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Redesign wheelchairs for stroke sufferers using the Quality Function Deployment method

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Abstract
The prevalence of stroke in Indonesia continues to increase, so there is a need for mobility assistance. In today's era, high mobility is necessary to live with freedom, but stroke sufferers still struggle to achieve comfort when using this mobility, namely wheelchairs. The author conducted research to redesign a wheelchair that is tailored to the needs of stroke sufferers. This research was conducted using the Quality Function Deployment method to obtain information on the needs of stroke sufferers and the Wilcoxon Difference Test method to determine the level of difference between old wheelchair designs and improvements. The results showed that the wheelchairs needed by stroke sufferers were multifunctional, ergonomic, flexible, safe, and materially sound. In the results of the Wilcoxon Difference Test, which was carried out based on the hypothesis, it is known that only the flexible attribute has no difference compared to the previous wheelchair design product. In contrast, the other four attributes have different values for the old wheelchair design and the improved design. Thus, redesigning wheelchairs is accomplished by obtaining design specifications that meet the needs of stroke sufferers.

Keywords:
Quality Function Deployment;
Stroke;
Wheelchairs;
Wilcoxon;

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INTRODUCTION

Nationally, the prevalence of stroke in Indonesia in 2018, based on a doctor's diagnosis in the population aged ≥ 15 years, reached 10.9%, or an estimated 2,120,362 people. According to the 2018 Basic Health Research data, the prevalence value of stroke in Indonesia has increased from 7% in 2013 to 10.9% in 2018, or an estimated 2,120,362 people. The total number of stroke sufferers in Indonesia is estimated at 500,000 every year, with around 2.5%, or 250,000 people, dying and the rest being either mildly or severely disabled. The limitations of stroke sufferers include the need for mobility to support themselves. Until now, wheelchairs were an alternative tool commonly used by stroke sufferers. The wheelchair is an interface mobility device between the user and the environment [1]. Not only for stroke sufferers, but wheelchairs are also commonly used by persons with disabilities for rehabilitation [2]. Together, the wheelchair and the human body constitute an anthropotechnical system [3] [4]. The wheelchair-user population needs to have their special requirements met [5]. In today's era, high mobility is necessary to have the opportunity to live a decent life, so that can improve the quality of life for every human being [6]. Unfortunately, this is difficult for stroke sufferers. Manual wheelchairs are necessary assistive devices that enhance locomotion for individuals with limited mobility [7]. However, previous users of wheelchair products reported a high degree of pain and shoulder pathology from using a wheelchair [8]. Based on this, there are problems wheelchair users face, one of which is that stroke sufferers still do not get the appropriate wheelchair mobility for their expected needs.

A stroke is a complex medical emergency that necessitates a well-functioning treatment system to optimize the care provided [9]. Stroke is not a single disease but can be caused by various risk factors; 85% of strokes are caused by

tiny blood vessel arteriolosclerosis [10]. There are several disorders, such as muscle weakness (hemiparesis), which generally occurs after a person has had a stroke, and this disorder primarily affects one side of the body more than the other [11]. Hemiparesis is a condition that causes partial weakness on one side of the body resulting from hemispheric vascular disorders or severe motor disorders. It affects about 65% of stroke patients [12]. A person suffering from hemiparesis will experience muscle weakness, resulting in difficulty moving around and losing balance. The risk for hemiparesis arises from the movement between the wheelchair and the bed, which is done manually and not carefully in stroke patients so that stroke sufferers can fall and experience hemiparesis. As a result of the occurrence of a stroke or post-stroke patient, it can cause several other problems, such as broken bones, minor injuries, major injuries, and open wounds. Caregivers are needed to support stroke sufferers' activities so they can move safely [13].

Based on previous research, it is known that the activity of daily living for stroke sufferers is moving from a wheelchair to a bed, which has the potential to cause them to fall. In this study, some information was obtained about the subtask difficulties experienced by stroke sufferers, including the difficulty in getting a chair that could be converted into a bed [14]. In addition, it is also known that nurses and caretakers of stroke sufferers may be at risk of musculoskeletal disorders due to the manual lifting and handling of patients when moving them from a bed to a wheelchair. This study resulted in more comfortable wheelchairs, but no additional tests were performed on the results obtained based on the size of the previous wheelchair [15].

