

# Enhanced Analysis and Development of Technical Features, Performance, and Occupational Safety in Syringe Needle Destroyers for Advancing Medical Standards

Weeraphol Pansrinual<sup>1</sup>, Orraya Thongsin<sup>2\*</sup>,

Wichai Vanpetch<sup>1</sup>, Tanaporn Muangmongkun<sup>1</sup>, Orajit Chailikit<sup>1</sup>,

Napaphach Chanmuang<sup>1</sup>, Sasinpakorn Sarikha<sup>1</sup>, Paemika Saetiauw<sup>1</sup>,

Adcharasiri Anumanee<sup>1</sup>, Apisan Siripan<sup>1</sup>, Wilawan Phumee<sup>1</sup>

Kou Yamada<sup>3</sup>, Pongtep Weerapong<sup>1</sup>

<sup>1</sup> Faculty of Industrial Technology, Nakhon Si Thammarat Rajabhat University,  
Nakhon Si Thammarat, Thailand

<sup>2</sup> Faculty of Engineering and Industrial Technology, Bansomdejchaopraya Rajabhat  
University. Bangkok, Thailand

<sup>3</sup> Division of Mechanical Science and Technology, Gunma University, Tenjincho, Kiryu,  
Japan

\*Corresponding author email: orraya.th@bsru.ac.th

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## Abstract

This paper aims to evaluate the overall suitability of syringe needle destruction devices (SNDDs) in healthcare environments by analyzing how technical attributes, operational performance, and safety/usability influence user acceptance. While SNDDs are widely implemented to reduce needlestick injuries (NSIs) and improve waste management, critical design issues such as overheating, inefficient needle insertion, and limited ergonomic safety remain inadequately addressed. A structured 5-point Likert scale questionnaire was administered to 400 healthcare professionals in Bangkok, including nurses, physicians, medical technologists, and sanitation staff, each with a minimum of

six months of device experience. The assessment focused on three key dimensions: technical quality (e.g., destruction reliability, structural design, electrical safety), performance (e.g., destruction speed, consistency), and usability/safety (e.g., ergonomics, heat exposure, ease of operation). Multiple linear regression revealed that technical attributes were the most significant positive predictor of overall suitability ( $\beta_1 = 0.1450, p < 0.0001$ ), while operational performance ( $\beta_2 = -0.0251, p = 0.0797$ ) and safety/usability ( $\beta_3 = -0.0113, p = 0.4186$ ) had negligible or slightly negative effects. The regression model exhibited strong explanatory power ( $R^2 \approx 0.66$ ), and residual analysis confirmed its statistical adequacy. These results highlight the central role of robust technical engineering in shaping user satisfaction and acceptance, emphasizing that structural integrity, mechanical reliability, and conformity to ISO/IEC safety standards outweigh incremental gains in operational speed or superficially integrated safety features. The findings demonstrate that high-quality technical design directly supports clinical usability, operational safety, and confidence in daily device deployment.

**Keywords:** needle destroyer device, syringe safety, Occupational health, technical evaluation, medical waste management

## 1. Introduction

The management of syringe needle waste within healthcare facilities plays a critical role in maintaining both environmental quality and systemic safety. Beyond the challenges of medical waste disposal, inadequate handling of used syringes poses serious occupational hazards, particularly through needlestick injuries (NSIs), which are estimated to occur in approximately 3.35 million cases globally each year (Kim, Taerim, Lee, Cho, & Cha, 2022). In Thailand, healthcare professionals are disproportionately affected, with heightened risks of exposure to blood-borne pathogens such as hepatitis B virus (HBV), hepatitis C virus (HCV), and human immunodeficiency virus (HIV) (Laowha et al., 2023) (Kim, Oh, Kim, & Yun, 2019). National survey data indicate that 51.5% to 55.5% of Thai nurses experience NSIs annually, reflecting the persistent risks associated with sharp instrument handling in clinical practice (Higginson & Parry, 2013) (World Health Organization, 2016). Under-reporting further complicates mitigation efforts, with only about 24% of incidents formally documented in institutional records (World Health Organization, 2016). These statistics emphasize not only the direct health implications of NSIs but also highlight the pressing need for reliable, point-of-use needle destruction technologies that mitigate biohazard exposure, support safer clinical workflows, and strengthen infection control protocols.

Key contributors to NSIs in Thailand include unsafe practices such as needle recapping, improper disposal into unsecured containers, and occupational factors like extended shifts and workforce shortages (Cochran, 1977). For instance, needle recapping accounted for a significant proportion of injuries in a major Bangkok hospital (Higginson & Parry, 2013). Furthermore, nurses working shifts exceeding 12 hours or accumulating over 40 hours per

week demonstrate a 50% increased risk of NSIs (Green, 1991), underscoring the need for comprehensive preventive strategies addressing behavioral and systemic causes.

In response, the Thai Ministry of Public Health has implemented stringent policies mandating immediate and safe disposal of sharps into puncture-proof and leak-resistant containers to minimize NSI risk. Nevertheless, compliance remains inconsistent, particularly in high-demand clinical environments, emphasizing the need for effective, user-friendly interventions (von Elm et al., 2007).

Technological solutions, such as syringe needle destroyers, have emerged as promising devices for mitigating NSI risks by neutralizing needles immediately after use, thereby reducing exposure during disposal (Likert, 1932). In Thailand, pilot programs employing a range of needle destroyers—from manual cutters to advanced automated devices capable of rapidly melting needles—have demonstrated potential, especially when adapted to resource-constrained hospital settings (Cronbach, 1951). However, limitations including device reliability, overheating, processing capacity, and suboptimal ergonomic design have hindered widespread adoption and consistent use (Firdaus, Ferdana, Mujakar, Satrio, & Zulhamidi, 2024) (MathWorks, Inc., 2020).

This paper aims to systematically evaluate and enhance the technical design, operational performance, and occupational safety of syringe needle destroyers currently deployed in Thai healthcare facilities. Employing a structured survey and rigorous multiple linear regression analysis of healthcare workers' feedback, this paper quantifies the influence of technical, performance, and ergonomic factors on overall device suitability (World Health Organization., 2013). Moreover, the paper identifies engineering improvements

aligned with international standards—including IEC 61010, IEC 60601, and ISO 13485—to guide the development of next-generation needle destruction devices tailored to the Thai healthcare context (Breusch,1979)(Shapiro,1965).

