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Antropometric Based Optimization Of Wheelchair Design For Enhanced User Ergonomics

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ABSTRACT

Background: Wheelchairs are vital mobility aids for many individuals,especially the elderly. However, wheelchair designs that do not meet the ergonomic needs of users can cause discomfort and health problems.This study aims to identify the ergonomic needs of elderly wheelchair users, analyze the suitability of existing wheelchair designs on the market and develop ergonomic design recommendations using an anthropometric approach.
Method: This research uses anthropometric methods and the data is analyzed using data normality test, data uniformity test, data sufficiency test and percentile calculation to determine optimal design criteria. The analysis shows that there is a gap between the existing design of the wheelchair and the ergonomic needs of the user.
Results: Data analysis showed significant variations in anthropometric dimensions among users. Based on these results, several design modifications were proposed, including adjustments to the seat width, backrest height, and footrest position. The designed prototype showed improvements in pressure distribution and sitting posture compared to the standard design.
Conclusion: Based on anthropometric data, wheelchair design adjustments are produced. The application of the anthropometric approach in wheelchair design adjustments succeeded in producing design criteria that are more in line with the ergonomic needs of elderly users.

1. Introduction

Wheelchairs are very important mobility aids for individuals with physical limitations (1). However, wheelchair designs on the market often do not fully meet the ergonomic needs of users. The mismatch between the wheelchair design and the user's body dimensions can cause discomfort, injury, and other health problems. Anthropometry, which is a branch of science that studies the dimensions of the human body, plays a key role in designing ergonomic products. "By considering variations in user body size, wheelchair designs can be customized to provide maximum comfort and safety" (2) (3). However, unfortunately, many current wheelchair designs still fail to accommodate user diversity, especially in developing countries where specific anthropometric data is often limited (4).

A major problem that often occurs in wheelchair design is the mismatch between the wheelchair dimensions and the user's body dimensions. This can lead to unergonomic postures, pressure on certain body parts, and an increased risk of musculoskeletal injuries. In addition, discomfort can also reduce the mobility and productivity of wheelchair users (5). Previous studies have shown that non-ergonomic wheelchairs can cause health problems such as back pain, skin pressure, and impaired blood circulation. In addition, poor design can also limit the user's mobility and increase the risk of injury from falls or rollovers (6). Therefore, efforts need to be made to improve wheelchair design by considering ergonomic and anthropometric factors.

Therefore, adjusting wheelchair design to the needs of users ergonomically through an anthropometric approach is very important. By considering the user's body dimensions, wheelchair design can be optimized to provide comfort, reduce the risk of injury, and increase user mobility and productivity. This study aims to analyze the ergonomic needs of wheelchair users using an anthropometric approach. The results of this study are expected to provide recommendations for wheelchair designs that are more ergonomic and in accordance with the specific needs of users, so as to improve the quality of life and welfare of wheelchair users (7).

History of Wheelchair Development

The concept of a wheelchair dates back to the 6th century BCE, with the discovery of wheeled chair artifacts in ancient China. However, the first modern wheelchair was invented in 1655 by a German craftsman named Stephan Farfler to assist the mobility of a nobleman suffering from gout (8). In the beginning, wheelchairs were simple in design and heavy, making them difficult to move or operate independently. Significant developments in wheelchair design occurred in the 19th and 20th centuries, with the advent of folding wheelchairs that were lighter and more portable. One important milestone in the development of wheelchairs was the invention of the folding wheelchair by American mechanical engineer Harry C. Jennings and orthopedist Herbert A. Everest in 1993. This design allowed the wheelchair to be folded and easier to carry, thereby increasing the mobility and independence of the user.

Significant developments in wheelchair design occurred in the 19th and 20th centuries, with the advent of folding wheelchairs that were lighter and more portable. Then, in the 1970s, power wheelchairs were introduced, which allowed users to operate the wheelchair independently without the assistance of others (9). Ergonomics is the study of the interaction between humans and other system elements, such as equipment, work, and the environment, with the aim of adjusting products, systems, and work environments to suit human capabilities and limitations (10). Another definition is put forward by the International Ergonomics Association (IEA), which states that ergonomics is "a scientific discipline that studies human interaction with other elements in a system, as well as a profession that applies theories, principles, data, and methods to design so that the system is adapted to human abilities and limitations" (11). Ergonomics comes from the Greek words "ergon" which means work and "nomos" which means natural law. Ergonomics can be defined as the study of the relationship between humans and their work environment, including equipment, work methods and the work environment itself. The main goal of ergonomics is to create a safe, comfortable, healthy and efficient work environment to improve human productivity and performance.

