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The Development of Functional Pants Design Method For Paralyzed Women Using Anthropometric Data

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Abstract This review summarizes the most rational and practical design method based on the current technology by reviewing nine anthropometric-based designs of functional pants for female wheelchair users from 2017 until 2021. This study uses the horizontal comparison method to analyze the differences between the design paradigms. The design paradigm can be divided into anthropometry, pattern making, and trial-fitting experiment. The review finds that 3D anthropometry and virtual human modeling are the most popular technologies in wheelchair functional pants design. Although the measurement tools and modeling methods are different, capturing human data more quickly and constructing block patterns more accurately is the general trend.

Keywords Functional pants, Design method, Anthropometric data, 3D scanning, Virtual model

Introduction

According to ISO 8559 - 2: 2017, the standard pants design and anthropometrics are based on the standing posture and human body dynamics. The ease allowance guarantees the human body's upright shape, considering the demands of walking, squatting, and sitting. However, the standard design method is not reasonable for wheelchair users, who are primarily in a sitting position (Pojilov-Nesmiyan, Ivanov, and Suprun, 2017). The different design paradigm leads to paraplegic wheelchair users who cannot buy suitable clothes, which is unfavorable to the patient's leg health, hindering blood circulation and causing various diseases such as pressure sores (Cui, 2015).

Tailor shops on the street used to provide tailor-made help for paraplegic wheelchair users. However, the traditional tailor shop has gradually been closed or transformed into advanced customization in the recent 20 years (Docin. Com, 2018). There are fewer places to make clothes, but the number of paraplegic wheelchair users, especially women, has not decreased. Over 15% of people around the globe are living with disabilities, and half are women and girls (WHO & World bank, 2011). In China, twenty-seven thousand female wheelchair users are added to the state statistics every year (Zhao, 2021). This vulnerable group has a right to access suitable, adaptive clothing to help them live with dignity.

With this in mind, this paper reviews the previous diagrams designed for functional pants of female wheelchair users, focusing on the measurement method of sitting body shape data and the design scheme of sitting pants. Based on a broader understanding of the development frontier of functional sitting pants. This research aims to find the best adaptive design diagram for local female paralyzed wheelchair users.

Literature Review Method

A research project was constructed to systematically review the design of functional pants for paralyzed women based on anthropometric results in the apparel technology and innovation industry (see Figure 1). Criteria for the inclusion and exclusion of papers were established according to the purpose of this study. Firstly, the research content of the paper must focus on the design of functional pants. Secondly, the description of the whole paper should include a description of the design process. Finally, specific anthropometric methods should be included in the data collection stage of the paper. The authors selected peer studies published between 2017 and 2021 because they represent the most advanced and commonly used measurement and design methods.

The databases used in the search include ProQuest, SCOPUS, IEEE, Taylor & Francis, Web of Science, and Springer Link. In the early retrieval process, medical and health journals such as Disability and Rehabilitation were considered in the screening. However, a few articles related to the clothing of the disabled and anthropometric methods were not included. In the initial search for relevant research papers, synonyms were repeatedly replaced to ensure that the search was broader.

In the search based on theme and keywords, the expression of ‘paralyzed women’ also uses keywords such as ‘disabled women,’ ‘paraplegic women,’ ‘female wheelchair users’, and ‘sitting women.’

'Functional pants design' is also described as 'adaptive pants design' and 'barrier-free lower garment design.' 'Anthropometry' is also expressed as 'body shape measurement.' Apreliminary search yielded 232 nonrepetitive papers. Based on each journal title and abstract, 195 papers were deleted because they were not related to the design of functional pants. The deleted studies included research focused on exoskeleton design, wheelchair design, furniture design, space design, and wearable devices for the disabled.

Among the 37 papers selected for full-text browsing and screening, 28 did not fully include the content this study was looking for, such as the design process. Apart from paralysis, the paper's target group involves various diseases, such as dialysis and fistula, which have also been deleted in this step. Finally, a total of nine papers were considered.