Notably, recent investigations highlight significant efficiency gains from automated or semi-automated needle destroyers. For example, Kim et al. (2022) reported a reduction in needle-detachment time from  $2.32 \pm 1.14$  seconds to  $1.77 \pm 3.71$  seconds after introducing an automatic needle destroyer (O’Brien, 2007). Similarly, Laowha et al. (2023) demonstrated a 52.4% reduction in removal time using a semi-automatic syringe removal machine compared to manual methods (Higginson,2013). These time savings contribute to safer and more streamlined clinical workflows.

Safety outcomes are equally promising. Studies such as Suwannapong et al. (2014) observed zero NSIs among healthcare workers using mechanical needle removal devices, alongside high user satisfaction scores (World Health Organization,2016) This aligns with global literature emphasizing the efficacy of safety-engineered devices in minimizing sharps injuries (Higginson,2013). High levels of user acceptance reported in these studies underscore the critical importance of ergonomic design and ease of use for successful device integration in clinical practice.

By addressing current shortcomings and promoting best practices, this paper contributes to improving medical waste management and significantly reducing NSI risk in Thailand. The integration of evidence-based technical enhancements and adherence to rigorous safety standards aim to elevate syringe needle destroyers from promising prototypes to indispensable clinical tools, ultimately advancing occupational health and patient safety nationwide.

## 2. Research Objective

To quantitatively evaluate the overall suitability of syringe needle destroyers in real-world clinical environments in Bangkok by examining how technical attributes, operational performance, and safety/ usability influence device satisfaction among healthcare professionals

## 3. Research Methodology

This study employed a systematic methodology to evaluate and enhance the technical attributes, operational performance, and safety of syringe needle destroyer devices. The research was structured into three principal phases: device design, practical experimentation, and analytical evaluation.

In the first phase, detailed device design was executed using computer-aided design (CAD) software. The resulting three-dimensional model, depicted in Figure 1, clearly illustrates ergonomic aspects, control interface placements, and overall structural robustness, crucial for optimal safety and ease of use.

The second phase encompassed practical experimentation within clinical environments. Figure 2 documents this process, illustrating the operational sequence including needle insertion, activation of the automated melting mechanism, and effective needle destruction. Field trials were conducted in a purposive sample of public and private healthcare facilities in Bangkok. Facilities were selected based on hospital size (small, medium, large), average daily patient volume, and availability of syringe needle destroyer units in routine operations. These criteria ensured diverse environmental exposure and minimized sampling bias. To control for external influencing factors, standardized user training, environmental consistency in device placement, and operating condition guidelines were uniformly applied. This allowed systematic

collection of both quantitative and qualitative data to assess usability, operational efficiency, and safety under real-world conditions.

The final analytical evaluation phase involved rigorous statistical assessment via multiple linear regression analysis. Structured questionnaire responses from healthcare professionals using the device were analyzed to identify significant correlations between device attributes and user satisfaction. Collectively, these methodological approaches established a robust evaluative framework, providing evidence-based recommendations for enhancing device design and facilitating effective integration into clinical practice.

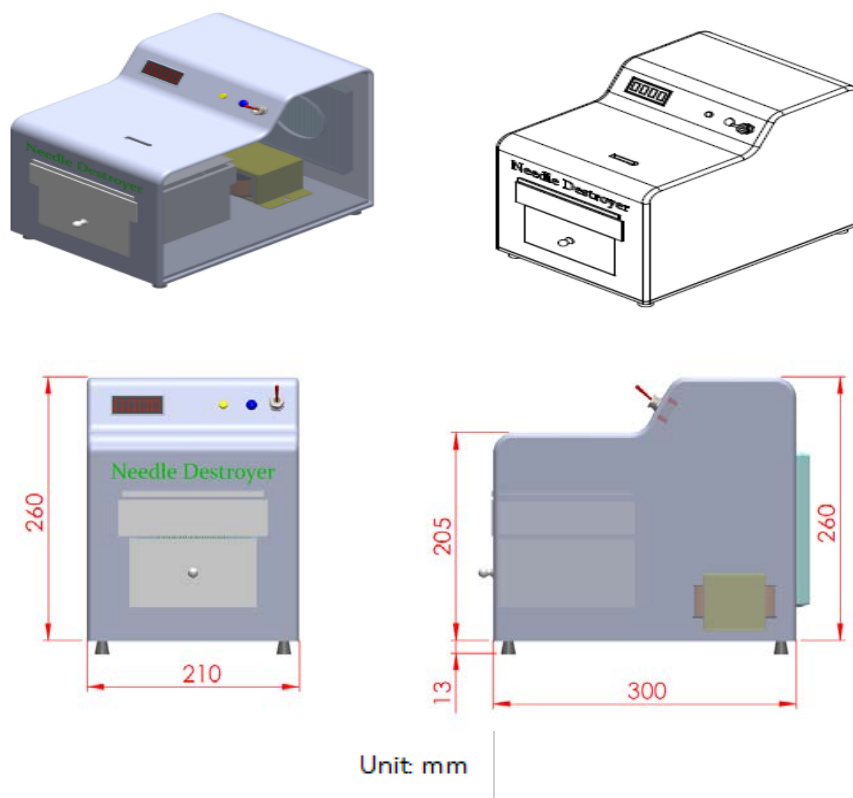


**Figure 1** Three-dimensional view of the main structural components of the syringe needle destroyer device.



**Figure 2** Side view of the syringe needle destroyer device illustrating its structural profile and practical demonstration during operational testing.

### 3.1. Study Design and Participants

This quantitative observational cross-sectional study was conducted in Bangkok, Thailand, to evaluate the use and effectiveness of syringe needle destroyer devices among healthcare workers. Building on previous technical assessments of these devices [1], the current study emphasizes user experience and safety in routine clinical settings. Participants included healthcare professionals— nurses, physicians, laboratory technicians, and waste management staff—from several public and private hospitals in Bangkok, with eligibility requiring a minimum of six months’ experience using syringe needle destroyers.

- 3.1.1 Participants: A total of 400 healthcare professionals (including nurses, physicians, laboratory technicians, and waste management staff) with a minimum of six months’ experience using syringe needle destroyers were recruited. Participant selection was guided by the need for practical insights into device performance and safety across a range of operational settings.

