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Mechanical Design and Analysis of Medical Gloves Remover

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Abstract: Medical gloves play a pivotal role in ensuring clinical and hospital safety, as well as optimizing performance. Throughout the medical field, it has been traditionally understood that medical gloves function as a vital barrier, safeguarding both healthcare providers and patients, thereby diminishing the transmission of infections. Presently, healthcare personnel take off their medical gloves manually, using their hands, before discarding them. Should healthcare workers not diligently follow post-precautionary practices, including thorough handwashing and sanitization, the potential for infection increases significantly. Consequently, it is imperative for this study to explore methodologies for the proper removal of used medical gloves from hands, eliminating the need for direct contact prior to disposal. The primary goal of this study was to design and analyse a removal tool for used medical gloves tailored to minimize the risk of infection. Primary and secondary data were procured through the utilization of observation, interviews, and scholarly journal articles. This was succeeded by a progressive sequence involving the evolution of design concepts, the creation of three-dimensional models, rigorous analytical procedures, and comprehensive assessments of usability. The results of our investigation indicate that the suggested configuration of the medical gloves remover is deemed acceptable with regard to its incorporated features, including the adaptable gloves remover structure, main housing, front panel, disposal bin, and bracket for attachment. However, potential refinements may be requisite to amplify the design's overall efficacy in facilitating the touchless removal of used medical gloves.

Keywords: Medical gloves, remover, design, analysis

1.0 INTRODUCTION

The safety and operational efficacy within clinical and hospital settings are significantly influenced by the utilization of medical gloves. These gloves have conventionally been conceptualized as a pivotal barrier, effectively isolating healthcare practitioners from patients and thus mitigating the transmission of various ailments. Thus, the primary focus of glove assessment has appropriately centered around the integrity of the barrier [1]. Diverse variants of gloves, encompassing latex, nitrile, vinyl-polyvinyl, polyethylene, synthetic materials, rubber, and neoprene, among others, are accessible to cater to distinct tiers of safeguarding necessitated by specific circumstances [2, 3]. While the World Health Organization (WHO) does not endorse the reuse of gloves, if such reuse is deemed necessary, it should be accompanied by the adoption of the most secure reprocessing approach [4].

In the context of medical procedures and examinations, it is imperative for healthcare personnel to don gloves, thereby preventing the dissemination of contagious agents and maladies. The selection of specific medical glove varieties is contingent upon the particular goals of the procedure at hand. These medical gloves are designed for single-use, necessitating adherence to stipulated performance criteria encompassing attributes such as resistance to tearing, prevention of leaks, and compatibility with biological systems [2].

The present practice involves the manual removal of medical gloves using the healthcare worker's own hands, which could potentially give rise to a heightened susceptibility to infection if proper post-precautionary measures are not diligently observed [5, 6]. To effectuate the removal of medical gloves, it is advised to grasp the glove from the opposite hand's side and delicately withdraw it from the hand. Improper utilization of contaminated gloves resulting from inadequate techniques

during both the donning and removal processes can facilitate the transmission of microorganisms. Consequently, in pivotal scenarios, the WHO advises that gloves must be discarded and hand hygiene measures should be executed when gloves display visible damage or are suspected to be compromised, following contact with bodily fluids, and upon conclusion of contact with contaminated areas on a patient's body [7-9].

It is plausible to propose a method for glove removal that circumvents the dispersion of microorganisms, ensuring that neither glove's exterior contacts the skin. The procedure involves securing the gloves onto a hook and employing an upward motion, originating from the palm area. As this maneuver unfolds, the individual's hand is disengaged from the glove, descending into a waste receptacle strategically positioned beneath the glove removal apparatus. This approach stands as a straightforward process, underscoring the importance of averting contact with soiled gloves to prevent exposure to potential hazards.

Given the outlined drawbacks that have the potential to impact the individual's health, there arises an essential imperative to design and develop a novel medical gloves remover tailored to reduce the risk of infection. Central emphasis is placed on the enhancement of advanced features and their associated mechanisms, aimed at substantially elevating operational efficiency, ensuring user safety, and mitigating potential hazards to users.