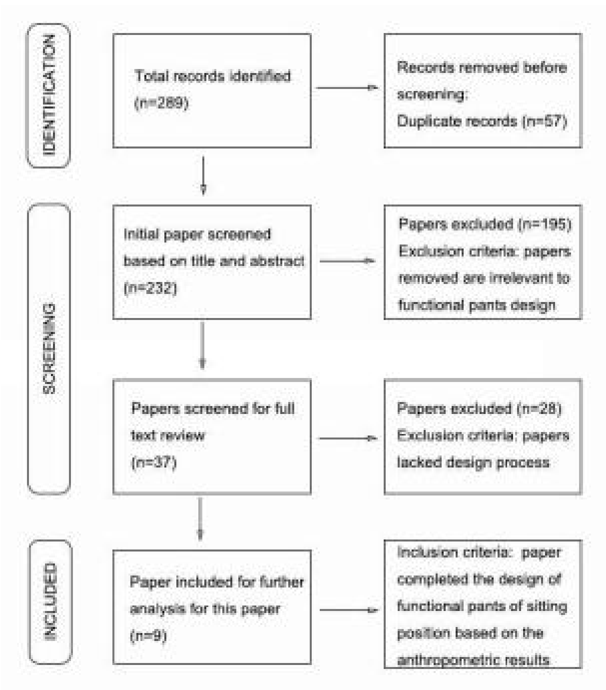

Figure 1. The research progress

Findings and Discussion

Findings and Discussion: Based on the nine articles chosen, the design steps of functional pants can be summarized into three parts: anthropometry and construction of a virtual body model, pattern making, and trial-fitting assessment. Table 1 shows the main themes and concepts covered by the selected papers. Regarding anthropometric methods, 78.8% of the studies used 3D scanning (n=7) and constructed a virtual human body model based on the scanning results. Virtual clothing design was used in four studies to test the design effect more intuitively before making samples. In addition, six of the nine studies used either virtual body fitting or actual body fitting to validate the design. (refer to appendices section for Table 1 Summary of themes and concepts of included papers)

Table 2 shows the demographic characteristics of the subjects involved in the selected articles. All participants were female, with an average age of 36.75 years. As for the geographical distribution of the research, one-third of the research was carried out in Australia (n = 3), two studies were carried out in Slovenia, and the others were from Croatia, Ukraine, Japan, and Mexico.

See Appendice 1: Table 1 Summary of themes and concepts of included papers

See Appendice 2 section for Table 2: Demographic characteristics of included papers

1. Anthropometric methods

1.1 3D scanning and manual measurement

Six articles used 3D scanning technology to collect human body data and construct a virtual human body, improving measurement efficiency. Rudolf et al. (2017) found that the sitting posture of paraplegic patients will not affect the scanning accuracy. The source of error is mainly the influence of breathing at different depths on the dimension of the schedule during the scanning process (Rudolf and Stefanovic, 2017). The laser measurement used in the included papers has controlled the measurement accuracy error within the allowable range $(0.05 < {}_{\circ} < 0.81)$ (Rudolf and Stefanovic, 2017). 3D scanning plays a positive role in providing more body data. However, considering the measurement cost and quantity, manual measurement is still commonly used in recent years.

Manual measurement is usually accompanied by a 1-on-1 interview, providing a more in-depth understanding of a single research sample (Pojilov-Nesmiyan et al., 2017). Two of the included papers used manual anthropometry, which focuses more on the individual differences and needs of the subjects. This method is different from 3D scanning, which aims to obtain more data quickly (Ichikari, Onishi, and Kurata, 2018). During the measurement process, Rizo-Corona etal. (2019) found that the measurement site does not limit the advantage of manual measurement and does not have to be carried out on a specific experimental site. The primary source of error is the clothing the subject is wearing. Clothing that is too loose can lead to a more significant measurement size.

