Design of Therapy Equipment for Osteoarthritis Patients Based on Static Bikes Using QFD and Human Centre Design Method

by Heru Prastawa

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Abstract. The most frequently affected by Osteoarthritis (OA) is the knee joint (genu osteoarthritis). Therapeutic exercises for sufferers of knee OA are divided into 6 (six) programs, including strengthening to increase the strength of muscle contraction. The design to develop is based on the existing tools and input from users so that it is easily accessed widely for OA sufferers or doctors or therapists. The best choices for knee OA therapy are aerobics and strengthening of the thigh muscles by training the quadriceps muscles. There are several methods used to train quadriceps muscles, including straightening the legs when sitting and bending the legs while lying on his stomach. Meanwhile, aerobics training requires technology in the form of a static bicycle. This study was conducted based on the product development process, it has several stages that start with making a mission statement. The stages are: identify customer's needs, establish target specifications, generate product concepts, select product concept(s), test product concept(s), and the last is set the final specifications. This stage of the study resulted in 3 alternative designs and 1 design selective, that have been synthesized from the expectation and desires of the stakeholders and will continue with the design details until the prototype is presented.

1. Introduction

Osteoarthritis (OA) is a degenerative disease in the joints that often occurs in the hands, hips, and knees involving cartilages, joint layers, ligaments, and bones, causing pain and stiffness in the joints [1]. The most frequent part affected by OA in the knee joint (genu osteoarthritis). In this joint, OA classification can be grouped into five levels 0-4, where the knee joint can function properly and there is no pain or can be said to be healthy. Level 4 of experiencing severe osteoarthritis is indicated by extreme pain and discomfort to walk even to move the joints in the knee due to reduced joint space and the cartilage is almost completely gone [2],[3].

As a result of OA for the elderly, especially in the knees, namely the disruption of daily life activities due to limited movement in the capsular pattern of the knee joint, impaired joint stability, and decreased functional knee to walk and as a buffer of body weight. Pain becomes the main symptom in joints that experience OA. Knee pain that is felt by people with OA causes a person to be afraid of making movements so that it reduces the quality of life [4].

Therapeutic exercises for sufferers of knee OA are divided into 6 (six) programs, including strengthening to increase the strength of muscle contraction (lifting), aerobics to increase cardiorespiratory endurance (swimming, running), flexibility exercises to increase range of motion and flexibility of joint muscles (stretching hamstring), neuromotor training to improve balance and

coordination (rocking board, walking on foam), mind-body training by integrating awareness/relaxation into physical movements (tai chi, yoga), and mixed exercises (more than one type of exercises) [5]

The best choices for knee OA therapy are aerobics and strengthening of the thigh muscles by training the quadriceps muscles [5]. Based on the results of an interview with Dr. Hari Peni Julianti, Sp.KFR, M. Kes, it was explained that there were several methods used to train quadriceps muscles, including straightening the legs when sitting and bending the legs while lying on his stomach. Meanwhile, aerobics training requires technology in the form of a static bicycle. Manual training in question is strengthening the thigh muscles by training quadriceps muscles. Straightening your legs when sitting is done by giving a weight of 1 kg of sandbags. Then the sandbag is tied to the ankle then the training is done by doing Flexi (from bottom to top) and extensions (from top to bottom) on the foot.

Currently, the tools used to carry out therapy for patients with OA include En-Tree [6] static bicycles [7], sandbags [7], stairs, parallel bars, and others. Based on the results of interviews, a tool that is often used for therapy of knee OA patients is a static bicycle. The tool can be used by people with OA in both mild and severe severity, the difference is in the need for help from nurses or therapists due to the difficulty of patients moving the feet. However, these tools have expensive prices and limited quantities for therapeutic use. Also, static bicycles do not have safe use so that therapy patients can fall while using it. Then, during the process of therapy requires help from nurses, while the number of nurses is limited. So, we need a therapeutic tool that can be used without having to use a nurse's help to operate it. Besides, a static bicycle is needed especially for people with OA with a severity of 3 (three) or osteoarthritis to the severity of 4 (four) or severe osteoarthritis. The safe and independent factor is expected to be able to reach and provide wider access to patients to be able to do healing therapy better.