This research was conducted to redesign the mobility design by creating wheelchairs that can be adjusted to the needs of stroke sufferers to minimize the unwanted things that stroke sufferers have. In the current or future product development process, consumers must be the top priority aspect, with several needs based on consumer desires so that consumers are satisfied with the products provided. The wheelchair development process used the Quality Function Deployment method. The method was chosen because this study will focus on designs that are in accordance with the specifications of the information needs obtained directly from caregivers or stroke sufferers. Quality Function Deployment is an information medium for discovering several wishes that follow the needs of stroke sufferers in using wheelchairs through the voice of the customer. When redesigning a product, increasing the prospect of comfort in the design is important. In this study, comfort was measured using the anthropometric method. The anthropometric method was chosen to understand the differences in performance between the two groups so that it could be used in designing more effective mobility [16]. In addition, a different test was conducted to validate the results of the proposed designs and ensure that the products were focused on user needs.

METHOD

Research Subjects and Objects

The subjects in this study were related parties, stroke sufferers, with the problem of the lack of mobility of stroke sufferers in using wheelchairs according to their needs. At the same time, the objective is to redesign a wheelchair to meet the needs of stroke sufferers.

Population and Sample

The population in this study were stroke sufferers and caregivers on Java Island. The sample population used is 30 people based on random data collection. The data collection technique for the sample used was to distribute questionnaires to encourage information about the needs of wheelchair users through the Quality Function Deployment approach. In addition, data for the Wilcoxon Difference Test was gathered by distributing questionnaires to determine the differences between the previous and proposed products.

Research Procedure

The research flow serves as a writer's guide in researching so that the results do not deviate from predetermined goals. The flow of research conducted in this study is shown in Figure 1.

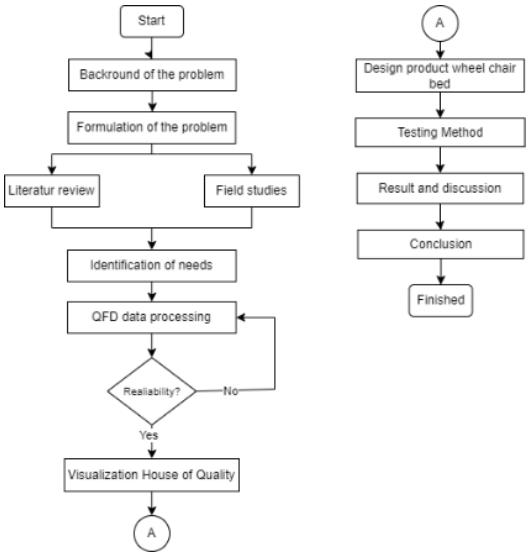


Figure 1. Research flow

Design Method

The analysis outlines the results of previous data processing to determine the root of the problem. Data analysis was also conducted to implement the Quality Function Deployment (QFD) method in this study. Quality Function Deployment (QFD) is a method for translating consumer perceptions and needs into a matrix and then interpreting them into a technical specification [17]. The QFD method can support implementing the philosophy of TQM (Total Quality Management) [18]. Figure 2 shows the flow of the quality function deployment method.

The process of implementing this method uses the voice of the customer. The design method used in QFD is as follows:

1. Distribute Questionnaire 1 (Open Questionnaire). This questionnaire aims to determine the wishes or needs of stroke sufferers for wheelchairs to be evaluated and repaired.
2. Processing Questionnaire Data 1, where the researcher summarizes the questionnaire results and groups them into several attributes.
3. Distribute Questionnaire 2 (Closed), where this questionnaire aims to find the important rating of each attribute that has been grouped. This second questionnaire asks about the importance of the adjusted attributes of the first questionnaire.
4. Processing Questionnaire 2 Data (Validity Test). Where this validation test is conducted, it aims to validate the answers to each of the attributes asked.
5. If the validation test results are positive or valid in the second questionnaire, you can continue with the following questionnaire. However, the validity test results are invalid, and you must repeat the data collection in the second questionnaire.
6. Distributing the third questionnaire is used to compare existing products and products to be designed.
7. Process Questionnaire 3 Data (Calculating Customer Competitive Evaluation) is used to compare each attribute of existing products with products to be designed.
8. Make a House of Quality concerning important ratings, customer competitive evaluation, and benchmarks for each attribute. Then, make an HOQ to see the attributes that need attention or must be maintained.

