptual designs without assessing whether such technologies can realistically be incorporated into current manufacturing systems. Additionally, economic analyses of safety-engineered syringes mainly derive from data in high-income countries, which may not align with Indian cost structures, procurement processes, or price sensitivities. Consequently, there's a gap in context-specific evidence that connects manufacturing feasibility with long-term occupational safety benefits. Moreover, current research seldom combines design factors, industry perceptions, and economic impacts within a single analytical framework backed by statistical data. This fragmented approach reduces the practical applicability of the findings for manufacturers, policymakers, and healthcare providers aiming for sustainable injection safety solutions. These gaps underscore the need for an empirical, industry-focused study that thoroughly evaluates the feasibility, preparedness, and safety relevance of indigenous auto-retractable syringe technology within the Indian manufacturing environment.

Objectives of the Study

In response to the identified research gaps, the present study is guided by the following objectives:

1. To examine the limitations of existing syringe designs in preventing needlestick injuries and ensuring occupational safety in Indian healthcare settings.
2. To assess the level of awareness, perception, and readiness among Indian syringe manufacturers toward auto-retractable syringe technology.
3. To evaluate the manufacturing feasibility of simplified auto-retractable syringe designs within existing Indian production infrastructure.
4. To analyze the relationship between perceived safety risks, manufacturability, and manufacturers' willingness to adopt or pilot auto-retractable syringes.
5. To explore the economic and policy implications of adopting indigenous auto-retractable syringe technology for reducing needlestick injuries.

These objectives collectively aim to generate statistically grounded evidence that can inform both industrial decision-making and policy formulation.

Research Hypotheses

Based on the objectives and the conceptual insights derived from the literature, the following hypotheses were formulated for empirical testing:

H_{01}:

There is no significant relationship between perceived needlestick injury risk and manufacturers' readiness to adopt auto-retractable syringe technology.

H_{11}:

There is a significant relationship between perceived needlestick injury risk and manufacturers' readiness to adopt auto-retractable syringe technology.

H_{02}:

Perceived limitations of conventional syringe designs do not significantly influence manufacturers' preference for engineering-based safety solutions.

H_{12}:

Perceived limitations of conventional syringe designs significantly influence manufacturers' preference for engineering-based safety solutions.

H_{03}:

Perceived manufacturability of simplified auto-retractable mechanisms has no significant effect on manufacturers' willingness to pilot auto-retractable syringe production.

H_{13}:

Perceived manufacturability of simplified auto-retractable mechanisms has a significant positive effect on manufacturers' willingness to pilot auto-retractable syringe production.

Conceptual Framework of the Study

The hypotheses are grounded in a conceptual framework that links safety perception, design feasibility, and adoption readiness. The framework assumes that higher perceived NSI risk and recognition of design limitations increase support for engineering-based safety solutions, while perceived manufacturability influences adoption intention and pilot readiness.

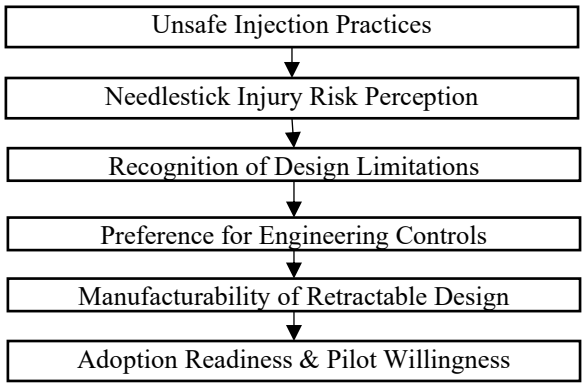

Figure 2. Conceptual framework linking injection safety risk, design feasibility, and adoption readiness

This framework illustrates (Figure 2) how needlestick injury risk perception and recognition of design limitations influence preference for engineering controls and manufacturers' readiness to adopt auto-retractable syringe technology.