2.0 MATERIALS AND METHODS

The assessment of user requirements holds paramount significance prior to advancing the design concepts of the medical glove remover. To achieve this, two predominant strategies were employed, encompassing survey and interview approaches. A set of questionnaires was meticulously prepared to elicit information about participants' background, engagements, medical history, product familiarity, and comparative assessment. The survey questionnaire was disseminated among medical personnel and assistant medical staff employed at government clinics and hospitals. Additionally, the survey was extended to members of the public who have utilized medical gloves amid the ongoing pandemic. The survey included 50 responses. The outcome data reveals that a majority of the participants noted that the incorrect manual removal method of medical gloves could readily subject the user to potential infection. There was about 89% who confirmed this susceptibility to infection due to improper manual glove removal, and a mere 8% expressed a contrary viewpoint. A significant portion of the participants (50%) concurred with the notion of the medical glove remover integrated with a sanitizing tool. Conversely, a notable proportion (26%) of respondents favoured the medical glove remover complemented by a disposal bin. The portable medical glove remover garnered the least preference, with 18% of the participants opting for this concept.

The interview sessions were arranged either through telephone conversations or in-person interactions, depending on the preferences of the interviewees. The selection encompassed five individuals, all of whom were medical staffs at a hospital. A range of inquiries were directed towards the interviewees, focusing on aspects pertinent to the examined issues. These questions included the personal experiences using standard removal method of medical gloves, challenges encountered while removing the gloves, potential of infection, and suggestions for enhancing the existing concept. The individuals interviewed concurred that manually removing medical gloves using hands, following the correct procedure to prevent infection, is agreeable; however, there is occasionally a slight concern. Besides, the recommendations offered by the interviewees propose the installation of a disposal bin as a thoughtful measure for infection prevention. Moreover, they endorsed the idea of integrating a glove remover with a sanitizing tool, highlighting its user-friendliness and cost-effectiveness.

Upon comprehensive assessment of the gathered data derived from both survey and interview sessions, the proposed design for the medical glove remover should conform to the following specifications: 1) easy to remove the gloves from the hands, 2) easy to dispose the gloves, 3) safe design features, 4) portable, 5) multifunction, and 6) durable. Subsequently, these criteria were employed as the foundation for a functional analysis conducted via a morphological chart. Within this approach, a range of functions aligned with the product specifications was identified, later expounded upon in a

brainstorming session. Consequently, the proposed design was segmented into seven distinct functional groups, incorporating gloves removal operating concept, remover design, disposal method, main body frame design, attachment design type, main structural material, and sanitizing system. Each function was systematically translated into a minimum of three detailed ideas, thus yielding a diverse array of potential solutions. By combining ideas across functions, six distinct design concepts were formulated. Figure 1 depicts the six design concepts through sketch illustrations.

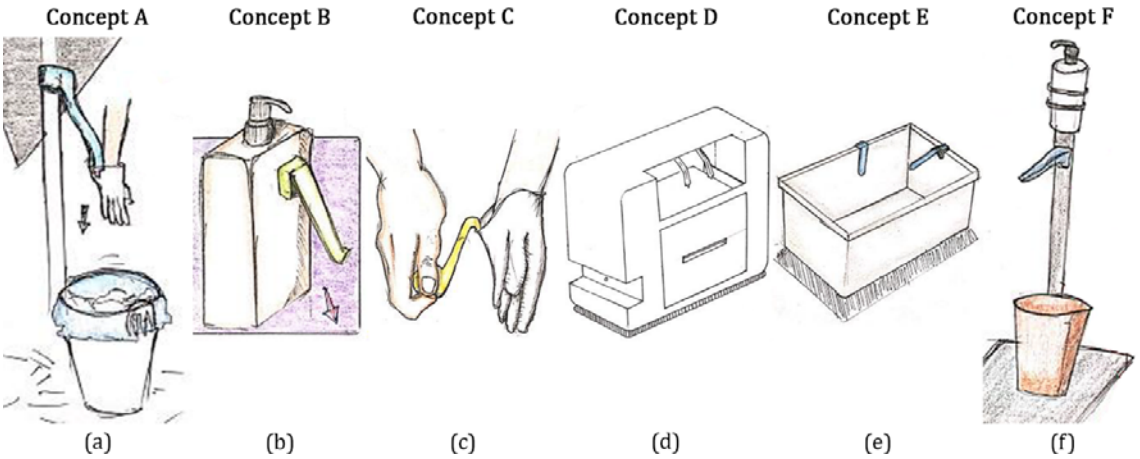

Figure 1: Six different design concepts (A – F) of the proposed medical gloves remover