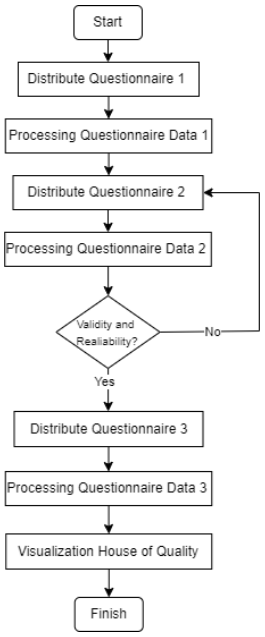


Figure 2. Quality Function Deployment Flow

Anthropometry

Anthropometry is one of the methods for measuring the human body [19]. Anthropometry was used in this study because it can provide information about an individual's body composition [20]. Anthropometry does not require a high level of technical skills, so it is crucial to understand the accuracy of anthropometric measurements [21].

Testing Method

The difference test aims to perform statistical analysis that helps observe the relationship between variables. In this study, the test authors compared the old wheelchair design with the results of improvements to several attributes needed by stroke sufferers in using wheelchair products. This comparison can give a clear overview through weakness and strengths of each, so that you can find out which elements or dimensions fit their user [22]. Figure 3 shows the flow of the testing method used in this research.

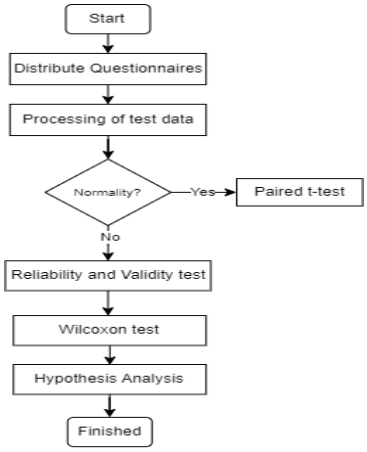


Figure 3. Testing Method Flow

The design method for the different tests is as follows:

1. Distribute Closed Questionnaires. This questionnaire aims to determine the differences in the attributes of the two wheelchairs—the old design and the remedial design for stroke sufferers.
2. Processing Questionnaire Data (Validity & Reliability Test).
3. The Wilcoxon Difference test is useful in comparing paired observations from two populations [23]. A different test was conducted on each attribute or aspect by knowing the resulting level of significance, whether $p < 0.05$ or $p > 0.05$.
4. Hypothesis testing is a way of making decisions based on data analysis, either from controlled trials or observation (uncontrolled). After the results of previous different tests are obtained, the next step is to determine the hypothesis based on the needs.

Method of collecting data

The data collection techniques used in this study for primary and secondary data types are presented below. Secondary data is the information used to complete objectives [24]. Secondary data is taken indirectly, and this data is usually obtained from sources such as journals, books, research literature, and other data.

Meanwhile, primary data is obtained directly from the source or subject used. Some of the primary data needed in the research based on the technical data collection is provided in Table 2.

Table 1. Secondary Data Collection

No.	Data Source	Required Data	Data Collection Techniques
1.	Previous research related to the design of wheelchairs in general and specifically for stroke patients.	The method is used to determine the novelty of the changes and improvements to be made to the design aspects.	Information about the method used and the results of studies related to redesigning wheelchair design.
2.	Books or reference literature on the Quality Function Deployment and Wilcoxon Test method.	Parameters for using the QFD method and the Wilcoxon Test.	The study results are related to the results obtained from the QFD method and the Wilcoxon test.

Table 2. Primary Data Collection

No	Data Source	Required Data	Data Collection Techniques
1	Caregivers/ stroke sufferers	Evaluation of previous wheelchair use.	Questionnaire
2		Stroke survivors' problems when transitioning from a wheelchair to a bed.	
3		Distributing questionnaires to find out the voice of customers on QFD and test data.	
4		The need for product design for stroke sufferers.	