Ergonomics is an interdisciplinary science that combines various fields of science such as anatomy, physiology, psychology, anthropometry and industrial engineering (12). By applying the principles of ergonomics, product design, work systems and work environments can be adapted to human abilities, limitations and characteristics in order to create optimal interactions between humans and their work environment. In the context of wheelchair design, ergonomics plays an important role in ensuring that the wheelchair fits the needs and characteristics of the user. This includes matching the wheelchair dimensions to the user's body size, comfortable seating position, ease of operation and other factors that can improve the safety, comfort and efficiency of wheelchair use.

The application of ergonomic principles in wheelchair design is essential to ensure user comfort, safety and health. According to "Ergonomic wheelchair design can improve mobility, independence, and social participation for users, andreduce the risk of injury and other health problems." Anthropometry is the study of the dimensions of the human body, including body size, shape, and proportion. This term comes from the word "anthropos" which means human, and "metros" which means size (2). Thus, anthropometry is the study of measuring the dimensions of the human body for various purposes, such as product design, equipment,or work environment.

Anthropometry has an important role in designing ergonomic products, facilities, and work environments. By considering anthropometric data, designs can be adapted to the size, shape, and abilities of the human body. This allows the creation of a product or work environment that is comfortable, safe, and efficient for users. In designing wheelchairs, anthropometric data is used to adjust the dimensions of the wheelchair to fit the user's body size. This includes adjusting the height of the backrest, seat width, leg rest length, and hand position on the drive wheel. By considering anthropometric data, wheelchairs can be designed in such a way as to provide comfort and ease of use for users of various body sizes (1)

2. Method

Place and Time of Research

The research was conducted at Charitas Hospital Km.7 Palembang City. which is located at JL. Colonel H. Berlian No.228, Sukarami, Sukarami District, Palembang City, South Sumatra Province. And the time of this research was carried out in a period of 6 months, starting from February 2024 to July 2024 with preparation to the implementation of research and consultation of research writing through several stages.

Data Collection Technique

In the data collection technique, this research will use a sampling technique method, namely "purposive sampling". This technique was chosen because it allows researchers to select subjects/participants in accordance with predetermined inclusion and exclusion criteria. (Syam, 2011).

The number of samples to be involved in this study was planned, 10 people. The determination of this sample size is based on statistical considerations, or available resources (Syakura, et al., 2021). The data in this study will be collected through several methods, namely:

a. Data Normality Test: The data normality test is carried out to determine whether the anthropometric data collected is normally distributed. This is important to ensure that the data can be used in further statistical analysis. The method used is the Kolmogorov-Smirnov or Shapiro-Wilk test. If the p-value is greater than the significance level ($\alpha = 0.05$), then the data is considered normally distributed.

b. Data Uniformity Test: The data uniformity test aims to ensure that the data collected comes from the same system and that there are no extremes in the data that could affect the results of the analysis. Data uniformity test steps include:
   - Calculate the mean ($\bar{x}$) and standard deviation (σ) of the data.
   - Determine the Upper Control Limit (BKA) and Lower Control Limit (BKB) with the formula:

   $BKA = \bar{x} + 3\sigma$ $BKB = \bar{x} - 3\sigma$

c. Data Sufficiency Test: The data sufficiency test is carried out to ensure that the number of samples taken is representative enough. The formula used is:

$$N' = [(k/s) * \sqrt{(N * \Sigma x^2 - (\Sigma x)^2)} / \Sigma x]^2$$

3. Result and Discussion

Anthropometric Data Collection Results

The anthropometric data collection process was carried out at the Werdha Dharma Bhakti orphanage located at Jl.Kolonel H.Berlian, Sukarami District. Measurements were made on a total of 10 participants with disabilities who use wheelchairs. Participants consisted of 5 men and 5 women with an age range between 60 to 90 years.