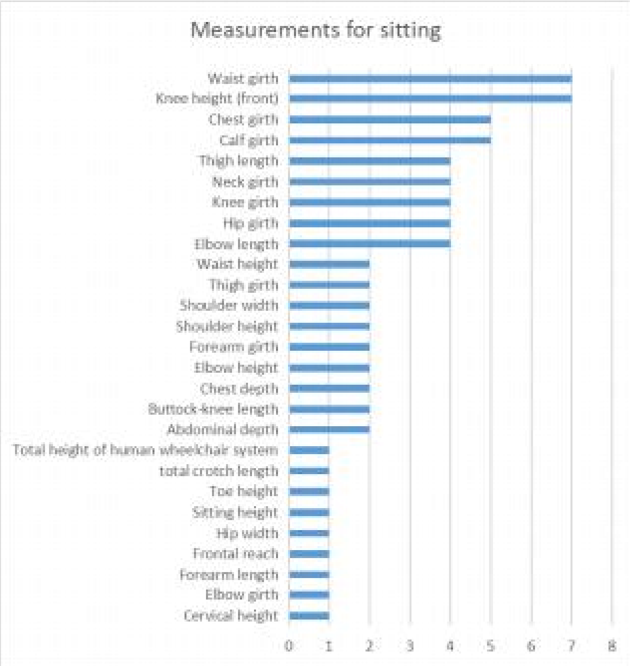

Figure 2. Measurements for sitting posture

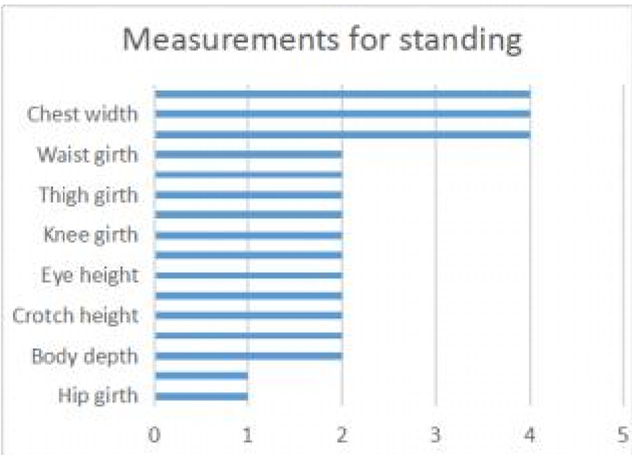

Figure 3. Measurements for standing posture

None of the measurements were statistically analyzed, and there was no region-specific population-type feature, nor was there any further subdivision of different sizes. The anthropometric data in the nine articles were used only for the subsequent design and development of customized functional pants.

1.3 Virtual body models

Seven studies used virtual mannequins for functional clothing design. The specific purposes of the virtual mannequins include displaying measurement methods, pattern making, and virtual garment detection. See Appendice 3: Table 3

In three of the studies, the virtual human model is a derivative of 3D measurement, mainly used to show the measurement site and method more intuitively. Two of the modeling processes used Artec Eva 3D optical hand scanners. The measured part is presented in perspective with the scanning diagram. Another study used Anthroscan 2016 (3.4.0.), where points mark the measured sites. To be more intuitive, the study used a large number of virtual models to show the measurement points from different angles.

In pattern making research, Marija and Slavica (2019) used an intelligent radio scanner to research a virtual manikin in pattern making. Its model generation principle is similar to Petrak and Naglic (2017), which is based on point measurement to generate a scattered grid and then create a manikin by filling in the blank of the grid. Cupar, Rudolf, and Stjepanovi ć (2021) used the kinematic construction method and innovated the approach method. Based on the skeleton structure, this method constructs the standard shape of muscle and skeleton and completes the calculation of the simulated human body in combination with the measured BMI. It can achieve a more accurate expression of delicate parts and corners.

2 Pattern making

The pattern making process discussed in the nine articles mainly includes two methods, real-life and virtual. Pojilov-Nesmiyan, Ivanov, and Supran (2017) focused on the fabric function and wearing experience, so the traditional natural pattern making method was used to complete the production of a sample garment. Other studies used different methods of virtual pattern making.

In virtual pattern making, considering the lifestyle of paraplegic women, Rudolf et al. (2017) introduced the sum of three-segment lengths from waist to thigh, thigh length, and front knee height as the value of pants length. The algorithm is similar to traditional manual pattern making, except that it relies on 3D virtual human body data.

Ichikari, Onishi, and Kurata (2018) developed Graphical User Interface for virtual pattern making. The virtual design and fitting effect can be constructed by importing the anthropometric measurement data into the system and selecting the clothing type desired by the user. The whole system is in the research and development stage. It is moderately friendly to the standard body shape. At present, the accuracy error is about 1.9% to 4.8%. Similarly, there is the pattern making method of Marija and Slavica (2019). The method is based on the rules of M. Müller & Son, and the OptiTex CAD/PDS construction system can directly generate the plane structure drawing after completing the effect drawing design only on the virtual human body to realize the output from 3D to 2D.

Cupar, Rudolf, and Stjepanović (2021) use the same pattern making software as Marija and Slavica (2019). Still, the result of Cupar, Rudolf, and Stjepanović (2021) will be more accurate due to the different methods of virtual human construction in the early stage. The specific method is shown in Figure 4; the construction of the virtual human model is based on skeleton, muscle, and skin. Therefore, in the pattern making progress, only the reverse weighting algorithm for the virtual model skin needs to be completed to obtain the block pattern of the tights. See Figure 4 at Appendices section.