Based on the above problem, the researcher intends to develop a design of a safe static bicycle therapy device, where the tool can be used independently without the help of nurses and pay attention to the safety of use. The design to develop is based on the existing tools and input from users so that it is easily accessed widely by OA sufferers or doctors or therapists

2. Literature Review

2.1. Knee Osteoarthritis and its severity

The knee is the most common part of osteoarthritis to take place in. Symptoms that occur are joint pain in the knee that is felt after activity and disappears after resting. Also, **crepitations** are found that are increasingly apparent with the increasing weight. This symptom is caused by the friction of both surfaces of the joint when the joint is moved [1]. As a result of knee OA for the elderly is the disruption of daily life activities due to limited movement in the capsular pattern of the knee joint, impaired joint stability, and decreased functional knee for walking and as a burden on the body. Knee pain felt by people with OA causes a person to be afraid of making movements so that it reduces the quality of life [2]. The severity of knee OA seen from the radiographic picture is categorized into 5 (five) groups based on the Kellgren-Lawrence criteria which are outlined in table 1 and illustration is shown in figure 1.

Table 1. Classification of radiological features of OA [2].

Degrees	Classification	Radiological Picture
0	Normal	There is no abnormal radiographic impression.
1	Doubtful	The appearance of small osteophytes due to proteolytic damage to the cartilage matrix, not accompanied by pain.
2	Minimal	Look osteophytes, normal joint gaps. The presence of fibrillation and erosion on the surface of the cartilage.
3	Moderate	Osteophytes, narrowing of joint gaps, synovial inflammation
4	Severe	Narrowing of the joint gap and the presence of sclerosis, the drastic decrease in synovial. Extraordinary pain, stiffness in the joints, and people with difficulty moving

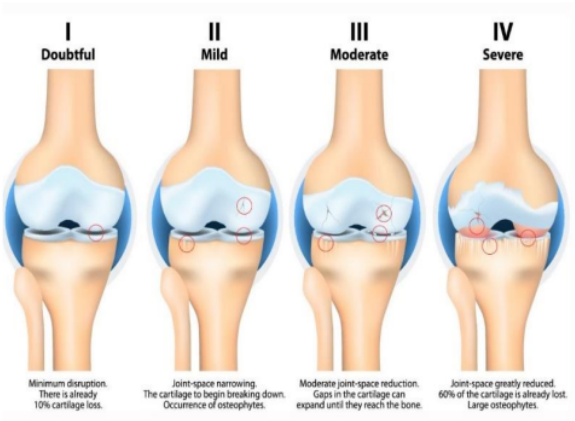


Figure 1 Severity of knee OA.
Source: www.ruperthealth.com

2.2. Product Development Process

This study was conducted based on [8] product development process, it had several stages starting with making a mission statement. The stages were: identify customer's needs, establish target specifications, generate product concepts, select product concept(s), test product concept(s), and the last was set the final specifications.

2.2.1. The House of Quality

The House of Quality is a part of Quality Function Deployment and has a purpose to process the customer's needs through their opinion and statement into specifications and characteristics (engineering requirement) that can be measured and set a target for each of those [9]. Two aspects need to be concerned, they are the dimension of the product and the viewpoint of the needs from the customer's perspective. Based on [10] there are seven steps to build a House of Quality. First of all, is the identification of a customer's needs (Voice of Customer) into a product attribute. Next is to set a priority rating for each of its attributes from the VOC. Then evaluate the existing product using the attribute(s) that have been made. After that, making a relationship matrix that describes the correlation between attributes and technical characteristics of the product. And then identify and analyze both of them based

on the designer's viewpoint about their correlation using four levels of scoring. Next is to identify and analyze the relevant interaction of each technical characteristics to another. And the last is to set the target or goal that can be measured to satisfy the customer's needs.