Table 1. Respondent Characteristics

No.	Name	Age (year)	Gender	Disability level	Length of Wheelchair Use
1	Acin	80	Female	Foot injury	8 months
2	Leni	68	Female	Post-stroke	1 year
3	Sriyani	86	Female	Post-stroke	2 years
4	Mardi	85	Male	Post-stroke	6 years
5	Yono	65	Male	Foot injury	5 years
6	Bakrie	69	Male	Foot injury	1 year
7	Sahatini	70	Female	Rheumatism	3 years
8	Surya	66	Male	Post-stroke	1 year
9	Jaya	89	Male	Post-stroke	8 years
10	Sulinda	73	Female	Post-stroke	2 years

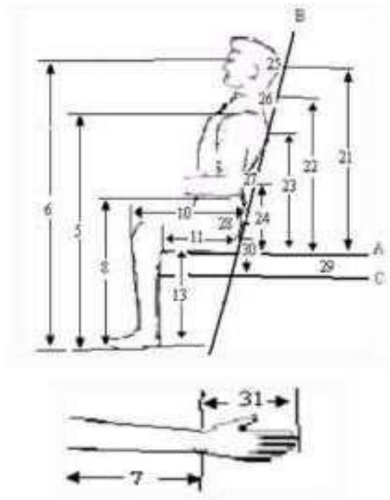

Figure 1. Sitting Body Dimensions

In this measurement, the body dimensions used are
- Sitting Shoulder Height (TBD - No, 23)
- Sitting Elbow Height (TSD - No. 24)
- Waist Circumference (LP - No, 27)
- Popliteal Height (TPO - No, 22)
- Popliteal Buttocks (PP - No, 30)

Anthropometric Data Analysis Data normality test

The data normality test uses a 95% confidence level with $\alpha = 0.05$, with the help of Microsoft Excel software using the Kolmogorov-Smirnov statistical test, provided that if Sig. > α, then H0 is accepted while if Sig <α, then H0 is rejected, then the results of the normality test are shown in Table.

Table 2. Elderly Anthropometry Data Normality Test Results

Normality test	Hip width	Popliteal height	Popliteal buttocks	Seated shoulder height	Elbow sitting height
N	14	14	14	14	14
Sig.	0,2	0.118	0.2	0.118	0.2
α	0.05	0.05	0.05	0.05	0.05

Based on the results of the normality test contained in the table, it can be concluded that the measurement results of hip width (LP), popliteal height (TPO), popliteal buttocks (PP), sitting shoulder height (TBD), sitting elbow height (TSD) show that the Sig value>α.Means that the data has been said to be evenly distributed / normal from a representative population (10 adults).

- Hip width : Sig. (0.2) > α (0.05), then H0 is accepted. Data is normally distributed.
- Popliteal height : Sig. (0.118) > α (0.05), then H0 is accepted. Data is normally distributed.
- Popliteal buttocks : Sig. (0.2) > α (0.05), then H0 is accepted. Data is normally distributed.
- Seated shoulder height: Sig. (0.118) > α (0.05), then H0 is accepted. Data is normally distributed.
- Sitting elbow height: Sig. (0.2) > α (0.05), then H0 is accepted. Data is normally distributed.

Anthropometric data uniformity test

The data uniformity test uses a 95% confidence level with α = 0.05, with the help of Microsoft Excel software, the results of the data uniformity test can be seen in the following table.