Research Tools

Research aids used in processing and analyzing the data in this study include:

1. Microsoft Excel
   Microsoft Excel is a spreadsheet worksheet application program. Microsoft Excel is used to process questionnaire data using the Quality Function Deployment (QFD) method.
2. Sigma XL
   Sigma XL is a statistical analysis software designed to simplify the measurement process. This report was used to visualize the House of Quality using the QFD method at the time of writing.
3. Statistical Package for the Social Science (SPSS). SPSS is a complete software alternative for quantitative data analysis [25]. This study used SPSS to conduct several tests for Normality, Validity, and Reliability to Wilcoxon

RESULTS AND DISCUSSION

At this stage, data processing is carried out using the Quality Function Deployment method and the Difference Test when redesigning the wheelchair. Here are the stages.

Quality Function Deployment

In the first stage, the Voice of the Customer is carried out. Consumer voices are collected and written in a product's attributes. Table 3 listed the result of the identification of needs regarding the level of importance of attributes in product design.

After obtaining the value of the importance of the attribute, the researcher then carried out the initial proposed design. Figure 4 depicts a 3D design of the proposed wheelchair product.

Table 3. Needs Attributes

No	Attribute	Criteria	Important Rating
1	Multifunction	Can be transformed into a bed.	3.40
2	Ergonomic	All wheelchair cushions are made from soft foam.	3.61
3	Flexible	Easy to carry	3.20
4	Safety	There is a secure armrest.	3.70
5	Material	Using hollow stainless-steel material, it can be strong up to 120 kg.	3.70

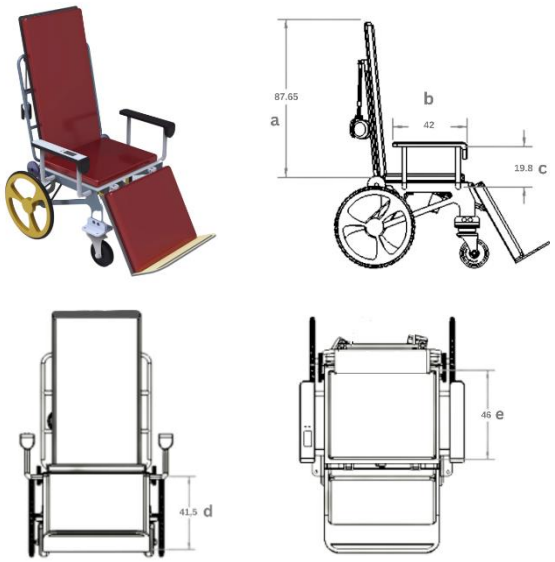


Figure 4. Proposed Design

The design above is a proposed wheelchair design based on the results of the previous questionnaire, where the wheelchair has the following attribute criteria:

1. Multifunctional, the wheelchairs proposed above have been equipped with additional features where the wheelchair can be transformed into a bed. This product can also be used as a comfortable bed for stroke sufferers at night.
2. Ergonomic, previous wheelchairs were not equipped with comfortable bearings. Therefore, an evaluation was given to the proposed design by procuring all cushions made of soft foam to increase the user's comfort.
3. Flexible, the flexibility of the above design is simple, with many needs fulfilled for stroke sufferers.
4. Safety, the armrest is provided as a secure and comfortable support. In addition, this safety is also to meet the needs of stroke users, so there is no need to move between wheelchairs and beds.
5. Material, the material used is hollow stainless steel, so it is believed to be able to withstand loads of up to 120 kg.

After knowing the importance of the attributes that consumers have asked about and designing the initial proposed design, the next step is to look for the relationship between technical response and user needs, which is done by distributing questionnaires back to users. So, values will be obtained that can determine how strong the relationship is between technical response and consumer needs.

Table 4 compares the CCE values obtained for the product with the initial proposed design and competitor products. In the next stage, benchmarking based on customer needs is carried out. At this stage, the customer needs of each attribute are compared so that each value is seen from the smallest value to the most significant value. The value represents each attribute, from not important to very important.

Based on Table 5 it is known that the largest improvement ratio value is for multifunctional needs in wheelchair products with a value of 1.11. So, this is a driving force for improvements to the multifunctional aspect.

Conduct benchmarking on metrics, making comparisons with technical, quantitative, and qualitative forms. This comparison is made with similar products so that the various dimensions or attributes needed in the developed product can be seen.