2.2.2. Identification of customer's needs (Voice of Customer)

Identification was conducted by asking several questions through interviews and questionnaires. Several aspects concerned that had been asked [8] there were desired use of the product, things that customers fond of about the existing product and things that customers did not like about it, and the last was about the opinion from them if they had any idea on how the product could be improved.

2.2.3. Established House of Quality

After the Voice of Customer (VOC) had been done and the attributes of the product had been listed, it was still considered as cannot be used directly to generate the concept. Therefore, the VOC must be defined again to the technical characteristics. Then to build the House of Quality, it needed to identify and analyze the attributes and technical characteristics of the product and look for the importance of each attributes to the customer and the satisfaction of existing products based on each attribute [10].

3. Methodology

3.1. Participants

The participants of this study consisted of two groups and both of them consisted of patients, doctors or nurses, lecturers in public health, and practitioners in elder gymnastics. The first group consisted of 30 people, this group was selected as a participant in identifying customer's needs and in making it to several attributes that related to design a therapeutic aid in reducing pain caused by knee Osteoarthritis. The second group consisted of 5 people, this small group was participated in helping to make House of Quality and Selection Concept(s).

3.2. Procedure

Compiling and circulating open questionnaires given to users/prospective users to get user's statements against static bicycle-based therapeutic tools.

Translating it into User's Needs based on user's statements, for example, after a user's statement could be pedaled by sitting, a static bicycle design requirement could be used in a sitting position. Based on the results of an open questionnaire, a closed questionnaire was created that was used to determine the relative importance and evaluate the competitor's products by giving a percentage weight to each attribute.

Conducting reliability testing for products and competitors by calculating the size of Cronbach's Alpha, as a material to consider whether or not the data can be used for the next calculation process.

The next step was to determine the relative importance of the attributes. The ranking of these attributes could be done by giving a percentage weight to each attribute by using a priority scale or level of importance. Evaluating the attributes of a competitor's product. The performance of a competitor was analyzed by giving a percentage weight to each attribute using a scale of priority or importance. Making a resistance matrix and identifying the relationship between product attributes and technical characteristics. Identifying relevant interactions between technical characteristics and determining the description of targets to be achieved for technical characteristics. The final step was to determine the target that must be achieved for each technical characteristic including, the level of difficulty of making the product, the level of importance, and the estimated cost level of each technical characteristic. For example, to determine the level of difficulty for product composition could be calculated with the steps: Difficulty Product Composition = (Weight of Each Technical Characteristics)/ (Weight of Technical Characteristics) x100%

4. Result and discussion

4.1. Determination of Customer Requirements

After the user's statement was collected, the list of statements was processed into a list of user needs for a static bicycle-based therapeutic device. This translation was done to facilitate designers in developing products so that the results could meet the desires and needs of users that must be owned by a static bicycle-based therapeutic tool. The results of translating user statements to a static bicycle-based therapeutic device contained 17 user requirements that must be owned by a static bicycle-based therapeutic product.

4.2. Data Validity and Reliability

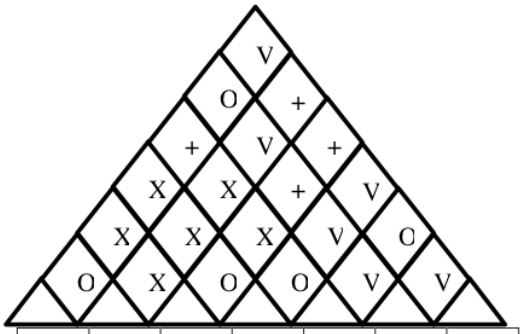
Questionnaires that had been distributed and collected again were first tested for their validity and reliability before processing the data. From the calculation results, it was known that all variables were declared valid and reliable. The reliability test results for products and competitors could be obtained by Cronbach's Alpha for Products of 0.77 and Competitors of 0.79. It could be concluded that the Cronbach's Alpha value obtained for the product and the competitor had passed the reliability test so that the data could be used for the next calculation process.