In short, concept A features a hole accompanied by a bracket that serves the purpose of fastening it to the pole. Upon securing the lock, the remover component gains the ability to rotate in a 360-degree range of motion. The installation and usage of this concept are both uncomplicated. Concept B, on the other hand, users can remove the medical glove and promptly sanitize their hands, promoting hygiene. Additionally, the remover can be replaced with various shapes as needed. In terms of the benefits associated with this concept, it offers portability; however, one drawback is its susceptibility to being lost. For concept C, users can effortlessly grip the remover and pull the glove for removal. The remover itself is designed to fit into a pocket due to its compact size. Notably, the advantage of this concept lies in its exceptional portability, making it convenient to transport anywhere. Concept D presents a glove remover that is securely affixed to a stationary housing through screw fastening. As a result, this particular design concept cannot be easily detached from the wall for the purpose of portability. Concept E introduces the notion of a glove remover being positioned securely above a disposal bin. The utilized gloves can be effortlessly discarded into the designated bin. In concept F, an approach is taken by securely attaching the remover to a rectangular hollow bar. This design presents a singular, straightforward mounting technique involving direct screwing onto a pole. A notable advantage is that the used medical gloves can be easily removed and directly discarded into the disposal bin.

Utilizing the concept screening approach, a comprehensive selection matrix was developed, established upon the stipulated user needs. Additionally, a pre-existing product was employed as a benchmark for reference. For every selection criterion, the concepts were evaluated using the symbols "+", "–", and "0", signifying superior, inferior, and equivalent performance in relation to the benchmarked product, respectively. This evaluation facilitated the computation of a net score for each concept, the summation of the "+" symbols contributing to this calculation. The concept with the highest net score will attain the top rank, while the concept with the lowest net score will be positioned last. Additionally, a supplementary evaluation was conducted on all concepts to determine whether any revisions were necessary. Table 1 illustrates the data analysis in the concept screening phase for all the proposed product concepts. The results indicate the selection of concept D, concept E, and concept F for subsequent evaluation.

The detailed evaluation of the three concepts took place during the concept scoring phase, aimed at determining the optimal design. Each selection criterion was assigned a rating scale value to indicate

its level of significance or importance. The rating scale possesses values ranging from 1 to 5, where 1 corresponded to "Poor", 2 to "Ok", 3 to "Fair", 4 to "Good", and 5 to "Excellent". Moreover, each selection criterion was assigned a weighted value (%) based on its contribution towards the product's functionality. Table 2 exhibits the concept scoring method performed on concept D, concept E, and concept F. Upon evaluation, concept D emerged with the highest cumulative score when compared to both concept E and concept F. Concept D was thus chosen as the ultimate design to be progressed further. Subsequent refinements were implemented on concept D to enhance specific attributes.

Table 1: Concept screening of all design concepts

No.	Selection Criteria	Concept A	Concept B	Concept C	Concept D	Concept E	Concept F	Competitor (Reference)
1	Gloves Removal Technique	0	+	+	+	+	+	0
2	Remover Design	+	+	+	+	+	+	0
3	Disposal Method	-	+	-	+	+	-	0
4	Hook Design	+	-	+	+	+	+	0
5	Sanitizing System	-	+	-	+	-	-	0
6	Attachment Type	+	+	-	+	+	+	0
7	Material	0	0	0	+	0	+	0
8	Dimension	+	-	+	0	+	+	0
	Sum 0's	2	1	1	1	1	0	0
	Sum –'s	2	2	3	0	1	2	0
	Sum +'s	4	5	4	7	6	6	0
	Net Score	2	3	1	7	5	4	0
	Rank	5	4	6	1	2	3	0
	Continue?	No	No	No	Yes	Yes	Yes	0