Table 3. Elderly Anthropometric Data Uniformity Test Results

Uniformity test	Hip width	Popliteal height	Popliteal buttocks	Seated shoulder height	Elbow sitting height
X	45.96	50.67	34	30.35	55.14
σ	4.14	1.05	3.093773	2.056 597	4.033027
BKA	57.8	48.42	41.15	37.3	66.8
BKB	34.1	46.17	26.8	23.40	43.48

Based on the results of the data uniformity test for hip width (LP), popliteal height (TPO), popliteal butt (PP), sitting shoulder height (TBD), sitting elbow height (TSD), it is known that the value is at BKA (Upper Control Limit) and BKB (Lower Control Limit) with the value X¯ not exceeding BKA or BKB. All anthropometric dimensions have upper control limits (BKA) and lower control limits (BKB) that indicate the acceptable range of data. Data that falls outside the BKA and BKB ranges are considered outliers and need to be reviewed or considered for exclusion from further analysis. Popliteal height had the narrowest control range, indicating relatively little variation in this dimension among participants. Hip width and sitting elbow height had the widest control ranges, indicating greater variation in these dimensions. Data that falls within the control range can be considered uniform and representative for the elderly population studied.

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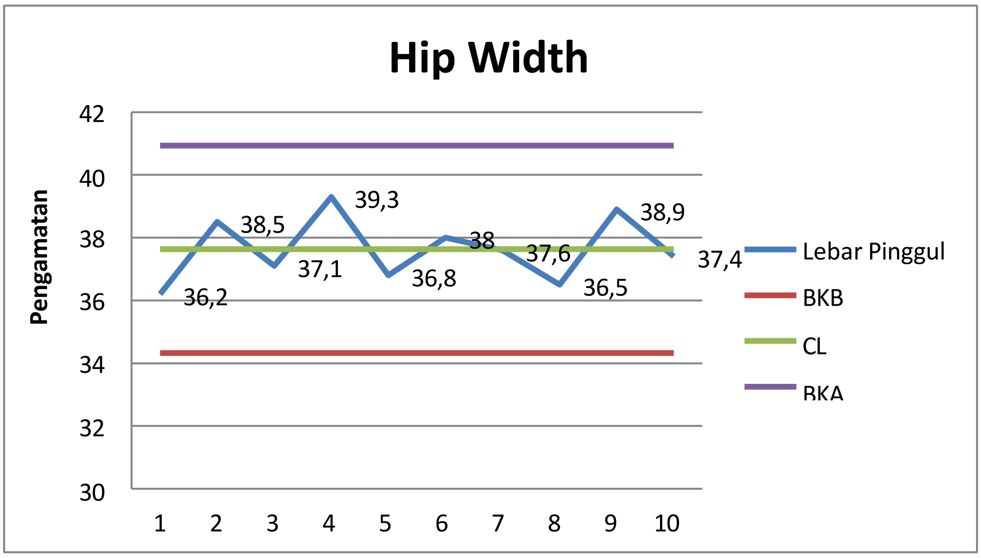

Figure 2. Graph of Data Uniformity Test of Hip Width

Based on the hip width data uniformity test graph, it can be seen that all measurement data are within the control limits, namely between the Lower Control Limit (BKB) of 34.33 cm and the Upper Control Limit (BKA) of 40.93 cm, with the center line or Central Line (CL) at 37.63 cm.