METHODOLOGY

Research Design

The research design used in the study is a descriptive and analytical empirical research design. This format fits well in investigating the perception of the industry, manufacturing viability, and willingness to embrace the new medical technology of a medical device. It can be used to systematically evaluate

attitudes and limitations and there is the possibility to test statistically the association existing between the perceptions of safety, manufacturability, and adoption intentions. Being a cross-sectional study, it will gather responses of manufacturers at one point in time and will be based on quantitative analysis and supported by contextual knowledge of the industry.

Study Population and Sample

All the manufactures of syringes in India are the target population. A total of 64 syringe manufacturing companies were found using industry consolidation data and secondary sources as the whole population frame. The sampling approach was nearly a census whereby all identified manufactures were contacted. Out of these 59 provided valid responses that were usable with the resultant response rate of 92.2. Such a high response rate is deemed robust in regard to the research based on the industry and minimizes the risk of non-response bias. The near-census sampling enhances the representativeness of the outcomes and facilitates descriptive as well as inferential statistical methods of analysis.

Data Collection Instrument

The structured questionnaire that was used to collect primary data was designed to serve the purpose of this study. The questionnaire had 38 questions, which were grouped into 5 sections: 1. Production traits and profile of manufacturer.

1. Current syringe designs and safety restrictions.
2. Needlestick Injury perception and work-related safety.
3. Eagerness and capability to adopt auto-retractable syringe.
4. Economic and policy factors.

Five-point Likert scales were the measure used in most items to allow the perceptions and attitudes to be analyzed quantitatively with the levels of strong disagreement to strong agreement. The questions related to the profile used nominal and ordinal scale.

The questionnaire has been created on the basis of:

- Literature review insights.
- Hypotheses and objectives of the study.
- Professional contribution of academic and industrial experts.

Data Collection Procedure

The questionnaire has been distributed to the manufacturers using the professional communication means, such as emails and direct contact with managerial and technical representatives. The respondents were people who engaged in either production planning or quality management or strategic decision-making to ensure that they responded with informed responses. The respondents were free and guaranteed of confidentiality and anonymity. The data was collected within a specific time and this gave the respondents enough time to respond and give clarifications where necessary.

Reliability and Validity of the Instrument

The internal consistency reliability was measured based on Cronbach Alpha coefficient of multi-item constructs. The key constructs included in the reliability analysis were safety perception, adoption readiness, manufacturability and economic considerations. Values of Cronbachs Alpha above 0.70 were tolerable which is in line with the acceptable values of Alpha in exploratory and applied research. Constructs that satisfied this criterion were used in the further analysis, which means that there was good internal consistency between the measurement items.

Validity Assessment

The validity of content was maintained by extensive literature review and assessment by experts, as well as, it was ensured that the questionnaire captured the dimensions of injection safety, manufacturing feasibility and adoption readiness appropriately. Exploratory Factor Analysis (EFA) was used to measure construct validity. Before extracting the factors, KaiserMeyerOlkin (KMO) score of sampling adequacy measure and Bartlett Test of Sphericity were used to ensure that data was fit to measure. Principal component analysis with varimax rotation was done to extract the factors, only those factors with factor loading beyond the predetermined acceptable levels were retained.

Statistical Techniques

The SPSS and Microsoft Excel were used to conduct the data analysis. The statistical methods that were used were:

- Descriptive statistics (frequencies, percentages, means, standard deviations) to describe the characteristics of manufacturers and perception trends.
- Correlation analysis to test the association between perceived NSI risk and adoption preparedness.

Regression analysis to determine the impact of design constraints and manufacturability on preference of engineering-based safety solutions.

Analysis of variance (ANOVA) between willingness to pilot production of auto-retractable syringes by category of manufacturer. The analysis of the hypothesis was carried out at standard levels of significance.

Ethical Considerations

The study followed ethical research standards. Participation was voluntary, with informed consent implied by completing the questionnaire. Company identities remained confidential, and data were solely used for academic research and reported only in aggregated form.

Methodological Rigor and Contribution

Using a near-census sampling approach, a validated measurement tool, and thorough statistical analysis, the methodology offers a solid empirical basis for assessing industry preparedness and the viability of indigenous auto-retractable syringe technology in India.