4.3. Determination of Characteristics

In determining the characteristics that had the aim to determine the desires and needs of consumers for products based on static bicycle therapy tools used the QFD (Quality Function Deployment) method. Consumer desires obtained from closed questionnaires in the form of attributes for work chairs will be adjusted to the characteristics of the technique. This was done using the House of Quality.

4.4. Designing with QFD

The design of the QFD was carried out to determine the level of difficulty, degree of importance, and estimated costs of the product characteristics seen from the House of Quality (HOQ). Difficulty Level; Level 2 was obtained for the time of painting and the quality of the machine where it was not too difficult to process and provide in the design. Degrees of Interest; A value of 19% is obtained for the type of material, where the type of material was important in the design as a consideration in making the design. Estimated Cost; the value was 11% on the time of painting and the quality of the machine, which is quite moderate/quite expensive because it was used to support the attractiveness of the product being designed. The House of Quality was a combination of all technical characteristics, attributes desired by users, product position and competitors against the same attributes depicted in Figure 2.



Degree of Relationship

X = Strong positive Relationship = 4
O = Medium positive Relationship = 3
V = Medium negative Relationship = 2
+ = Strong Negative Relationship = 1

Customer Requirement		Relative Importance	Product composition	Material Type	Material Strength	Tool Weight	Life of use	Duration of Painting	Machine Quality	Existing Product User Perception
Design	The sitting position is used	5	+	x	o	+	v	+	o	4
	Triangular frame shape	4	o	x	x	o	x	+	v	4
	Rectangular pedal shape	4	+	x	o	o	v	+	o	5
	Load weight according to practitioner/doctor's recommendation	5	v	x	x	o	x	+	x	3
	Black colour	3	x	v	+	+	v	x	x	4
Function	The main function of therapeutic devices	5	+	x	x	x	x	+	o	4
Material	Iron frame	4	x	x	x	x	x	o	x	4
	Plastic pedal	4	o	x	x	x	x	+	v	4
	Rubber frame leg linings	4	v	x	x	x	x	+	+	4
	Rubber pedal adhesive	5	x	x	x	o	o	+	v	4
Degree of difficulty			3	3	3	3	3	2	2	
Degrees of Interest			13%	19%	17%	15%	16%	6%	14%	
Cost estimation			16%	16%	16%	16%	16%	11%	11%	

Degree of difficulty
1 = Easy = 0-5%
2 = Easy enough = 6-11%
3 = Difficult = 12-17%
4 = Very Difficult = 18-

Cost estimation
0 –10 = Cheap
11–20 = Medium
21–30 = Expensive

Degree of interest
0 – 10 = Less Important
11 – 20 = Important
21 – 30 = Very Important

Figure 2. The house of quality.

4.5. *Alternative Design*

This stage aimed to gather alternatives that could be used to solve problems in the design of static bicycle pedal therapy equipment products using the Morphological Chart is showed in table 2

Table 2. Morphological chart.

Function	How to realize Functions		
	1	2	3
Position of Use	Sit	Lie down	Stand
Frame Shape	Triangle	Rounded	Box
Pedal Shape	Rectangle	Box	Hexagon
Weight Load	recommended by practitioners/doctors	1/2 load of ordinary static bicycle	Same with an ordinary static bicycle
Colour	Black	Gray	White
The main function	Therapeutic	Sports	Play
Frame Material	Iron	Aluminium	Plastic
Pedal material	Plastic	Rubber	Aluminium
Frame Leg Upholstery	Rubber	Plastic	Fabric
Pedal Adhesive	Rubber	Plastic	Fabric
	Alternative I	Alternative II	Alternative III

The Morphological Chart of static bicycle pedal therapy equipment products was displayed in the form of a matrix of 10 x 3. 10 was a function that must be achieved and 3 was an alternative that might be applied. The combination formula used was:

$$_{10}C_3 = \frac{10!}{3!(10-3)!} = \frac{10!}{3!7!} = 120$$

From the combination calculation results, the total number was very large, then a solution was found to reduce the total number to be more organized, namely the consideration of the interview results by sorting the answers of the most respondents and getting the 3 alternatives.