Table 2: Concept scoring data for concept D, concept E, and concept F

No.	Parameter		Concept D		Concept E		Concept F	
	Selection Criteria	Weightage (%)	Rating	Score (%)	Rating	Score (%)	Rating	Score (%)
1	Gloves Removal Technique	25	1.25	5	1	4	1.25	5
2	Remover Design	15	0.6	4	0.6	4	0.6	4
3	Disposal Method	10	0.4	4	0.2	2	0.2	2
4	Hook Design	5	0.2	4	0.2	4	0.2	4
5	Sanitizing System	10	0.4	4	0.2	2	0.2	2
6	Attachment Type	20	0.8	4	0.6	3	0.8	4
7	Material	10	0.4	4	0.3	3	0.4	4
8	Dimension	5	0.25	5	0.2	4	0.2	4
	Total Score	100	4.3		3.3		3.85	
	Rank		1		3		2	
	Develop?		Yes		No		No	

Utilizing SolidWorks, a computer-aided design (CAD) software, a comprehensive three-dimensional (3-D) model of the finalized design was generated. The construction of the 3-D model components leveraged various modelling features available in the software, including methods such as revolved, extruded cut, extruded, mirrored, and shell. Following the complete construction of each individual design part, a systematic assembly process was undertaken to bring them together into the final configuration. Figure 2(a) shows the complete assembly of the medical glove remover design in its three-dimensional (3-D) model representation. This particular concept entails a remover that can be

affixed to the housing structure. It incorporates a designated compartment to accommodate a sanitizer bottle. Notably, the benefits of this medical glove remover concept encompass the direct disposal of gloves into a disposal bin or drawer, thereby greatly lessening viral infection risks. The operational mechanism involves extracting the glove towards the securely attached remover. To fabricate this design, polylactic acid (PLA) and acrylic materials are employed. A thorough examination of the model files preceded the preparation of the preliminary functional mock-up for initial functional evaluation as shown in Figure 2(b). Subsequent steps involved prototype construction using a combination of metalworking and 3-D printing approaches. The different phases of prototype fabrication, along with the completed prototype, are visually represented in Figure 2(c).

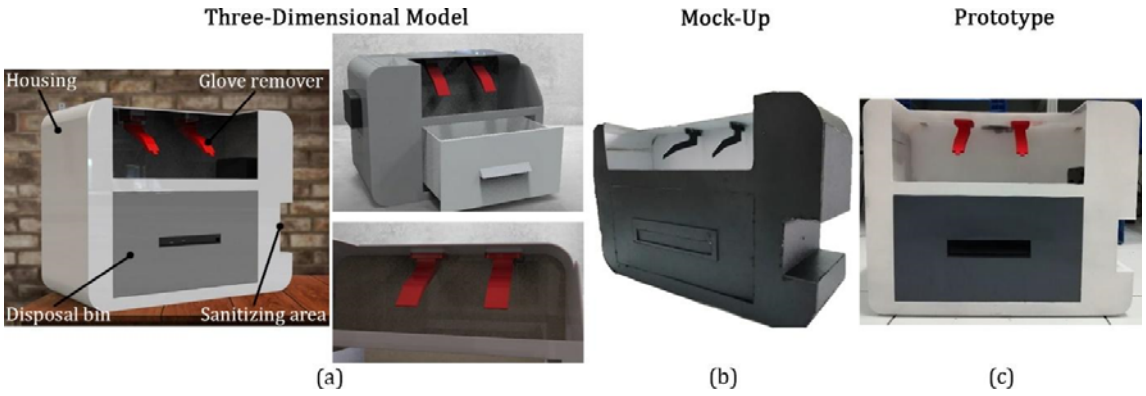

Figure 2: The 3-D model of medical gloves remover in different views. (b) Mock-up of proposed product. (c) Finished prototype

In order to assess the structural integrity of the proposed gloves remover, a 3-D linear static finite element analysis (FEA) was executed. Given that the key emphasis of the innovation rests on the mechanism to remove the medical gloves from the hand without contact, the computational structural analysis scrutinized the structural integrity of the remover design. FEA stands as a widely recognized numerical technique extensively employed to investigate challenges linked to mathematical modelling across the domains of science and technology [10-14]. The geometrical model of the glove remover design was exported into ABAQUS, an FEA software, in the ACIS file format (.sat). The material properties assigned to the model (PLA) were assumed to be isotropic, linearly elastic, and homogenous. Table 3 outlines the specific elastic modulus (E) and Poisson's ratio (v) values considered for PLA during the analysis.