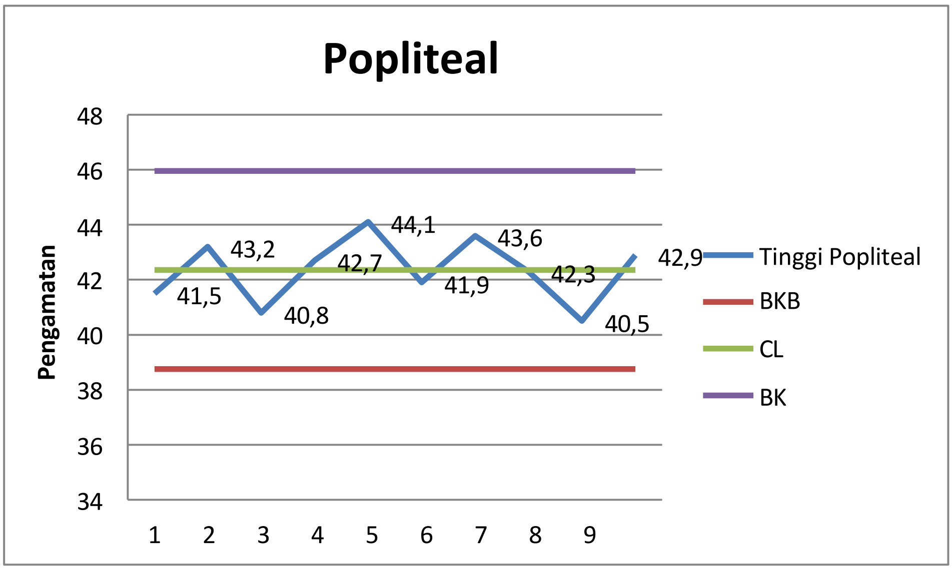

Figure 3. Popliteal Height Data Uniformity Test Chart

Based on the popliteal height data uniformity test graph, it can be observed that all measurement data are within the predetermined control limit range. The data is distributed between the Lower Control Limit (BKB) of 38.75 cm and the Upper Control Limit (BKA) of 45.95 cm, with the Central Line (CL) or average line at 42.35 cm.

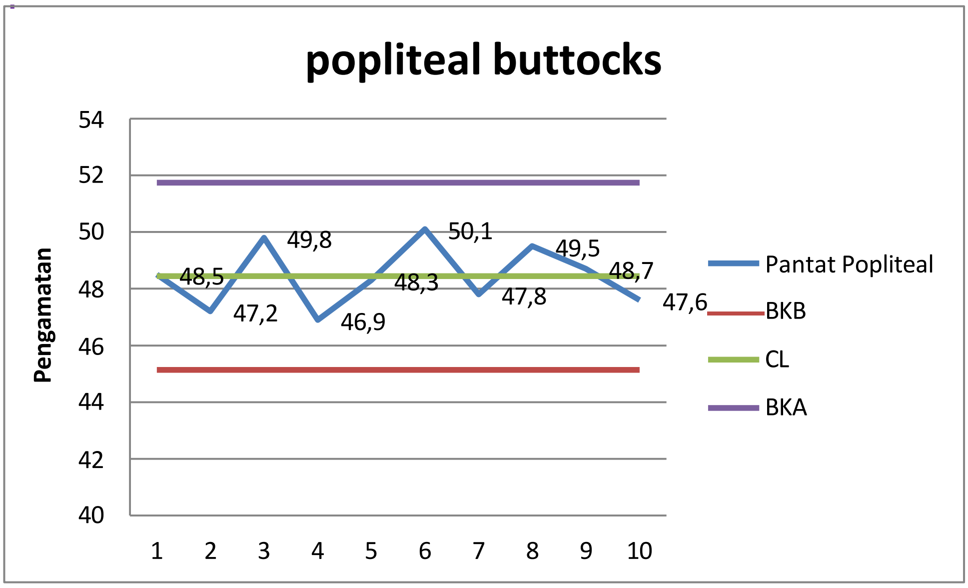

Figure 4. Popliteal Buttocks Data Uniformity Test Chart

Based on the popliteal buttock data uniformity test graph, it shows that all measurement data are within the predetermined control limit range. The data is distributed between the Lower Control Limit (BKB) of 45.14 cm and the Upper Control Limit (BKA) of 51.74 cm, with the Central Line (CL) or average line at 48.44 cm.