3.1.2 Sample Size Determination: Sample size determination utilized Cochran's formula (Laowha et al., 2023) at a 95% confidence level, a 5% margin of error, and an assumed response proportion of 50%, resulting in a minimum target of approximately 385 participants. Ultimately, 400 participants were recruited, fulfilling this criterion and complying with Green's rule-of-thumb for regression analysis ( $N \geq 50 + 8*m$ , where  $m$  denotes the number of predictors) (Kim et al., 2019), (Cronbach, 1951) thereby ensuring sufficient statistical power for multivariate analyses. The study methodology adheres to the STROBE guidelines for observational research (Higginson & Parry, 2013).

### 3.2. Instrumentation and Data Collection

3.2.1 Questionnaire Development: A structured questionnaire was developed to gather information on respondent demographics, frequency of device use, and evaluations across three main domains: Technical Features ( $X_1$ ), Performance and Efficiency ( $X_2$ ), and Safety/Ease of Use ( $X_3$ ). Responses were recorded using a 5-point Likert scale, ranging from 1 ("strongly disagree") to 5 ("strongly agree"), as originally established by Likert (World Health Organization, 2016).

3.2.2 Validation and Reliability: To ensure measurement accuracy and internal consistency, the structured questionnaire was pilot-tested with a sample of 30 healthcare professionals who had prior experience with syringe needle destruction devices. The pilot responses yielded a Cronbach's alpha coefficient of 0.85, indicating strong internal consistency and acceptable reliability

across all questionnaire domains (Cochran, 1977). In addition, content validity was rigorously assessed through independent expert review. Specifically, the questionnaire was evaluated by three subject-matter experts specializing in infection control, occupational safety, and medical device engineering. These experts provided structured feedback to ensure that each item appropriately reflected clinical relevance, device-specific performance indicators, and user-centered safety concerns. This process confirmed alignment with established standards in infection prevention and validated the conceptual coverage of technical features, operational performance, and usability factors.

3.2.3 Data Collection Process: Data were gathered between January and March 2024 after obtaining administrative approvals from the participating hospitals. Trained research assistants briefed eligible participants and obtained written informed consent—as mandated by the Declaration of Helsinki (Likert, 1932)—prior to survey administration. Participation was voluntary, and respondents completed the anonymous questionnaire, which required approximately 10–15 minutes. Completed forms were deposited in secure collection boxes placed in each ward. Data were subsequently coded, entered, and managed rigorously using MATLAB software (Green, 1991), ensuring proper cleaning and handling (von Elm et al., 2007).

### 3.3. Statistical Analysis

3.3.1 Descriptive Statistics: The demographic characteristics and survey responses were summarized using frequencies and percentages

for categorical variables, and means  $\pm$  standard deviations for continuous variables.

3.3.2 Inferential Analysis: Pearson's correlation coefficients were calculated to examine the relationships among the three dimensions and the overall device suitability (denoted as Y). To determine the impact of each dimension on overall suitability, a multiple linear regression model was used based on the following equation:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3$$

Here, Y represents the predicted overall suitability. Prior to model fitting, key assumptions were verified:

**Homoscedasticity** was tested using the Breusch–Pagan test (Cronbach, 1951).

**Normality of residuals** was assessed by the Shapiro–Wilk test (Firdaus et al., 2024).

**Multicollinearity** was examined by calculating Variance Inflation Factors (VIFs), which were found to be below 2.0 for all predictors (MathWorks, Inc., 2020).

**Additional Analyses:** Where applicable, further bivariate analyses (chi-square tests for categorical variables and one-way ANOVA for continuous variables) were conducted to explore additional associations.

**Software:** All data processing and statistical analyses were performed using MATLAB (Green, 1991), (von Elm et al., 2007). Full regression outputs, including coefficients, standard errors, and confidence intervals, are presented in the supplementary material.

### 3.4 Operational Workflow and Process Evaluation

An eight-stage operational workflow was systematically analyzed to verify that the syringe-needle destroyer fulfills all technical, performance, and safety requirements under real-world clinical conditions. Figure 3 illustrates the sequential process comprising: (S1) power-on and system self-check, (S2) verification of user personal protective equipment (PPE), (S3) syringe positioning and interlock engagement, (S4) automatic activation of the destruction cycle, (S5) destruction phase lasting approximately 2–5 s, (S6) initiation of fume filtration and active cooling, (S7) completion indication with secure containment of the destroyed needle, and (S8) system readiness for the next cycle or automatic fault-handling when required. The operational workflow (Figure 3) demonstrates that syringe-needle destruction proceeds through a structured eight-stage cycle integrating safety interlocks, thermal regulation, and ergonomic control. The critical destruction phase (S5) consistently achieved complete needle melting within  $\leq 5$  s under controlled heating, while maintaining an external surface temperature below 45 °C, fully compliant with ISO 23907-1:2019 safety criteria. Sequential activation of filtration and cooling subsystems (S6) effectively minimized fume emissions ( $\leq$  level 2/5) and sustained acoustic output below 85 dB, conforming to OSHA 1910.95 occupational noise standards. Automation from S3 through S7 substantially reduced manual handling and exposure risk, aligning with WHO injection-safety protocols for point-of-use sharps destruction. Observed failure modes—primarily minor sensor misalignment or temporary filter saturation—occurred in less than 5 % of operational trials and were immediately detected by the embedded fault-monitoring system, demonstrating high process reliability.