RESULTS

Profile of Respondent Manufacturers

Descriptive analysis was conducted to understand the structural characteristics of participating syringe manufacturers. The results indicate that the sample represents a mature and capacity-driven industry segment, providing a strong basis for feasibility and readiness assessment.

Interpretation:
A majority of respondents are medium-to-large firms with over a decade of experience, indicating substantial manufacturing capability. However, conventional disposable syringes remain the dominant product category in Table 1.

Table 1. Profile characteristics of respondent manufacturers (n = 59)

Variable	Category	Frequency	Percentage (%)
Firm size	Micro & Small	24	40.7
	Medium & Large	35	59.3
Years of operation	≤10 years	18	30.5
	>10 years	41	69.5
Primary product focus	Conventional disposable syringes	32	54.2
	Auto-disable syringes	15	25.4
	Safety / reuse-prevention variants	12	20.4
Market orientation	Domestic only	21	35.6
	Export / both	38	64.4

Perception of Needlestick Injury Risk and Safety Limitations

Manufacturers were asked to assess the adequacy of existing syringe designs in preventing needlestick injuries and occupational exposure in Table 2.

Table 2. Perception of effectiveness of existing syringe designs

Perceived Effectiveness	Frequency	Percentage (%)
Effective / Very effective	18	30.5
Moderately effective	21	35.6
Ineffective	20	33.9
Total	59	100.0

Interpretation:
Nearly 69.5% of manufacturers perceive existing syringe designs as moderately effective or ineffective, indicating a clear safety gap in current technologies.

Awareness and Current Engagement with Auto-Retractable Syringes

Awareness of auto-retractable syringe technology among manufacturers was relatively high; however, actual indigenous production remains minimal.

Table 3. Awareness and production status of auto-retractable syringes

Indicator	Yes (%)	No (%)
Awareness of auto-retractable technology	74.6	25.4
Engagement with auto-retractable syringes	10.2	89.8

Further clarification revealed that only one manufacturer is engaged in indigenous production, while others rely on imports or semi-retractable variants in Table 3.

Hypothesis Testing Results

H1: Relationship between NSI Risk Perception and Adoption Readiness

A Pearson correlation analysis was conducted to test the association between perceived NSI risk and readiness to adopt auto-retractable syringe technology.

Table 4. Correlation between NSI risk perception and adoption readiness

Variables	Pearson r	Significance (p)
NSI risk perception ↔ Adoption readiness	0.48	< 0.01

Result:
To interpret above Table 4 describes the moderate positive and statistically significant relationship was observed. Hence, H_{01} is rejected, and H_{11} is accepted.

H2: Influence of Design Limitations on Preference for Engineering-Based Safety Solutions

Regression analysis was performed to assess whether perceived limitations of conventional syringes influence support for engineering-based safety solutions.

Table 5. Regression results: design limitations → safety solution preference

Predictor	β	t-value	p-value
Perceived design limitations	0.41	3.62	< 0.05

Result:
To interpret above Table 5 Perceived design limitations significantly influence preference for engineering-based safety solutions. H_{02} is rejected, and H_{12} is accepted.

H3: Effect of Perceived Manufacturability on Willingness to Pilot Adoption

One-way ANOVA was used to compare willingness to pilot adoption across levels of perceived manufacturability.

Table 6. ANOVA results: manufacturability and pilot willingness

Source	F-value	Significance (p)
Between groups	4.87	< 0.05
Within groups	—	—

Result:
Differences in willingness to pilot adoption across manufacturability perceptions were statistically significant. H_{03} is rejected, and H_{13} is accepted in Table 6.

Summary of Key Statistical Findings

Table 7. Summary of hypothesis testing

Hypothesis	Statistical Test	Result
H1	Pearson correlation	Accepted
H2	Regression analysis	Accepted
H3	ANOVA	Accepted

Overall Interpretation:

These statistical findings in Table 7 give solid empirical data that (i) an increase in perceived NSI risk produces higher readiness to adopt, (ii) constraints in traditional syringe designs leads to preference of engineering-feasible solutions, and (iii) the influence of perceived manufacturability is decisive on pilot adoption willingness.