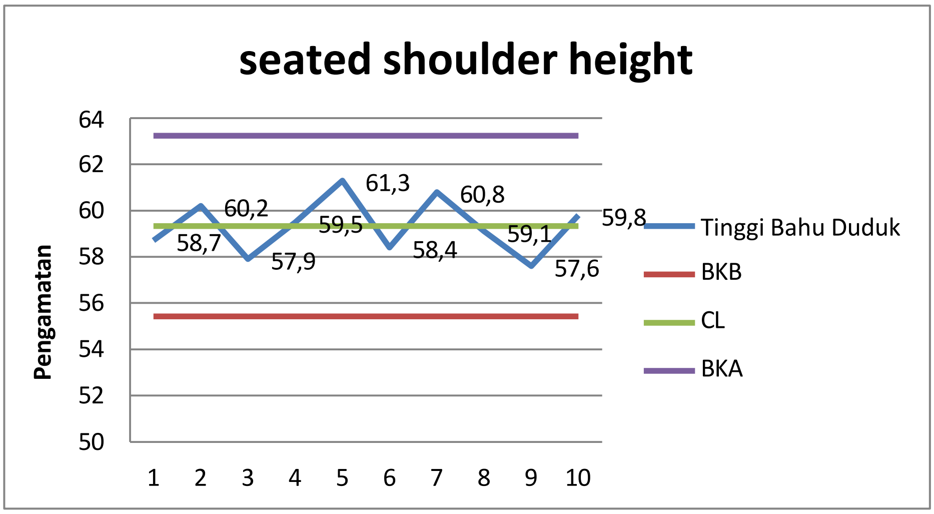

Figure 5. Data Uniformity Test Chart of Sitting Shoulder Height

Based on the sitting shoulder height data uniformity test graph, it shows that all measurement data are within the predetermined control limit range. The data is distributed between the Lower Control Limit (BKB) of 55.43 cm and the Upper Control Limit (BKA) of 62.23 cm, with the Central Line (CL) or average line at 59.33 cm.

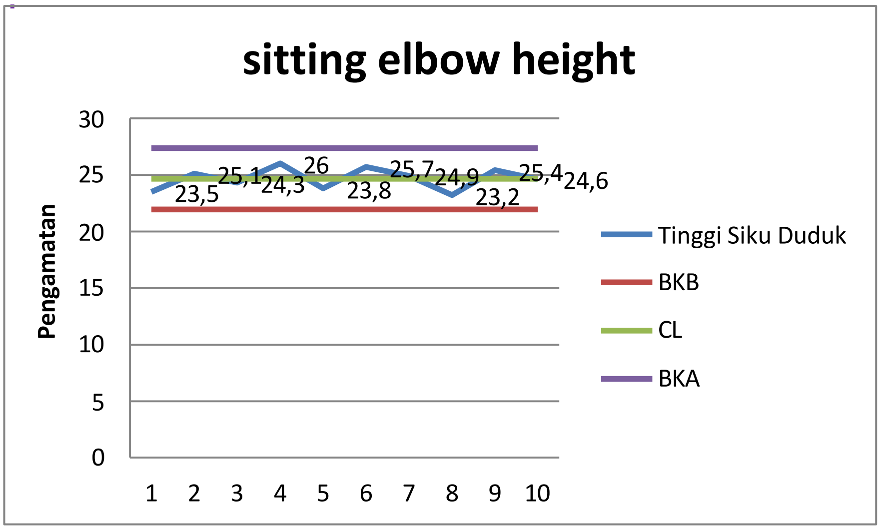

Figure 6. Elbow Height Data Uniformity Test Chart

Based on the sitting elbow height data uniformity test graph, it shows that all measurement data are with in the predetermined control limit range. The data is distributed between the Lower Control Limit (BKB) of 21.29 cm and the Upper Control Limit (BKA) of 27.35 cm, with the Central Line (CL) or average line at 24.65 cm.

Anthropometric data sufficiency test

The anthropometric data sufficiency test is declared sufficient if the value of N'<N. with a confidence level of 95%, and an accuracy level of 5%, the following results are obtained in Table 4.

Table 4. Elderly Anthropometry Data Sufficiency Test Results

Data sufficiency test	Hip width	Popliteal height	Popliteal buttocks	Seated shoulder height	Elbow sitting height
N'	3.6	0,86	3,6	2,7	2,9
N	14	14	14	14	14

Interpretation of results:

- Hip width: N' = 3.6 < N = 14 (Sufficient data)
- Popliteal height: N' = 0.86 < N = 14 (sufficient data)
- Popliteal buttocks: N' = 3.6 < N = 14 (Data sufficient)
- Seated shoulder height: N' = 2.7 < N = 14 (Sufficient data)
- Sitting elbow height: N' = 2.9 < N = 14 (Sufficient data)

Based on the results of the data sufficiency test, it can be concluded that:

For all anthropometric dimensions measured (hip width, popliteal height, popliteal buttocks, sitting shoulder height, and sitting elbow height), the value of N' is smaller than N. This indicates that the number of samples taken (N = 14) is sufficient to represent the elderly population in this study. The data collected can be considered representative and adequate for use in further analysis and determination of ergonomic wheelchair design specifications. Popliteal height had the lowest N' value (0.86), indicating that this dimension had relatively little variability among participants. Popliteal hip and buttock width had the highest N' values (3.6), indicating greater variability in these dimensions compared to the other dimensions. Anthropometric measurements include (list of body dimensions measured, e.g. sitting height, hip width, arm length).