4.6. *Concept Selection*

The three alternative concepts will be selected using the objective weighted method and making concept 1 as a reference so that the selection criteria obtained from user needs and product attributes are made simpler [8]. Concept selection is done by distributing online questionnaires containing information related to descriptions, illustrations, how to use the product, and some questions regarding the selection of concepts that have been made.

Figure 3. Alternative concept.

Respondents at this stage consisted of 7 experts who had backgrounds as practitioners of elderly gymnastic instructors and or academics who were experts in the field of ergonomics. In conducting concept selection there are 5 assessments where 1 (one) is very bad compared to the reference of up to 5 (five) for very better than the reference shown in Table 4. Concept 1 is a reference so that each criterion is given a value of 3 (the same as a reference) but the team considered that there were 1 criterion which were not appropriate so according to Ulrich and Eppinger, concept 2 was used as a reference for this case and concept 1 would be given a value 2 [8]. Based on the calculation results, concept 3 had the highest final value of 354 so concept 3 selected as the final design of a static bicycle-based therapeutic apparatus.

Table 3. Concept selection.

Selection Criteria	Weight	Concept					
		1 Reference		2		3	
		Value	Value Weight	Value	Value Weight	Value	Value Weight
Functional	25						
Lightweight therapeutic apparatus	12	3	36	3	36	4	48
Suitable for various positions	13	3	39	5	65	3	39
Comfort	20						
Tied to the ends of both sides	10	3	30	4	40	4	40
Pedal comfort in pedaling	10	3	30	4	40	5	50
Flexibility of use	15						
Used at different locations	5	3	15	1	5	4	20
Can change the weight of the load	5	3	15	4	20	5	25
Height can be adjusted	5	2	10	3	15	2	10
Ease of use	20						
Easy to clean	6	3	18	3	18	4	24
Ease of storage when not in use	5	3	15	2	10	3	15
Ease to adjust height/paddle load	9	3	27	4	36	3	27
Ease of manufacture (manufacturing process)	20						
Low cost of raw materials	8	3	24	3	24	4	32
Low component complexity	6	3	18	2	12	1	6
The number of assembly stages is small	6	3	18	3	18	3	18
Total value		**295**		**339**		**354**	
Ranking		**3**		**2**		**1**	
Continue?		**No**		**No**		**Develop**	

Figure 2 shows concept 3 that combines a simple design, strong, and safe material used so that the therapeutic apparatus is designed not to be damaged easily. Therapeutic devices are made to

reduce the magnitude of the dimensions of the product that fills the room by eliminating the seat on a static bicycle so that the product is designed as a pedal without a seat. Also, the therapeutic apparatus is designed to be used simply and flexibly so that it can be used in various seats with the same function as a static bicycle.

The design has a size of p x l x t of 39 cm x 35 cm x 28 cm based on anthropometric considerations. Besides, a hole is given in the oval-shaped tool leg with a size of 2.5 cm with a radius of 1.5 cm. The tool is given a hole in the leg to prevent the tool from sliding when in use so that it can tie a rope that will be connected to the seat used. Pedals are also equipped with adhesive so that the foot is more comfortable during the paddle process made of fabric. The tool has two functions, namely therapeutic tools and sports equipment. So, the load on the paddle weights an ordinary static bicycle by using a magnetic load that does not cause noise. Pedal load level adjustment can be done by turning the knob on the tool leg. A monitor on the body of the device that can show the number of turns, time, and calories is added to provide information as well as the round body shape of the tool is designed to add aesthetics.

5. Conclusion

The conclusion from the results of QFD processing obtained 10 attributes of the product design of a static bicycle pedal therapy device. The level of difficulty of the product has a type of technical characteristics that are not too difficult at the time of painting and the quality of the machine with the highest degree of importance is the type of material with a value of 19%. This can be the researchers' priority as a reference to improve the design of a static bicycle pedal therapy device. Then from the QFD results obtained 3 alternative designs for static bicycle pedal therapy products using the Morphological Chart under the wishes and needs of users.

Acknowledgment

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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11