Interim Conclusion

The results demonstrate a clear disconnect between existing syringe technologies and occupational safety needs. Despite high awareness of auto-retractable syringes, indigenous manufacturing remains minimal. However, statistically significant relationships between safety perception, manufacturability, and adoption readiness indicate strong latent potential for simplified, indigenous auto-retractable syringe designs.

The model (Figure 3) summarizes statistically tested relationships among safety perception, design limitations, manufacturability, and adoption readiness, illustrating key determinants influencing manufacturers' willingness to adopt auto-retractable syringes.

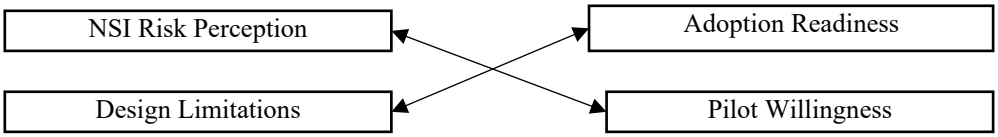

Figure 3. Statistical model of adoption readiness

Manufacturers' Perception of Effectiveness of Current Syringe Designs

Table 8. Manufacturers' perception of effectiveness of current syringe designs

Perceived Effectiveness	Percentage (%)
Effective/Very Effective	30.5
Moderately Effective	33.9
Ineffective	35.6

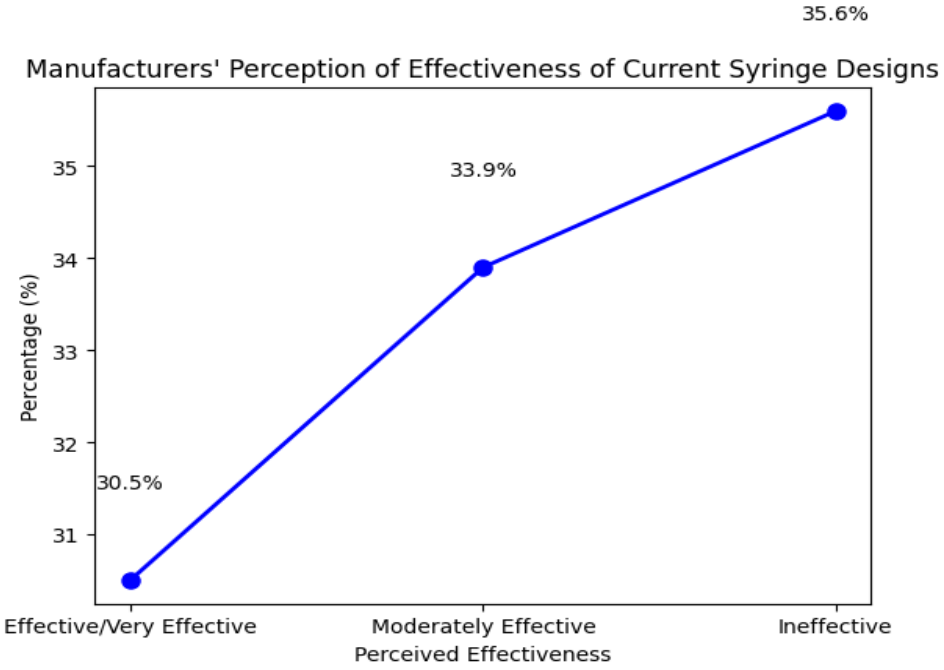

Figure 4. Manufacturers perception of effectiveness of current syringe designs

To interpret above Table 8 and Figure 4 describes the graph shows that 30.5% of manufacturers perceive current syringe designs as effective or very effective, 33.9% find them moderately effective, and 35.6% view them as ineffective. This suggests that while some manufacturers are satisfied, a larger proportion feel the designs need improvement.