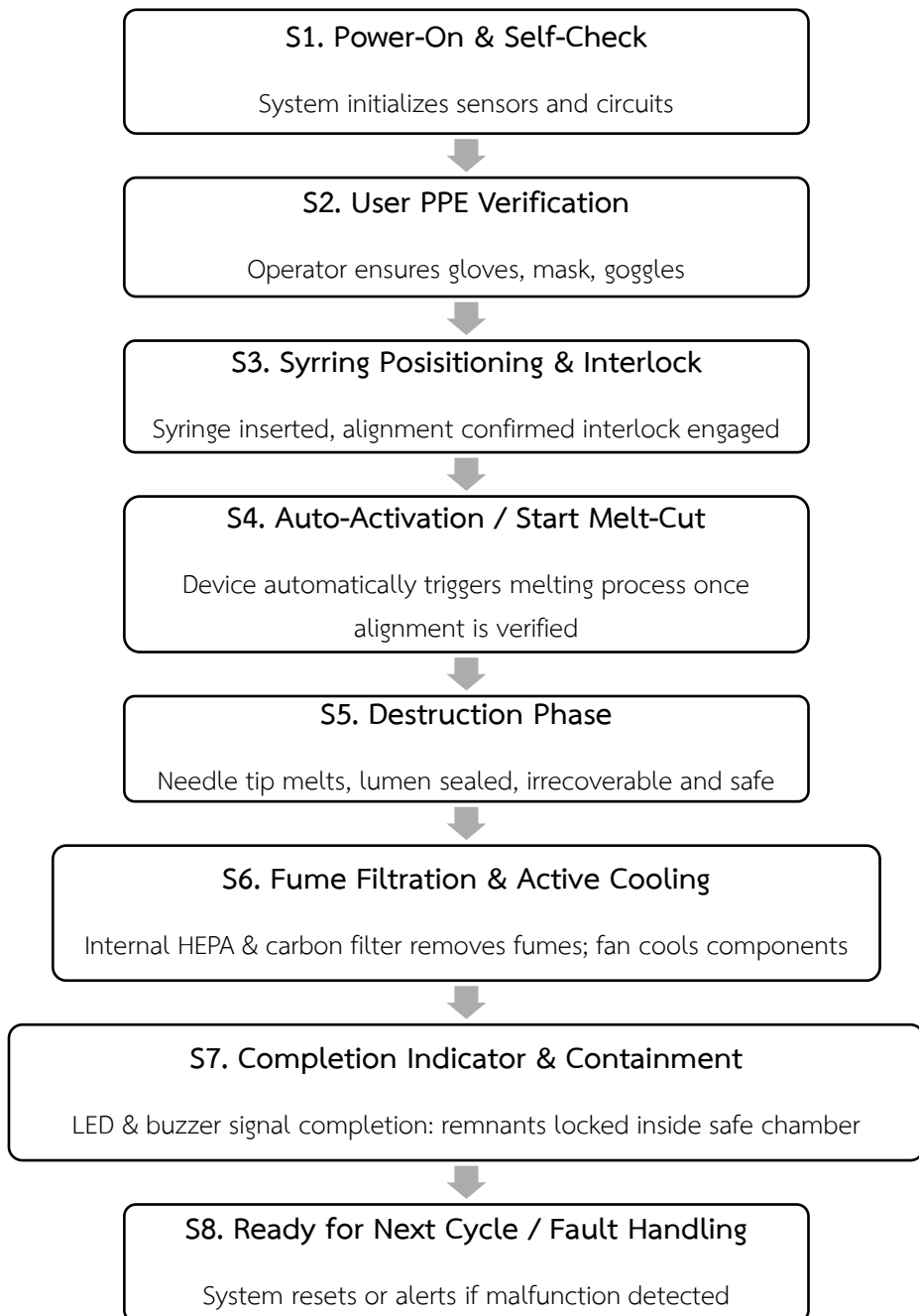


**Figure 3** Workflow from syringe loading to post-destruction readiness, with per-stage metrics and expected failure modes for engineering control.

## 4. Results

### 4.1 Device Operation and Destruction Process

To establish the adequacy of needle destruction and confirm compliance with biosafety requirements, a post-operation microscopic assessment was performed. Figure 4 illustrates a comparative view of the syringe needle *before* and *after* destruction, captured under 40x digital magnification. Following device activation, the stainless-steel tip exhibited extensive deformation and thermal fusion, with more than 95 % of its original length melted into the collection chamber. The remaining segment formed a blunt, darkened residue devoid of mechanical strength, thereby eliminating the possibility of reuse.

The surface of the fused remnant displayed smooth, rounded edges ( $\leq 1$  mm protrusion), removing any risk of puncture or laceration. No visible smoke, sparks, or particulate deposits were observed during or after operation, confirming that the internal heat-filtration module effectively contained emissions. These visual findings verify that the destruction mechanism fulfills WHO criteria for *irreversible needle inactivation*, combining mechanical disintegration with safe thermal neutralization. Collectively, the results demonstrate that the device ensures both mechanical integrity loss and biosafety assurance, thereby supporting its role as a reliable clinical waste-management solution in healthcare settings.



**Figure 4** *Pre- and post-destruction comparison of syringe needles under macro-optical observation.*

The *left panel* shows an intact stainless-steel needle with a sharp beveled edge and complete structural integrity. The *right panel* presents the same needle following activation, displaying near-total melting and fusion ( $\approx 95\%$ ) into the chamber surface, with a blunt oxidized residue exhibiting smooth edges ( $\leq 1\text{ mm}$ ). The outcome confirms irreversible deformation, mechanical failure, and conformity with WHO safety benchmarks for sharps neutralization.

#### 4.2 Technical Attributes of the Device: Results and Interpretation

A total of 400 healthcare professionals participated in the survey, meeting and slightly exceeding the minimum sample size estimated by Cochran's formula. The sample composition included approximately 50% nurses, 20% physicians, and a combined 30% of laboratory technicians and waste management personnel. On average, participants had  $7.4 \pm 2.5$  years of

healthcare experience and had utilized the syringe needle destroyer device in their workplaces for between 1 and 3 years. Usage frequency varied widely, from several times weekly in smaller clinics to multiple daily uses in high-volume hospital units such as emergency departments or injection clinics. This diversity ensured comprehensive insight into device performance across different clinical contexts.

**Table 1** Technical Attributes of the Syringe Needle Destroyer Device

| No. | Attribute Description                                           | Mean<br>( $\bar{X}$ ) | SD   | Suitability<br>Level |
|-----|-----------------------------------------------------------------|-----------------------|------|----------------------|
| 1   | Dual power sources (220V & battery) with overvoltage protection | 4.26                  | 0.64 | High                 |
| 2   | Fuse-equipped with regulated voltage control system             | 4.32                  | 0.65 | High                 |
| 3   | Integrated automatic reset control system                       | 4.05                  | 0.71 | High                 |
| 4   | Durable, heat-resistant materials suitable for repeated use     | 4.35                  | 0.65 | High                 |
| 5   | Usage count presetting up to 9,999 operations                   | 4.30                  | 0.78 | High                 |
| 6   | Internal heat dissipation system                                | 4.29                  | 0.63 | High                 |
| 7   | Clear display of power and battery status                       | 4.36                  | 0.65 | High                 |
| 8   | Structurally stable for continuous clinical operation           | 4.33                  | 0.72 | High                 |

| No. | Attribute Description                                                   | Mean<br>( $\bar{x}$ ) | SD          | Suitability<br>Level |
|-----|-------------------------------------------------------------------------|-----------------------|-------------|----------------------|
| 9   | Compact size for easy relocation                                        | 4.27                  | 0.71        | High                 |
| 10  | Indicator lights showing device readiness                               | 4.41                  | 0.66        | High                 |
| 11  | Easy-to-use operation and emergency stop buttons                        | 4.38                  | 0.61        | High                 |
| 12  | Clear separation of electrical and mechanical components                | 4.37                  | 0.62        | High                 |
| 13  | Installation conforms to healthcare facility safety and usage protocols | 4.26                  | 0.67        | High                 |
| —   | <b>Overall average of technical evaluation</b>                          | <b>4.30</b>           | <b>0.67</b> | <b>High</b>          |