The anthropometric data collected is then statistically processed to obtain percentile values (5th, 50th, and 95th percentiles) which will be used as a reference in determining ergonomic wheelchair design specifications and according to user needs. The calculation of percentile values is carried out to determine the size that suits the majority of elderly wheelchair users. The calculated percentile values are the 5th, 50th, and 95th percentiles with the following calculations.

Table 5. Percentile Value of Elderly Anthropometric Data

Body Dimensions	5th percentile	50th Percentile	95th Percentile
Sitting Height (cm)	48.94	50.67	52.39
Hip Width (cm)	39.15	45.96	52.77
Popliteal buttocks (cm)	28.91	34	39.08
Seated shoulder height (cm)	26.97	30.35	33.72
Elbow sitting height (cm)	48.51	55.14	61.76

Thus, the following implications for ergonomic wheelchair design were concluded.

- Seating Width: Use the 95th percentile (52.77 cm) to accommodate the majority of users. Consider an adjustable design for the comfort of users with smaller hips.
- Seating Height: Use the 5th percentile of popliteal height (48.94 cm) to ensure the user's feet can comfortably touch the floor or footrest.
- Seating Depth: Use the 50th percentile of the popliteal buttock (34.00 cm) as a reference, with adjustment options to accommodate variations in thigh length.
- Backrest Height: Use the 95th percentile of seated shoulder height (33.74 cm) as the minimum to provide adequate support for the majority of users.
- Armrest Height: Use the 50th percentile of sitting elbow height (55.14 cm) as a reference, with possible adjustments to accommodate variations in user elbow height.

Recommended Ergonomic Wheelchair Dimensions

Based on the anthropometric data obtained, the results of the ergonomic wheelchair measurement design for the needs of elderly users are ergonomically obtained.

Before

After

Figure 6. Wheelchair Redesign ergonomic

GEA FS871 Wheelchair is a practical and economical standard wheelchair, made of chrome-plated iron material, and can be folded so that it can be easily put into the car. GEA FS871 wheelchairs are widely used in hospitals, clinics, health centers and for personal use, because they are famous for their strength and durability.

The product fiur used is:

- Made of chrome-plated steel
- A practical and economical wheelchair
- Armrests and comfortable and padded
- Rotatable footrest
- The rear wheel uses solid rubber material
- Maximum load 100 kg
- Wheelchair weight 17.1 kg

Table 6. Size of Ergonomic Wheelchair for the Elderly

Seat section	Recommended Size (cm)	Calculation basis
Seat width	53	95th percentile hip width
Seat height	49	5th percentile popliteal height
Seat length	34	50th percentile popliteal buttocks
Seat back length	40	95th percentile sitting shoulder height
Sitting elbow base height	25	50th percentile sitting elbow height - chair height

4. Conclusion

Based on the results of research and analysis of elderly anthropometric data for ergonomic wheelchair design adjustments, the following conclusions can be drawn:

a. Based on the identification of ergonomic needs of elderly wheelchair users, it was found that aspects of comfort, ease of use and size adjustment are critical factors that need to be considered in wheelchair design.
b. Analysis of the suitability of existing wheelchair designs on the market to the ergonomic needs of users showed gaps, especially in terms of size adjustment and optimal posture support.
c. The application of the anthropometric approach in the adjustment of wheelchairs successfully produces design criteria that are more in accordance with the dimensions of the user's body, including hip width, popliteal height, popliteal buttocks, sitting shoulder height and sitting elbow height.
d. Then, the suggestions that can be given by researchers are:
    - Implementation of the research results: wheelchair manufacturers are advised to adopt the design criteria generated from this research to improve the ergonomics of their products.
    - Further research: it is recommended to conduct further research that covers other aspects such as materials, adjustable mechanisms and additional features to improve the functionality of the wheelchair.

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