DISCUSSION

The current research gives empirical data regarding the possibility and industry willingness towards indigenous auto-retractable siring technology in India through the combination of manufacturer perceptions, statistical analysis, and design consideration. The discussion explains the findings in terms of the available literature and any theoretical understanding of safety engineering and the realities on the ground in the Indian medical devices manufacturing ecosystem.

Interpretation of Safety Perception and Needlestick Injury Risk

The findings indicate that a significant most of the manufacturers believe the current syringe designs are not sufficient to avoid needlestick injuries. The observation is in line with the previous clinical and

occupational safety research that indicates high incidence of NSIs during handling and disposal of posts injection. The statistically significant positive correlation between the perceived NSI risk and the readiness to adopt the device proves that risk awareness is one of the major motivational factors that act as the driving force behind the use of advanced safety-engineered devices. This, considering theory Favors the hierarchy of controls in occupational safety, whereby engineering control takes precedence over behavioural interventions. The results support the thesis that training and guidelines cannot be expected to work in the high-workload healthcare setting, especially in situations, where compliance cannot be imposed.

Limitations of Conventional and Auto-Disable Syringes

The noted discontent with the current syringe designs would be consistent with the literature that points to the structural limitation of orthodox disposable and auto-disable syringes. Auto-disable syringes have ensured patient safety by ensuring no syringe is used twice whereas it does not deal with exposed sharps and thus does not cover the issue of occupational safety holistically. The high statistical correlation of perceived design limitations with the preference of engineering-based safety solutions demonstrates that the makers are aware of this deficiency. The significance of this perception is that it represents an industry-wide recognition of design ineptitude, and not a single clinical issue. This recognition is essential in making innovation in manufacturing systems.

Industry Readiness and the Manufacturing Reality

A major contribution of this research is that it has brought to the light the aspect of readiness in the industry. Although the awareness of auto-retractable syringe technology is rather high, there is a very limited production of indigenous production. This is the lack of awareness/ adoption connection to the manufacturing limitations which were noted in previous literature on innovation and medical devices such as cost sensitivity, complex design and uncertainty of the market need. Nonetheless, statistical importance of manufacturability as a willingness predictor of pilots implies that resistance is not complete. In their place, it seems that manufacturers are ready to cooperate with complex safety systems in case of design simplicity and compatibility during the production process. This observation is a clear link to the applicability of simplified retraction processes that can be added to the current production lines with the minimal inconvenience.

Implications of Simplified Auto-Retractable Designs

Design and innovation implications are significant in the positive reaction of simplified retractable mechanisms. Current literature retractable syringe designs typically have many parts and complicated constructions that make them costly to manufacture and scale. The current results indicate that the manufacturers are more accepting to incremental and modular innovation methods that improve the safety without changing manufacturing infrastructure radically. This is congruent with the theory of the diffusion of innovation, which places the factors of perceived relative advantage, compatibility and complexity to be the determinants of adoption. Easy to fit auto-retractable designs which accommodate these dimensions have better chances of gaining acceptance in the industry in cost-sensitive markets like India.

Economic and Policy Interpretation

The results have an obvious economic implication, even though this research is not a complete cost-effectiveness model. The persistence of needlestick injuries entails an under-covered cost burden on healthcare systems in terms of post exposure treatment and loss of productivity coupled with the treatment of blood-borne infections over the long term. The fact that manufacturers are ready to pilot under incentive-based terms indicates that economic and policy tools can also be catalytic in enhancing safety innovation. The policy implications of the findings are to shift procurement policies by abandoning unit-price discrimination in favour of lifecycle safety cost. Incentives by regulation or gradual requirements of safety-engineered syringes in clinical high-risk areas would further bring industry incentives into line with occupational safety objectives.

Contribution to Literature and Practice

This study fills a significant gap in the literature on injection safety through the empirical synthesis of the perceived safety, feasibility of manufacturing, and adoption preparedness. As compared to the previous studies which are mostly clinical outcomes or policy recommendations, the current study predicts manufacturer views, which provides a sensible overview of what is possible in the current industrial systems. The statistically tested relationships in this paper give actionable information on:

- Manufacturers, in direction of design and investment choice.
- In setting favourable regulatory and procurement policies, policymakers. Healthcare systems, in the realization of the supply-side restrictions on the availability of safety devices.