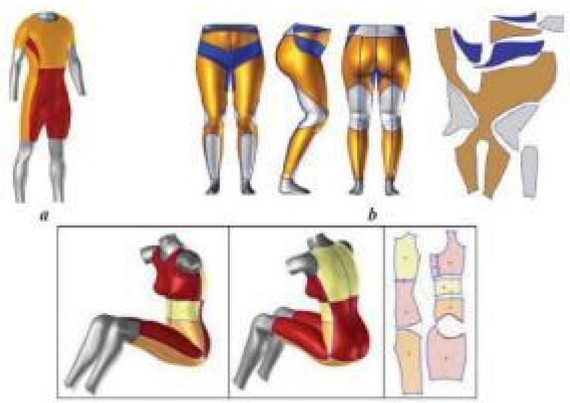

Figure 4. 3D virtual pattern making based on kinematic human models

3 Trial-fitting assessment

The trial-fitting assessment in the nine articles mainly includes the structural test of the pants silhouette and the experience test of the material properties. The silhouette assessment is based on various software for quantitative analysis, while the wearing demand testis constructed by the method of interview for investigation.

3.1 Silhouette assessment

The trial-fitting assessment can be divided into simulation fitting and real-person fitting. Four studies involve using a 3D virtual body for fitting detection. The primary purpose is to test whether the pants' structural design and relaxation are reasonable to optimize the design scheme before production.

Unlike the other three items using the observation method to judge the ease allowance of virtual fitting, Rudolf, Stjepanović, and Cupar (2021) used blender 3D software to show the loose amount in the form of surface tension. As shown in Figure 5, X andY represent the magnitude of the tension in the horizontal and vertical directions, respectively, and the color distinguishes the strength of the tension. The red area has the most significant pulling force, the yellow and green areas have a little better, and the blue area has the most negligible pulling force. Areas with high tension indicate that ease allowance needs to be added to improve the pattern design.

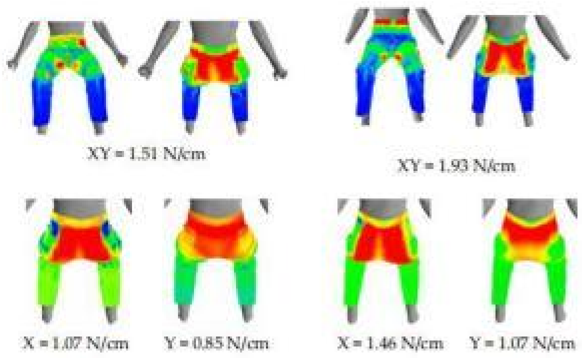

Figure 5. Virtual prototypes without ease allowances and tension in trouser fabric

3.2 Material properties assessment

Pojilov-Nesmiyan, Ivanov, and Supran (2017) tested wheelchair users'demand for functional pants in terms of fabric through interviews and questionnaires after trial-fitting. The test item contained 15 properties: air permeability, water absorption, dustproof, antistatic, tensile strength, and friction-breaking strength. As shown in Figure 6, air permeability, dustproof, and no irritation to the skin were ranked in the top three, accounting for 19%, 17%, and 15%, respectively.

In addition, at the end of the interview, most respondents also expressed the hope that the designer would pay attention to the performance and comfort of the functional pants, which could provide a clear direction for the design and management of the wheelchair in the future.

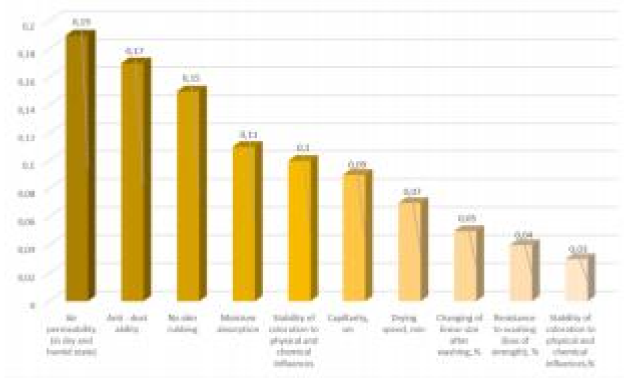

Figure 6. Statistical bar chart of fabric performance demand

Conclusion

The design method of functional pants for wheelchair users can be summarized based on the review of 9 selected papers. The design of functional pants for paralyzed female wheelchair users has strong customization characteristics. It is necessary to repeatedly test and adjust the design diagram, which can be divided into roughly six steps, including demand investigation, pants design, pattern making, assembly and construction, quality control, and comprehensive evaluation. In anthropometry and design, the most advanced technology is 3D kinematic virtual modeling, which has the characteristics of accuracy and can quickly capture human anthropometric data. In pattern making, the reverse weighting algorithm of virtual human skin can complete the structural transformation from 3D to 2D. It is the most intuitive and convenient method to generate a pants prototype.