Table 4. Customer Competitor Evaluation

No	Attribute	n	Proposed Product		Competitor Product	
			Total *score*	CCE	Total *score*	CCE
1	Multifunction	30	100	3.8	58	2.83
2	Ergonomic	30	105	3.43	75	3.40
3	Flexible	30	87	3.27	82	3.33
4	Safety	30	105	3.53	83	3.50
5	Material	30	104	3.60	85	3.27

Table 5. Improvement Ratio

Need	Important Rating	Goals	Improvement Ratio
Multifunction	3.40	3.70	1.11
Ergonomic	3.61	3.60	1.03
Flexible	3.20	3.00	1.03
Safety	3.70	3.60	1.03
Material	3.70	3.50	1.01

Table 6 illustrates the comparison between product type specifications based on their metrics. Data processing results, the final metric selection is determined according to be the benchmark metric for wheelchair bed products. Table 7 is known the details of several specifications that will be applied to wheelchair product improvements.

House of Quality

The House of Quality (HOQ) aims to find a correlation between consumer needs and engineered characteristics of focused significance [26]. Figure 5 shows the HOQ of wheelchair products.

Table 6. Benchmark on Metric Competitor

No	Need	Metrics	Wheelchair Bed	OneMed
1	2	Wheelchair Size (cm)	180 x 59	94 x 28
2	2,3	Risk of Body Injury	☒	☑
3	1	Transform into a bed.	☑	☒
4	1	Backrest adjustment	☑	☒
5	2,4,5	Comfortable pillows	☑	☒
6	3	Easy to carry	☑	☒
7	4, 5	Wheelchair weight resistance (kg)	120	100
8	3,5	Wheelchair weight (kg)	45	1.7

Table 7. Final Metric Design

No	Metrics	Wheelchair Bed
1	Wheelchair Size (cm)	180 x 59
2	Risk of Body Injury	☒
3	Transform into a bed	☑
4	Backrest adjustment	☑
5	Comfortable pillows	☑
6	Easy to carry	☑
7	Wheelchair weight resistance (kg)	120
8	Wheelchair weight (kg)	45 kg

Based on Figure 5 the results of the visualization above, it can be seen that the output is based on the index of the actions that need to be taken on each existing attribute. The Safety attribute receives an action index A, which means that the Safety attribute in the initial proposed design needs to be improved to improve the quality of the product. In contrast, the Multifunction, Ergonomic, and Material attributes receive an action index B, which means that these three attributes need to be maintained to maintain product quality and innovate products sustainably. Finally, the Flexible attribute receives an action index C, meaning it is necessary to maintain the quality of its existing products.

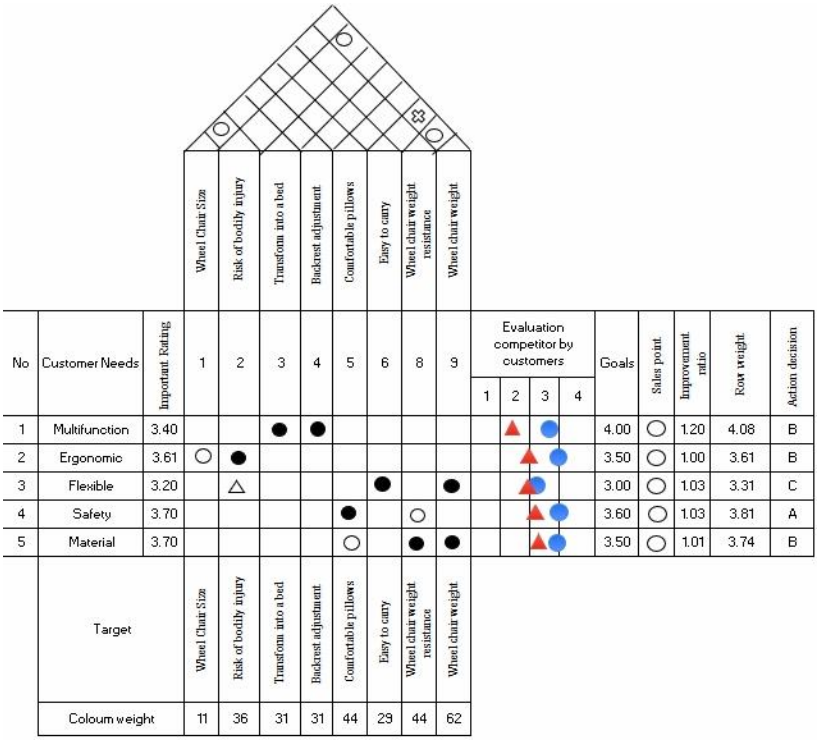


Figure 5. House of Quality

Evaluation of Proposed Design

Evaluation is feedback given to the designer by the user. The evaluation aims to maximize the adjustment of the wheelchair design according to the needs of the users. Consumers evaluate products to show considerable variability in how much they actively express particular meanings [27].