Table 3: Material properties of PLA used in the analysis

Properties	Value	References
Elastic modulus	4.107 GPa	Dharmalingam et al. [15]
Poisson's ratio	0.3	Dharmalingam et al. [15]
Yield strength	26.082 MPa	Subramaniam et al. [16]

Regarding the applied load, a force of 75 N, was exerted on the surface of the tip of remover structure. This load simulates the pulling force while removing the gloves from the hand. In terms of support conditions, the top surface of the remover that contacting the attachment region were fixedly constrained in all directions, encompassing translation and rotation as illustrated Figure 3. The mesh type utilized was a four-node solid tetrahedral element, systematically applied to the model. To ensure the precision of mesh construction at critical junctures, a consistent mesh size of 4.5 mm was adopted. As a result, the total number of elements and nodes of the model was 7,805 and 12,585, respectively. The model's contact surfaces were uniformly considered under a bonded contact type.

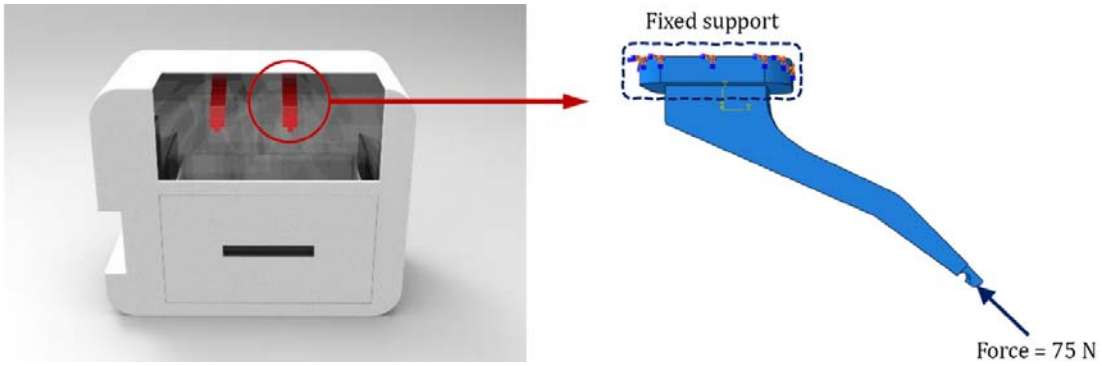

Figure 3: The location of fixed support and the force (75 N) applied on the remover model

The completed prototype underwent testing to assess its functionality and usability in removing the used gloves from the hand without contact. The prototype usability testing was performed at a place where the proposed product can be fixedly attached to a wall.

3.0 RESULTS AND DISCUSSION

The general dimensions of the product prototype produced in this study were 500 mm, 256 mm, and 400 mm for the length, width, and height, respectively, as shown in Figure 4. The material choice entails the utilization of acrylic and PLA. Acrylic is a type of transparent plastic chosen due to its remarkable attributes such as robust strength, stiffness, affordability, and optical clarity. It can be easily fabricated through cutting and bending processes. Furthermore, acrylic demonstrates superior weather resistance compared to numerous other transparent plastic materials. As for the PLA, it can be printed under low-temperature conditions without the need for a heated bed. PLA is easily printable, cost-effective, and yields components suitable for integration in this study. Additionally, it stands out as one of the most ecologically conscious material presently available. Noteworthy properties of PLA printing encompass commendable dimensional precision, rigidity, commendable strength, and budget-friendly characteristics.

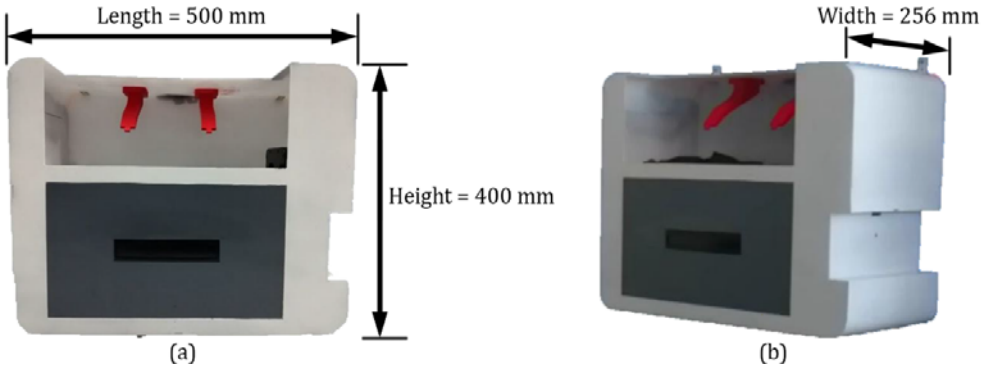

Figure 4: General dimensions of the product shown for the (a) length and height, and (b) width