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Appendices

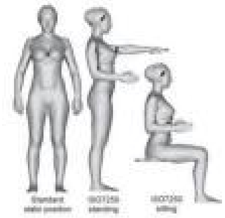
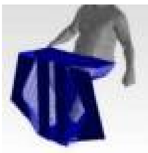
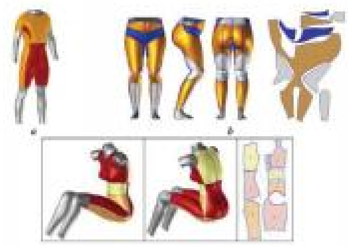
Year	Author	Themes and concepts from the paper								
		Reuirements survey	Special material	Trial-fitting	Antropometric	Virtual 3D scanning	Kinematic 3D models	Pattern making	Virtual garment design	Surface dimensions
2017	Petrak,S., Naglic, M.M.				×	×	×			×
2017	Rudolf. A., Stjepanovic, Z	×	×	×	×	×			×	
2017	Pojilov-Nesmiyan, G., Ivanov, I., & Suprun, N	×	×	×	×					
2017	Rudolf, A., et al.,			×	×	×				
2018	Ichikari, R., Onishi, M., & Kurata, T.		×	×	×	×				
2019	Rizo-Corona, L., et al.				×					
2019	Marija, N., & Slavica, B.			×	×	×		×	×	
2021	Cupar, A., Rudolf, A., & Stjepanović, Z.,			×	×	×	×	×	×	
2021	Rudolf, A., Stjepanovič, Z., & Cupar, A				×	×	×		×	×

Appendice 1: Table 1 Summary of themes and concepts of included papers

Table 2 shows the demographic characteristics of the subjects involved in the selected articles. All participants were female, with an average age of 36.75 years. As for the geographical distribution of the research, one-third of the research was carried out in Australia (n = 3), two studies were carried out in Slovenia, and the others were from Croatia, Ukraine, Japan, and Mexico.

Demographic characteristics				
Reference	Sample size	Gender	Age	Nationality
Petrak,S., Naglic, M.M. （2017）	80	F	26.5	Croatia
Rudolf. A., Stjepanovic, Z （2017）	20	F	51.5	Slovenia
Pojilov-Nesmiyan, G., Ivanov, I., & Suprun, N （2017）	—	F	—	Ukranie
Rudolf, A., et al., （2017）	6	F	38.5	Australia
Ichikari, R., Onishi, M., & Kurata, T. （2018）	—	F	—	Japan
Rizo-Corona, L., et al. （2019）	14	F	34.5	Mexico
Marija, N., & Slavica, B. （2019）	—	F	27	Slovenia
Cupar, A.,Rudolf, A., & Stjepanović, Z., （2021）	—	F	—	Australia
Rudolf, A., Stjepanovič, Z., & Cupar, A （2021）	22	F	22	Australia

Appendice 2: Table 2. Demographic characteristics of included papers

Designers	Virtual body models	Tools	Usages
Slavenka Petrak, Maja Mahnic Naglic		Anthroscan 2016 (3.4.0.)	The simulant shows the measuring method according to ISO 20685:2010, the international standard of measurement, marking the position
Andreja Rudolf, Zoran Stjepanovič		Artec Eva 3D optical hand scanner	Try on the design effect to detect the stress of the fabric on the body surface
A. Rudolf, J. Repnik, I. Drstvenšek, L. Görlichová, A. Salobir, J. Kirbiš, I. Selimović		Artec Eva 3D optical hand scanner	The purpose of using the virtual model is to display the measurement site and simulate fitting accurately
Ryosuke Ichikari, Masaki Onishi, Takeshi Kurata		Adjusted Dhaiba model	Simulated fitting experiment
Marija Nakić, Slavica Bogović		Intellifit radio scanner; The Virtual Dressing Room	In addition to displaying the measured parts, the virtual human body can also be used for pattern making based on existing technology
Andreja Cupar, Andreja Rudolf, and Zoran Stjepanović		Autodesk Maya 2012; Maya software plug-in MuscleCreator	The inverse weighting calculation method of creating human skin from 3D modeling can obtain the block pattern of tights in a simulated human body
Andreja Rudolf, Zoran Stjepanović, and Andrej Cupar		Atos V6.0.2-6 software; Blender 3D	Creating the simulated human body model aims to improve the 3D measurement method, the weighted analysis of bone, muscle, and BMI, and the calculation accuracy of small parts in the scanning process

Appendice 3: Table 3. Virtual body models and usages