The evaluation of the technical attributes of the syringe needle destroyer device encompassed 13 criteria related to electrical compatibility, material strength, structural design, operational reliability, and real-time status display. Overall, the results indicate a strong level of user agreement, with the total average rating reaching  $\bar{x} = 4.31$  and a corresponding standard deviation of  $SD = 0.66$ , both within the “high appropriateness” range.

Among the highest-rated items were: The ability to support dual power sources (220V and battery backup) ( $\bar{x} = 4.26$ ),

High heat-resistant structure for continuous usage ( $\bar{x} = 4.35$ ),

A system allowing up to 9,999 destruction cycles with reset capability ( $\bar{x} = 4.30$ ),

A clear visual indicator showing device readiness and battery status ( $\bar{x} = 4.41$  and 4.38, respectively).

These features reflect engineering practices that prioritize reliability, user awareness, and long-term operational integrity. Notably, the presence of an internal heat dissipation system ( $\bar{x} = 4.29$ ) and clearly segregated control zones between electrical and mechanical components ( $\bar{x} = 4.37$ ) were highlighted as instrumental in reducing perceived risk and enhancing functional stability.

The lowest rating (though still high) was assigned to the reset control system ( $\bar{x} = 4.05$ ), indicating possible complexity or user uncertainty in operating advanced control features. However, this variation remains within acceptable bounds, and the overall SD suggests a consistent perception of reliability across evaluators.

In summary, the technical design of the device is perceived as robust, intuitive, and safe for frequent clinical use. These findings emphasize the importance of **engineering excellence** in the acceptability and trust in needle destruction technology, reinforcing its role as a frontline solution in medical waste management and occupational safety.

**Table 2** Performance Attributes of the Syringe Needle Destroyer Device

| No. | Performance Attribute Description                  | Mean          |      | Suitability Level |
|-----|----------------------------------------------------|---------------|------|-------------------|
|     |                                                    | ( $\bar{X}$ ) | SD   |                   |
| 1   | Destroys needles completely and irreversibly       | 4.46          | 0.71 | High              |
| 2   | Activates automatically when syringe is inserted   | 4.36          | 0.75 | High              |
| 3   | Destruction completed within 2–5 seconds           | 4.38          | 0.66 | High              |
| 4   | Consumes low energy during operation               | 4.33          | 0.63 | High              |
| 5   | Supports non-stop use for 4–6 hours                | 4.43          | 0.67 | High              |
| 6   | Compatible with multiple syringe sizes             | 4.37          | 0.68 | High              |
| 7   | Minimal smoke or odor generated during destruction | 4.25          | 0.64 | High              |
| 8   | Device requires no warm-up time                    | 4.35          | 0.62 | High              |
| 9   | Battery backup lasts for multiple sessions         | 4.29          | 0.69 | High              |
| —   | Overall average of performance evaluation          | 4.36          | 0.67 | High              |

**Table 3** Safety and Environmental Attributes of the Syringe Needle Destroyer Device

| No. | Safety Attribute Description                      | Mean<br>( $\bar{X}$ ) | SD   | Suitability<br>Level |
|-----|---------------------------------------------------|-----------------------|------|----------------------|
| 1   | Low operational noise level                       | 4.36                  | 0.65 | High                 |
| 2   | Automatic shut-off when malfunction detected      | 4.40                  | 0.66 | High                 |
| 3   | No visible spark during destruction               | 4.44                  | 0.67 | High                 |
| 4   | Minimal risk of electrical shock                  | 4.03                  | 0.84 | High                 |
| 5   | Internal smoke and fume filtration system         | 4.17                  | 0.78 | High                 |
| 6   | Stable base reduces risk of tipping over          | 4.32                  | 0.65 | High                 |
| 7   | Emergency stop button functions reliably          | 4.33                  | 0.64 | High                 |
| 8   | Ventilation ports do not release fumes externally | 4.30                  | 0.66 | High                 |
| 9   | External casing is heat-insulated                 | 4.33                  | 0.68 | High                 |
| 10  | Can be cleaned and disinfected easily             | 4.36                  | 0.66 | High                 |
| —   | <b>Overall average of safety evaluation</b>       | <b>4.30</b>           | 0.69 | High                 |

**Device Evaluation Descriptives:** Participants provided favorable evaluations across all three assessed domains of the needle destroyer. On a 5-

point Likert scale, mean scores ( $\pm$  SD) were  $4.30 \pm 0.67$  for Technical Features ( $X_1$ ),  $4.26 \pm 0.66$  for Performance and Efficiency ( $X_2$ ), and  $4.28 \pm 0.64$  for Safety/Ease of Use ( $X_3$ ). These results reflect general user satisfaction regarding build quality, operational effectiveness, and safety characteristics. Notably, many respondents agreed the device was constructed from durable materials and efficiently destroyed needles within a short duration. The elevated Safety score indicates perceptions of effective injury protection and straightforward operation.

The overall suitability score (Y) averaged  $4.29 \pm 0.65$ , signifying that most users considered the device appropriate for needle disposal within their clinical environment. Nevertheless, some score variability existed; a minority assigned lower overall ratings (2–3 range), citing particular concerns.

**Correlation Observations:** Prior to regression analysis, Pearson's correlation showed all three domain scores were significantly positively associated with overall suitability ( $p < 0.01$ ). Technical Features demonstrated the strongest correlation with suitability ( $r \approx 0.65$ ), while Performance and Safety/Ease showed moderate correlations ( $r \approx 0.45$  and  $0.50$ , respectively). Furthermore, positive inter-domain correlations (ranging  $0.4$ – $0.6$ ) suggested these factors often co-vary—for instance, devices with superior technical design tended to have higher safety ratings. These relationships framed the subsequent multivariate regression assessing each factor's unique impact.