Based on the observations and the visualization of the House of Quality matrix, it is known that the Safety attribute needs to be improved in quality. Therefore, a questionnaire is distributed again to determine what specific aspects need to be evaluated for the Safety attribute. Based on the results of distributing the questionnaires, improvements to the initial design proposals are evaluated, including the following:

In Table 8, it is known that several evaluations need to be carried out from the proposed design so that an existing solution is obtained based on the known evaluation results. Therefore, it is necessary to design the addition based on the evaluation received.

Table 8. Evaluation Proposed Design

No	Evaluation	Solution
1	There is no safety on the headboard of the wheelchair bed.	Adding safety in the form of a rebuttal limit at the top end of the wheelchair bed.
2	Using tire parts with a rough base.	Changing the wheelchair bed tires with a rougher surface mat.
3	There is no control section to push the wheelchair.	Adding a push handle to the back of the wheelchair.

Anthropometry

The dimensional measurements used in the proposed wheelchair product are taken based on the dimensions of a conventional wheelchair. So, anthropometric ergonomics has not been applied. The process of improving the redesign of wheelchairs needs to be done to increase comfort according to stroke sufferers, along with the comparison sizes used after applying anthropometric ergonomics through Indonesian anthropometric data with the following dimensions and percentages listed in Table 9.

Table 9. Anthropometric Data

Measurement	Percentile	Improvement Anthropometry Size (cm)	Rounding (cm)	Proposed design (cm)
		Chair		
Sitting Height (a)	95	95.28	96	87.65
Forearm Length (b)	95	54.4	55	42
Sitting Elbow Height (c)	5	10.84	10	19.8
Knee Height (d)	5	36.16	36	41.5
Popliteal length (e)	95	49.65	50	46
		Bed		
Shoulder Width (f)	95	47.19	48	48
Height (g)	95	187.63	188	196.5

Table 10. Design Size Comparison

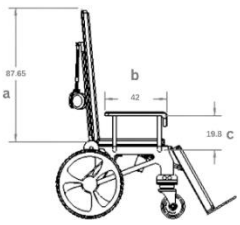
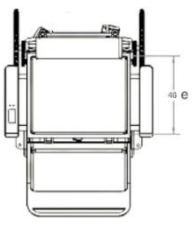
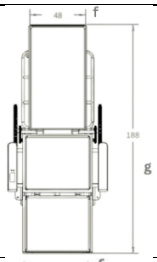
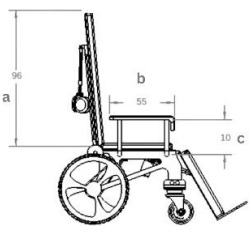
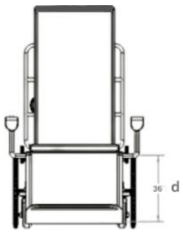
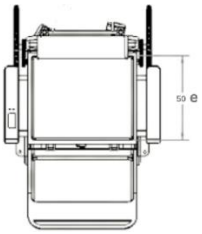
Before				
After				

Table 10 describes a comparison of the size or dimensions of the wheelchair between the previous design and the improved design by applying anthropometric data to the design process.

It is necessary to have several anthropometric measurements that will be used in the wheelchair design process as several aspects required are written in Table 9. This data is known based on the anthropometric measurements of normal Indonesian people.

Improvement Design

Based on the evaluation that has been carried out, design improvements and additional safety features are provided according to the needs expressed by the users. Table 11 lists some additional 3D designs on the wheelchair bed design based on the evaluation that has been carried out.