Ergonomic principles have been incorporated into the study's design. The proposed product aims to uphold the standards of regular living and work routines, enhancing not only daily comfort but also work efficiency. The product features a hinge-mounted design with an average height, designed to accommodate both genders' average heights. The product is intended to be wall-mounted at a height of 110 cm from the ground, aligning with parameters suitable for the average height of the Malaysian population.

The findings from the 3-D linear static FEA analysis were presented by illustrating the highest magnitudes and patterns of equivalent von Mises stress and total deformation. Visual representation of

stress and deformation distributions in the models was accomplished through the utilization of a color contour plot. This plot employs shades of red to highlight the most critical regions and shades of blue to indicate less critical areas. The results showed that the maximum equivalent von Mises stress was recorded at the tip of the remover structure with the value of 1.603 MPa. This indicates that the region was susceptible to failure which could be due to the application of the load at that location. Plus, the reason behind the highest stress magnitude recorded could potentially be attributed to an amplified bending resistance within the structure when countering the applied load. However, the maximum stress value recorded was still lower than the yield strength of PLA which is 26.082 MPa. This observation is further substantiated by the Factor of Safety (FOS) computation, yielding the value of 16.27. The minimum stress value of 935.259 × 10^{-6} MPa, on the other hand, was generated at the fixed support part. Figure 5(a) shows that high stress concentration was found at the tip of the remover and surrounding regions compared to the area near to the fixed support.

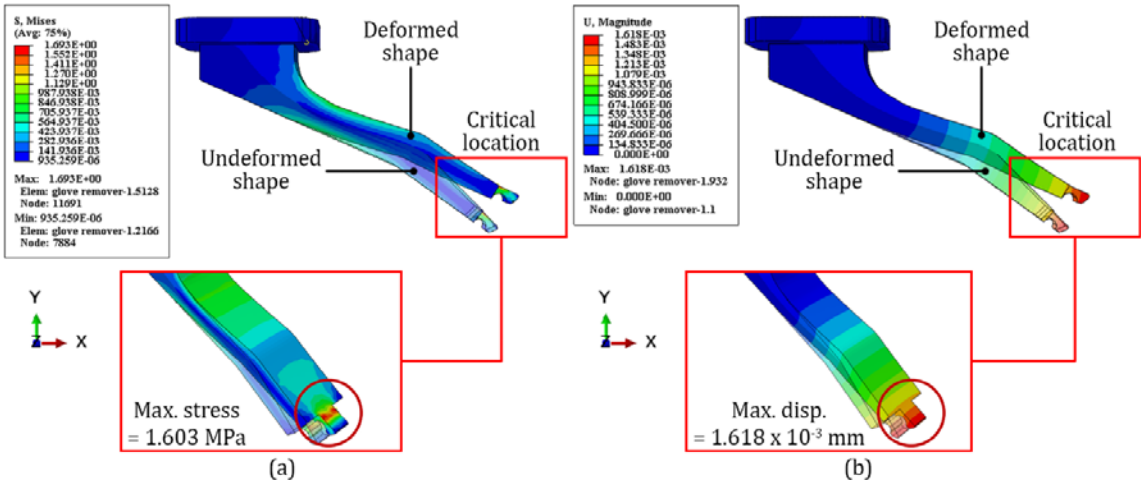

Figure 5: The critical region recorded within the glove remover model for the (a) von Mises stress and (b) total deformation results

For the total deformation results, it is worth highlighting that the highest value of displacement (1.618 × 10^{-3} mm) was displayed at the tip of the remover. This corresponds to the distribution of the stress results obtained earlier. Figure 5(b) illustrates the dispersion of total deformation in the remover model, revealing the prominently affected area to be concentrated at the tip of the remover. It is foreseeable that the maximum total deformation at the remover's tip will increase due to increased bending stress induced by the applied load. In order to mitigate the risk of significant deformation that could potentially result in failure, the inclusion of a supplementary minor support at the underside of the remover is recommended.