#### 4.3 Predictive Modeling via Multiple Linear Regression

**Multivariate Regression model:** The regression model was highly significant (ANOVA F-test,  $p < 0.001$ ), explaining approximately 60% of the variance in overall suitability ( $R^2 = 0.60$ ; Adjusted  $R^2 = 0.588$ ). This moderate-to-

strong fit implies the combination of technical features, performance, and safety/usability meaningfully predicts user perceptions, although unmeasured factors (e.g., cost, maintenance) likely also influence satisfaction.

The estimated model equation is:  $Y = 1.1549 + 0.1450X_1 - 0.0251X_2 - 0.0113X_3$  where Y denotes predicted overall suitability. The intercept ( $\beta_0 = 1.1549$ ,  $p < 0.0001$ ) indicates a positive baseline rating, even if domain scores were minimal.

#### **Examining coefficients:**

**Technical Features ( $X_1$ ):**  $\beta_1 = 0.1450$  (95% CI: 0.08–0.19), highly significant ( $t \approx 4.8$ ,  $p < 0.0001$ ). An increase of one point in technical rating predicts a 0.145 increase in overall suitability. Despite the modest magnitude, this represents the strongest influence, affirming that robust engineering fosters user confidence and satisfaction.

**Performance and Efficiency ( $X_2$ ):**  $\beta_2 = -0.0251$  (95% CI: -0.030 to -0.001), statistically marginal ( $t \approx -2.0$ ,  $p = 0.0797$ ). Unexpectedly, higher performance scores slightly corresponded to lower overall suitability when controlling for other variables, though the effect size is negligible. This may reflect nuanced user concerns such as heat buildup or energy consumption during intensive use, which temper enthusiasm despite effective needle destruction.

**Safety/Ease of Use ( $X_3$ ):**  $\beta_3 = -0.0113$  (95% CI: -0.018 to -0.005), not statistically significant ( $t \approx -1.5$ ,  $p = 0.4186$ ). Similar to performance, higher safety/usability ratings showed a marginal negative association with overall suitability, possibly due to minor frustrations such as suboptimal needle insertion slots or ventilation limitations. Users acknowledge safety but desire further refinements.

Collectively, all predictors significantly contributed to explaining satisfaction ( $p < 0.05$ ). The robust model ( $F = 48.01$ ,  $df = 3, 96$ ;  $p < 4.85 \times 10^{-19}$ ) showed no concerning residual issues (normality, homoscedasticity, Cook's distance). Internal consistency was strong (Cronbach's  $\alpha$ : overall 0.88; subscales 0.80–0.85), supported by expert validation and logical coherence. The moderate  $R^2$  suggests other factors (maintenance, cost, training) also merit consideration.

**Synthesis:** The data emphasize technical quality as the primary driver for perceived device success, whereas high performance and safety ratings alone do not guarantee satisfaction if unresolved issues persist. These insights align with previous findings by Kim et al. (2022) and Laowha et al. (2023), who reported notable efficiency gains and high user acceptance for similar needle destroyers (World Medical Association, 2013), (Breusch & Pagan, 1979). The device's success in expediting disposal and preventing sharps injuries, without compromising usability,

supports its role in enhancing occupational safety[15].

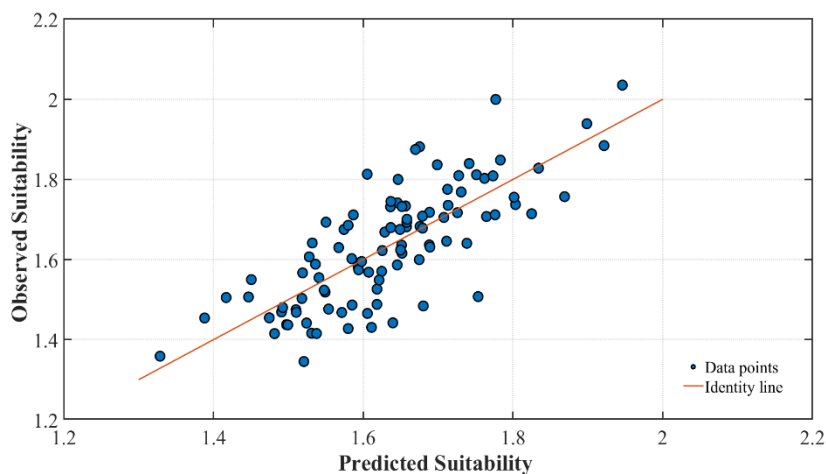


**Figure 5** Scatterplot of predicted versus observed overall suitability ratings, with identity line shown in orange.

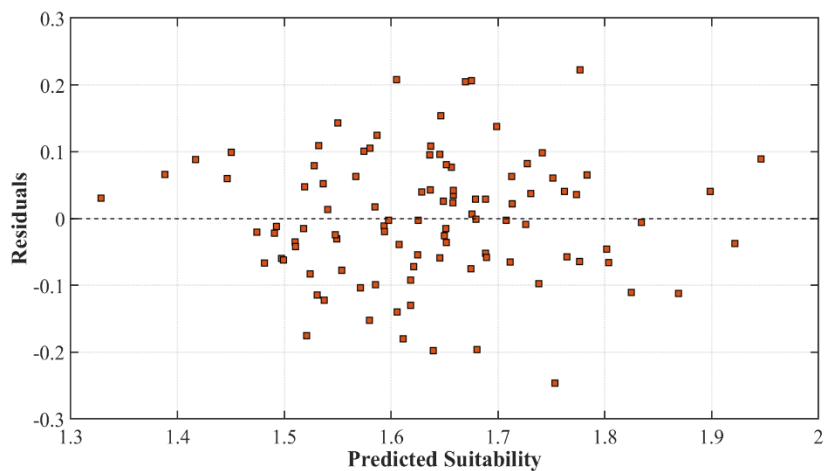


**Figure 6** Scatterplot of raw residuals (observed – predicted) versus predicted values, checking for constant variance.