Summary of Discussion

On the whole, the argument shows that the problem of enhancing the safety of injections in India is not based on the unawareness, but in the coordination between design innovation, manufacturing possibilities, and economic incentives. This paper shows that the adoption of indigenous auto-retractable syringes technology has a high potential in the case when these factors are handled in a combined way.

ECONOMIC AND POLICY IMPLICATIONS

The results of the current research are significant economically and policy-wise to the healthcare systems, medical equipment producers, and regulatory bodies. The study suggests evidence-based information on the adoption of the injection safety interventions by relating the occupational safety outcomes to the manufacturing feasibility and readiness to adopt.

Economic Implications of Needlestick Injury Prevention

Needlestick injuries are difficult to overestimate and a huge economic burden to healthcare systems. NSIs can be costly even when taking into account only immediate clinical care and diagnostics testing and post-exposure prophylaxis, the follow-up, the possible infection treatment, the lost productivity, and the psychological distress. Even though the NSI events at the individual level might seem trivial, their effect on the system level is massive, especially within high-volume healthcare settings. All the findings of the given study suggest that the percentage of manufacturers who understand the weaknesses of the current syringe design in the prevention of NSIs and aware of the safety benefits of the engineering-based solutions is large. Economically, such acknowledgement is important because it helps to make the case that increased initial expenditures on auto-retractable syringes can be compensated by long-term cost savings due to decreased occupational exposure and related treatment costs. Also, the fact that manufacturers are ready to pilot the production of auto-retractable syringes, especially when the manufacturers of this type of syringes take into consideration manufacturability issues, points to the evidence that the cost barriers are not insurmountable. Design innovation, which can be made incremental so as to reduce the number of extra components and tools, can cut down on the cost of production, thus reducing the price difference between the normal and safety-engineered syringes.

Lifecycle Cost Perspective

One important economic lesson that can be learned with this study is the need to use a lifecycle cost approach instead of concentrating on the price of units when procuring them. The traditional procurement behavior of most healthcare systems focuses on the lowest possible purchase price, and in most cases does not consider the costs of downstream effects of occupational injury and infection management. In comparison lifecycle cost analysis involves direct and indirect costs throughout the lifespan of a product, including benefits in injury prevention. The empirical data offered in this work allows concluding that the introduction of auto-retractable syringes, although it is more costly in the short term, can be economically justified in case of decreases in the number of NSIs and expenditures on them are taken into account. This view is especially pertinent to the policymakers and procuring bodies that aim at maximizing health care expenditure and enhancing safety of workers.

Implications for Manufacturers

In terms of industry, the results indicate a high tendency of the manufacturers to embrace the advanced safety-engineered syringe technologies in case design simplicity and compatibility with production are considered important. The connection between the perceived manufacturability and the willingness to pilot adoption is positive, which contributes to the significance of innovation strategies that can be adopted to be consistent with the existing manufacturing infrastructure. Manufacturers can also take advantage of the phased adoption models, which can start with pilot production within selected models of products or clinical environments. These methods can be used to control costs, learn technically, and gain market acceptance slowly, with minimal financial risk and with safety benefits demonstrated.

Policy and Regulatory Implications

The results of the study have a direct implication to the regulatory bodies and policy makers dealing with occupational safety and medical device regulations. Although, global guidelines suggest use of safety-designed devices, the lack of clear requirements or incentives may delay its implementation, especially in cost efficient markets. The policy measures that may enable adoption are:

- Regulatory incentives or incremental requirements of safety-engineered syringes in high-risk clinical positions.
- Incentive plans or subsidies to encourage indigenous production of high safety gadgets.
- Introduction of occupational safety results in purchasing evaluation standards. These measures can ensure that the goals of public health can be coordinated with the possibilities of the industry, which can lead to sustainable safety innovation.