In terms of product usability testing, there are several important steps needed to be taken in order to successfully operate the tool. Firstly, the prototype can be positioned on the wall at a height of 110 cm from the ground. Next, the hands are inserted into the housing and securely grip the glove onto the medical glove remover. The hands can then be elevated in an upward direction. The gloves are drawn from the hands until they are detached. The hands are positioned beneath the automated sanitizer to disinfect the hands subsequent to glove removal. The drawer is extended to verify that the used gloves are properly contained, and the plastic garbage bag can be replaced once the medical glove bin reaches its full capacity. Figure 6 exhibits the working operational steps of the medical glove remover prototype.

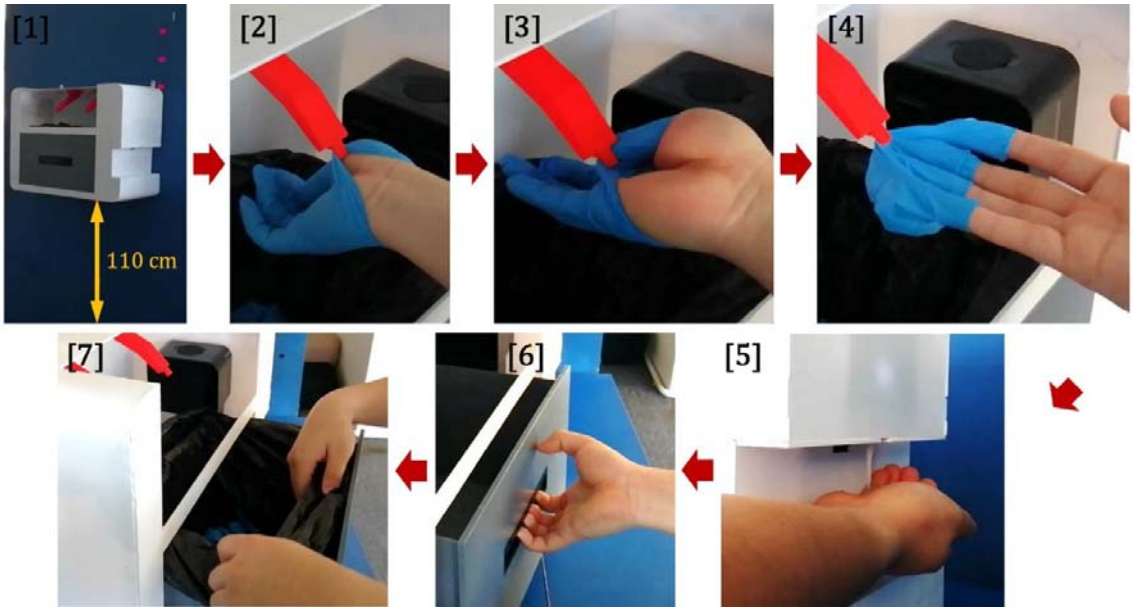

Figure 6: The usability testing of the prototype

The proposed product has been tested to two medical staffs. The height of the male and female staffs are 171 cm and 154 cm, respectively. According to the users, the tool is deemed fitting for application, and their contentment was evident during the testing phase. As a result of the test, users found the tool comfortable to use, allowing them to remove the glove without hand contact and at an appropriate height for medical glove removal. Besides, the testing involved individuals with two distinct hand sizes. The results indicated that the provided space volume was adequate. The testing demonstrated that the remover design effectively facilitated the easy removal of medical gloves due to its thin and elastic configuration. However, the suggestion offered by the testers is to expand a bit the tip of the glove remover to facilitate the effortless removal of medical gloves.

4.0 CONCLUSION

Through a comprehensive process of design development, computational structural analysis, and usability testing, it is deduced that the proposed medical glove remover design yields satisfactory outcomes. The mechanical stress and total deformation induced within the design remained within acceptable thresholds when subjected to the applied load. The enhanced operational mechanism of the medical glove removal centered around accommodating diverse hand sizes, bolstered safety features, and ergonomic enhancements, effectively mitigates or even precludes unfavourable occurrences. As a result, this innovative medical glove remover design is well-equipped to address the deficiencies found in removing the used medical gloves.

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