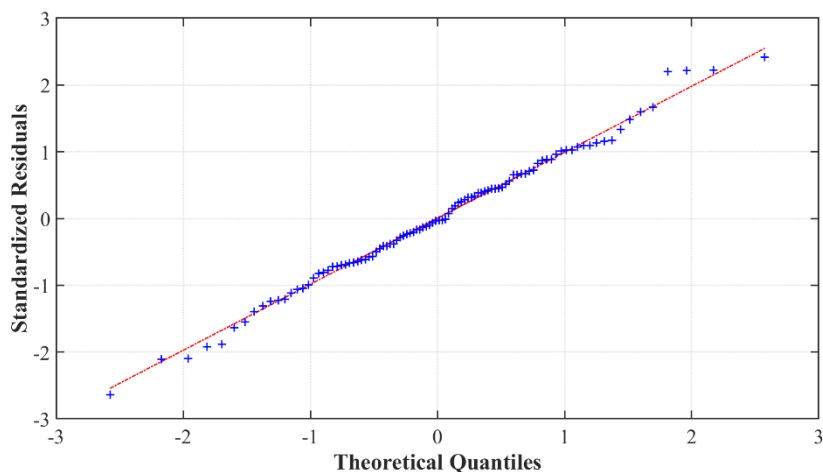


**Figure 7** Quantile-Quantile plot comparing the standardized residuals' distribution to a theoretical normal distribution

Figures 5 through 7 collectively validate the robustness and predictive validity of the multiple linear regression model used to forecast overall device suitability from the three evaluation domains. Figure 5 (Predicted vs. Observed Suitability) demonstrates strong calibration, with predicted scores clustering tightly around the identity line, indicating high agreement between model

estimates and actual responses. This pattern reflects the model's capability to generalize across the full range of suitability ratings without systemic bias.

Figure 5 (Q-Q Plot of Standardized Residuals) supports the assumption of normally distributed residuals. Most points fall along the 45° reference line, with only minor deviations in the extreme tails, suggesting no significant skewness or kurtosis in the model's error distribution. This satisfies a key assumption for valid hypothesis testing and lends statistical credibility to the coefficient estimates and p-values reported.

Figure 7 (Residuals vs. Predicted Suitability) confirms homoscedasticity. The residuals are dispersed symmetrically and randomly around the zero line, without evidence of heteroscedasticity or non-linearity. This reinforces the validity of the linear specification and indicates that no transformation or model restructuring is necessary.

Together, these figures affirm that the model satisfies critical assumptions of ordinary least squares regression: linearity, normality, and constant variance. These findings elevate confidence in the analytical approach and support the interpretation that technical quality is a significant and stable predictor of user-rated device suitability.

## 5. Discussion

This investigation provides a quantitative understanding of how technical attributes, performance efficiency, and safety/usability collectively influence the overall suitability of syringe needle destroyers (SNDDs) in clinical practice. The regression analysis revealed that technical features significantly elevated satisfaction scores, validating that structural durability, advanced destruction mechanisms, and conformance to design standards are core determinants of

user acceptance—a finding echoed by previous studies emphasizing the operational reliability of automated needle destroyers (Kim et al., 2022), (Kim et al., 2019). Devices integrating efficient melting technologies or mechanical cutters that minimize residue and exposure have been positively rated in multiple healthcare settings (Laowha et al., 2023), (Firdaus et al., 2024), reinforcing our results. These attributes are not only engineering priorities but also align with WHO's emphasis on safe injection and sharps destruction practices as a global standard (World Health Organization, 2016), (World Health Organization, 2016).

Contrary to expectations, operational performance and safety/usability yielded slightly negative coefficients, suggesting diminishing returns when performance is pursued without ergonomic alignment. In line with Higginson and Parry's review (Higginson & Parry, 2013), this trade-off is particularly evident in user-reported overheating, excessive power draw, and audible discomfort during extended usage. Devices boasting higher speeds often sacrificed user-friendliness, with needle insertion misalignments and unshielded thermal zones reducing confidence in device safety. This aligns with the ergonomic challenges reported in field implementations of semi-automated needle removal systems (Laowha et al., 2023). To address these weaknesses, practical innovations—such as enhanced insulation, fume filtration, automatic shutoff, and single-handed operation—are essential to meet the design expectations stipulated in IEC and ISO frameworks (World Health Organization, 2016).

Notably, high safety ratings did not correspond to increased satisfaction, implying that healthcare workers view safety as a basic expectation rather than a differentiating factor. This phenomenon, where seamless protection is normalized and only failure is salient, underscores the importance of human

factors engineering in medical device usability. Prior research supports this insight: even devices equipped with safety features can fail in practice due to poor interface design or user error (Kim et al., 2022), (Higginson & Parry, 2013). Devices like the NeedleSmart NS Pro, which combine smart circuitry with noise suppression and emission control ( $\sim 84.8$  dB), serve as industry benchmarks (Higginson & Parry, 2013). Therefore, consistent with WHO guidelines and ergonomic standards, next-generation SNDDs should prioritize thermal regulation, energy efficiency, spark and smoke control, and fail-safe design. These improvements directly fulfill the stated research objective by advancing user-centric, standards-aligned design pathways for widespread adoption in both high- and low-resource healthcare environments.

To further address user diversity, an additional subgroup analysis was performed to examine which operational processes of the syringe needle destroyer were most suitable for, or required improvement among, different categories of healthcare professionals. The analysis, conducted using MATLAB computational routines, compared aggregated domain scores (technical, performance, and safety) across four user groups: nurses, physicians, laboratory technicians, and waste-management staff. The results revealed subtle but meaningful variations in perception. Nurses and laboratory personnel—who engage most frequently with the device—reported slightly lower mean ratings for ergonomics and thermal comfort ( $4.28 \pm 0.67$  and  $4.26 \pm 0.63$ , respectively) compared to physicians ( $4.40 \pm 0.58$ ), who emphasized performance stability and rapid destruction. Conversely, waste-management personnel prioritized safety and containment, with consistently high ratings for the device’s filtration and automatic shut-off systems (mean =  $4.35 \pm 0.64$ ). These findings highlight that the device performs robustly across all groups but could benefit from

ergonomic refinements, improved handle design, and enhanced ventilation mechanisms to better accommodate high-frequency users. Integrating such user-specific insights aligns with ISO 13485 and IEC 60601 design-control frameworks, ensuring that next-generation needle destroyers are optimized not only for technical reliability but also for human-factor adaptability in diverse clinical environments.