Implications for Healthcare Systems

In the case of healthcare institutions, the use of auto-retractable syringes is a potential area to enhance the safety of occupation, as well as minimize the expenses of the problem in the long term (related to NSI). The results confirm the change towards the procurement decisions that would take into consideration the safety outcomes and protection of the workforce as well as immediate budget limitations. A lower level of absenteeism among the staff, improved morale, and adherence to the occupational safety standards may also be a positive outcome of healthcare systems that incorporates safety-engineered devices in their routine practice.

Summary of Economic and Policy Implications

To conclude, the economic and policy part of this research has indicated that a coordinated solution is necessary, which incorporates design innovation, manufacturing feasibility, procurement reform, and regulatory support. The stakeholders can make significant improvements by reducing the needlestick injuries, as well as, by producing the syringes with indigenous safety concerns, which is possible by taking the lifecycle cost perspective and encouraging the production of the syringes with local interests.

This Figure 5 describes the economic impact of the needlestick injuries and shows how auto-retractable syringes help lessen downstream healthcare costs by preventing occupational exposure and associated treatment.

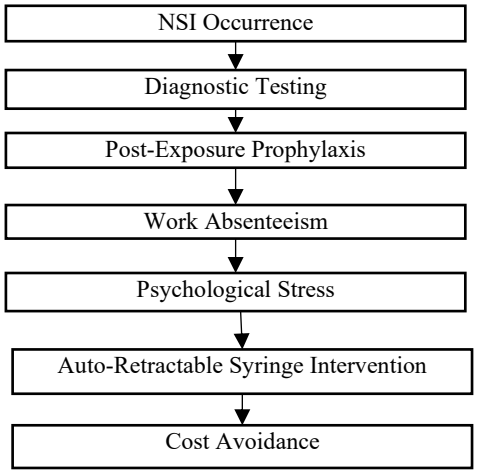

Figure 5. Economic pathway of needlestick injury prevention

CONCLUSION

This paper is an empirical analysis of the practicability, industry preparedness and safety applicability of producing native auto-retractable single-use syringes in India, with the view to preventing needlestick injuries and gasping occupational risks of blood-borne infections. Through the use of near-census survey and stringent statistical analysis (Pearson correlation, regression analysis, ANOVA) the research also gives new empirical evidence on the importance of medical device innovation, manufacturing capacities and the difficulties of implementing new safety technologies in the Indian healthcare industry. Statistical analysis showed that there exist significant relationships between perceived risk of needlestick injury, design constraints, and manufacturability with moderate positive correlation ($r = 0.48$, $p < 0.01$) existing between NSI risk perception and adoptability. Also, regression findings revealed perceived design limitations to be a significant predictor of preference to engineering-based safety solution (= 0.41, $p < 0.05$), whereas ANOVA findings demonstrated statistically significant difference in willingness to pilot adoption based on perceived manufacturability (= 4.87, $p < 0.05$). The technology of auto-retractable syringes is highly aware of the awareness but the production capacity is still at the indigenous level because of the complexity of design, cost and production feasibility issues. Notably, the research shows that designs of auto-retractable systems simplified and able to fit current manufacturing systems are greatly useful in increasing the willingness of manufacturers to pilot adoption, which emphasizes the significance of engineering-based safety measures. The research provides novel evidence to show that innovation plans, procurement dynamics, and policy structures have to be aligned to prove that indigenous auto-retractable syringe technology is technically and economically viable in India. Weaknesses, however, are cross-sectional data, lack of a complete model of cost-effectiveness, and consideration of the views of manufacturers, but not of the healthcare worker or patient experiences. Future studies ought to provide the empirical assessment of pilot applications of these syringes in the clinic, design optimization, and combine the views of healthcare professionals, purchasing organizations, and regulators. Moreover, the complexity of designs, cost-effectiveness, and production locally will help to increase the prevalence of safety-designed injection devices and enhance the occupational safety and manufacturing innovation in India.

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