After several evaluations of the design carried out, Figure 6 shows the result of the final wheelchair bed design that can meet the needs of stroke sufferers:

Table 11. Proposed Design Evaluation

No	Solution	Visualization
1	Adding safety in the form of a rebuttal limit at the top end of the wheelchair bed	
2	Changing the wheelchair bed tires with a rougher surface mat	
3	Adding a push handle on the back of the wheelchair	

Figure 6. Wheelchair Bed Improvement Design

Difference Testing

A different test is carried out to increase some of the attributes needed by stroke sufferers. The purpose of this assessment is to determine the level of difference in stroke patients by comparing the old wheelchair design and the proposed wheelchair design. Normality, validity, reliability, and Wilcoxon tests were conducted using closed questionnaires. This questionnaire has the following scale details: (1) Disagree, (2) Agree, (3) Disagree, and (5) Strongly agree.

The normality test shows that the data set is free from invalid sub-samples [28]. Based on the distribution of the questionnaires that have been carried out, the following are the results of the questionnaires given to a sample of 30 existing caregivers/stroke sufferers. From the results of distributing the questionnaire, the Shapiro-Wilk normality test was carried out using tools from SPSS software. It is known that the significant value obtained from all the attribute requirements is worth 0.000, where the value is below (<0.05), so it can be interpreted that the data obtained is not normally distributed. Therefore, the Wilcoxon test is used for different perceptions based on acquired data that are known not to be normally distributed.

The next step is to test the validity of the values used for the next test. It is known that the rtable used as a parameter for this hypothesis is 0.361, taken from a significance rtable of 5% with a total of n, namely 30 data points. Based on Table 12 the correlation values obtained for all attributes, it is known that the r count value of each attribute is greater than the r table value of 0.361, so it can be concluded that all attributes are defined as valid. Then, a reliability test was carried out to determine the level of reliability of several valid questions. According to Imam Ghazali, data can be reliable if Cronbach's alpha value is > 0.7. In the calculation results, it is known that the reliability value obtained is 0.734, which is known to be> 0.7. So, it can be concluded that the data is reliable.

Table 12. Validity Test Result

No	Attribute	Pearson Correlation
1	Multifunction	0.069
2	Ergonomic	0.811
3	Flexible	0.644
4	Safety	0.799
5	Material	0.500

Table 13. Wilcoxon Test Result

No	Attribute	Asympt. Sig (2-tailed)
1	Multifunction	0.000
2	Ergonomic	0.011
3	Flexible	0.599
4	Safety	0.011
5	Material	0.037

Then, the Wilcoxon differential test was carried out to measure the significance of the two groups of paired data, which were old products with improved designs. The Wilcoxon test is used for non-parametric data that is not normally distributed. The critical limit used in this study is 0.05. The Wilcoxon test of difference was used. The critical limit value used in this study is 0.05, using the following hypothesis:

H0: There is no change from the old wheelchair product design to the improved design
H1: There are design changes to old wheelchair products with improvements

Based on the required attributes obtained, the following are the results of the Wilcoxon different test on each required attribute.

The results of Table 13 show that the significance value obtained from the Multifunction, Ergonomic, Safety, and Material attributes is <0.05 and is interpreted based on the hypothesis that H1 is accepted. At the same time, H0 is not sufficient evidence to be accepted. So, with these results, it can be seen that there are differences in the attributes of Multifunction, Ergonomic, Safety, and Material on old wheelchairs with improvements. Whereas the Flexible attribute obtains a significance value of > 0.05, it means that H0 is accepted, while H1 is not sufficient evidence to be accepted. So, with these results, there is no difference in the Flexible attribute of old wheelchairs with improvement.

CONCLUSION

This research led to the design of a wheelchair that fits the needs of stroke sufferers. Based on the results of the Quality Function Deployment method, it was found that the wheelchair needed can be transformed into a bed (multifunction), has a soft/comfortable wheelchair cushion (ergonomic), is flexible, has a safe armrest (safety), and has a frame with substantial weight (material). The results obtained in this study are new regarding the specific needs of stroke sufferers compared to several studies that have been carried out by previous research, there are improving wheelchairs with designs that can adjust the height of the wheelchair frame according to medical needs, wheelchairs using Augmented Reality markers [13] [15]. In addition, the researcher suggested that future researchers could use the design from the study to develop the wheelchair bed design. In addition, further research must include and pay attention to the cost aspects used in research.

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