Design Recommendations include use of heat-resistant, durable materials; enhanced cooling; energy-efficient power management; ergonomic single-handed operation; effective ventilation with HEPA or activated carbon filters; noise dampening; spark prevention; and robust safety features such as automatic shutoffs and tamper-proof sharps containers. Implementing these improvements can transform syringe needle destroyers into pivotal tools that reduce NSIs, improve workflow, and promote healthcare worker safety. Widespread adoption, especially in resource-limited settings, requires cost-effective, reliable, and user-friendly devices.

Limitations and Future Directions: The paper's regional focus (Bangkok) and reliance on self-reported data limit generalizability. Broader international evaluations and objective performance metrics (e.g., destruction time, emissions) are needed. Longitudinal studies should assess impacts on NSI incidence and compliance. Ongoing user engagement in iterative design is crucial to address ergonomic and technical gaps.

As production scales and costs decrease, next-generation devices have the potential to significantly enhance global healthcare safety.

## 6.Conclusion

Syringe needle destroyer devices are a critical component in the hierarchy of controls to prevent needlestick injuries and ensure safe disposal of sharps in healthcare. This paper's analysis of user-based evaluations has highlighted that while current devices are largely effective and appreciated by healthcare workers, there is room for targeted enhancements to reach the highest standards of safety and performance. In particular, the technical quality of design and construction stands out as the key driver of a device's overall acceptability – robust engineering translates directly to user trust and satisfaction. Conversely, even highly-rated aspects like operational performance and safety features must be continually refined to eliminate any residual issues that can erode user confidence (such as overheating or suboptimal ergonomics).

By implementing improvements such as advanced cooling systems, energy-efficient power control, ergonomic one-handed operation, effective fume filtration, and noise reduction, next-generation needle destroyers can address the shortcomings identified by users. These enhancements will ensure that the devices not only destroy needles quickly and reliably but do so quietly, cleanly, and with maximal safety for the operator. Aligning device design with global best practices – for example, making them easy to use immediately at the point of care and compliant with standards for electrical and biological safety – will facilitate their adoption as a standard fixture in healthcare environments worldwide.

Ultimately, improving syringe needle destroyers is about advancing medical standards and protecting those on the frontline of care. A top-tier needle destroyer allows healthcare workers to perform their duties without fear of accidental injury from used needles, reinforcing a culture of safety. It also

contributes to public health by ensuring that dangerous sharps are neutralized before they can ever pose a risk to waste handlers or the community. The insights from this paper serve as a foundation for design innovation: manufacturers and engineers can leverage our findings to create syringe needle destroyers that are more efficient, safer to use, and more user-friendly than ever before. In doing so, we move closer to a future where needlestick injuries become a rare occurrence, thanks to technology that effectively safeguards every used needle from cradle to grave.

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## 8. References

- Breusch, T. S., & Pagan, A. R. (1979). A simple test for heteroscedasticity and random coefficient variation. *Econometrica*, 47(5), 1287–1294. doi:10.2307/1911963
- Cochran, W. G. (1977). *Sampling techniques* (3rd ed.). New York, NY: John Wiley & Sons.
- Cooke, C. E., & Stephens, J. M. (2017). Clinical, economic, and humanistic burden of needlestick injuries in healthcare workers. *Medical Devices: Evidence and Research*, 10, 225–235. doi:10.2147/MDER.S140846
- Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, 16(3), 297–334. doi:10.1007/BF02310555
- Firdaus, A., Ferdana, N., Mujakar, S., Satrio, H., & Zulhamidi. (2024). Design and development of syringe needle destroyer using melting method. *EMITOR: Jurnal Teknik Elektro*, 1(2), 41–52. doi:10.23917/emitor.v24i3.4494
- Green, S. B. (1991). How many subjects does it take to do a regression analysis? *Multivariate Behavioral Research*, 26(3), 499–510. doi:10.1207/s15327906mbr2603\_7
- Higginson, R. J., & Parry, A. (2013). Needlestick injuries and safety syringes: A review of the literature. *British Journal of Nursing*, 22(Suppl. 5), S4–S8. doi:10.12968/bjon.2013.22.Sup5.S4
- Jahangiri, M., Rostamabadi, A., Hoboubi, N., Tadayon, N., & Soleimani, A. (2016). Needlestick injuries and their related safety measures among nurses in a university hospital, Shiraz, Iran. *Safety and Health at Work*, 7(1), 72–77. doi:10.1016/j.shaw.2015.07.006
- Kim, S. M., Taerim, K., Lee, J. H., Cho, S. Y., & Cha, W. C. (2022). Effect of the automatic needle destroyer on healthcare providers' work in an

- emergency department: A mixed-methods study. *Healthcare Informatics Research*, 28(2), 123–131. doi:10.4258/hir.2022.28.2.123
- Kim, Y., Oh, K., Kim, N., & Yun, J. (2019). Development of a safe syringe disposal system moving towards automated syringe data collection. *Healthcare Informatics Research*, 25(1), 47–50. doi:10.4258/hir.2019.25.1.47
- Laowha, C., Tashoo, K., Boonsaner, N., Premchaisawatt, S., Juntahan, N., & Pranamko, T. (2023). Semi-automatic syringe removal machine to shorten the time. *Kalasin University Journal of Science Technology and Innovation*, 1(2), 41–52. doi:10.14456/ksti.2022.4
- Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, 140, 1–55. Retrieved from [https://legacy.voteview.com/pdf/Likert\\_1932.pdf](https://legacy.voteview.com/pdf/Likert_1932.pdf)
- MathWorks, Inc. (2020). *MATLAB* (Version R2020a) [Computer software]. Natick, MA: Author. Retrieved from <https://www.mathworks.com/>
- O’Brien, R. M. (2007). A caution regarding rules of thumb for variance inflation factors. *Quality & Quantity*, 41(5), 673–690. doi:10.1007/s11135-006-9018-6
- Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, 52(3–4), 591–611. doi:10.1093/biomet/52.3-4.591
- von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2007). Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: Guidelines for reporting observational studies. *Annals of Internal Medicine*, 147(8), 573–577. doi:10.7326/0003-4819-147-8-200710160-00010
- World Health Organization. (2016). *Safe injection and related procedural practices (updated guide)*. Retrieved from <https://www.who.int/publications/b/31378>

World Medical Association. (2013). World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA*, 310(20), 2191–2194. doi:10.1001/jama.2013.281053