Ergonomics Design Procedure for Female Urination Device in Computer System

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***Abstract*—The purpose of this paper is to establish ergonomics design procedure and method for FUD, supporting the whole design process and guidance based on the relationship between FUD and anthropometry dimensions. The ergonomics design process of FUD includes: the definition of design features, the definition of body dimensions, design, and evaluation. Computer- Aid Design (CAD) system of FUD ergonomics design includes four subsystems: 3D scanning system, model reconstruction system, product design system, fluid simulation system. Firstly, perineum was scanned with 3D scanning system; Then 3D model was reconstructed in model reconstruction system, and anthropometric data was measured in CATIA; The urination device computer model was designed in CATIA based on 3D human perineum model and its using function; Urine collector model was imported into fluid simulation system for urine fluid simulation when using; then model was optimized based on simulation results; At last, usability and comfort evaluation was conducted with FUD rapid prototyping model. The CAD system for FUD design can be applied in the usability and comfortable design of FUD. The main contributions of this work are given by a method to identify the required design features to guide the FUD design and manufactures in CAD system according perineum virtual models.**

***Index Terms*—female urination device, computer-aided design system, model reconstruction, perineum virtual models**

I. Introduction

Female urination device (FUD) or female urination aid (collector) is a device which aids a female to urinate while standing upright or confined to bed [1]. It is possible for a woman to aim her urine from the standing position or recumbent posture without assistance. FUDs have increased in popularity since the 1990s, due to the ease of use. The application field of the FUDs includes but not limited to: (1) Medical: Woman who falls ill and confined to bed, who is in a weak bladder or bladder condition, who is wearing a spic a brace or suffering from a spinal fracture, who needs assistance to sit on the toilet, who is using a wheelchair or is chair-bounded, who is giving a urine sample (especially useful for pregnant women), and so on; (2) Travel: The ultimate solution is for traveling, outdoor activities and events, while standing without removing clothes; (3) Aviation and apace: Urine collection equipment for the female aviator or astronaut. FUD is a useful tool, which can provide comfort and convenient use for women to urine in different conditions.

There are a variety of patented FUD products and market products in existence. Patented FUD products have a long history dating back as far as 1922, with the invention of the "Sanitary Protector" by Lacy [2]. A more recent example of a patented FUD product is the "Female Urination Aid Device" [3]. Market products include the P-MATE, the Mid-stream Urine Collection Device, the Uri-Aid Female Urine Collection Aid, the Go Girl, and the She wee Portable Urine Device, and so on. All of these products have different shapes, and all were designed with the curve surface in openings, matched to the physiology structure of the female perineum region. For the design of products contact with human body, like FUD, shoes, helmet shell, the ergonomics design guide is in need. So far, there is no special method used in the ergonomics design of FUD.

Ergonomics has become a popular word in the design of products related to people, with its use to denote quality of design and ease-of-use [4]. Ergonomic design focuses on the compatibility of the objects and the environments with the human using them. The principles of ergonomic design can be applied to everyday objects and work places. Ergonomic design is said to be human-centered design focusing on usability. It seeks to ensure that human restrictions and capabilities are met and supported by design options. In a word, the ergonomic design is the science of making things comfortable and efficient. Comfort is one of the greatest aspects of design effectiveness. Comfort in human-machine interface and mental aspects of product or service is a primary ergonomic design concern. Efficiency is quite simply making something easier to do [5]-[7].

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Anthropometry is considered as the very ergonomic core of many attempt to resolve the dilemma of "fitting the tasks to the human" [8]. As products are designed for specific types of consumers, an important design requirement is selection and efficient utilization of the most appropriate anthropometric database [9], [10], FUD design, like shoes, helmets, clothing and other products, they are the products intimate contact with the human body. Comfort and effectiveness need to be considered in their design, based on the relevant size and surface shape of human body.

With the rapid development of computer technology and advanced design and manufacturing technologies, such as Computer-Aided Design (CAD) [11]-[13], automating the process of manufacturing, the customized and comfort design of shoe lasts [14]-[28], helmet shell [29]-[32], glove [33], [34], apparel [35], [36], spectacle frame [37] becomes possible. The design of these products becomes more convenient and easier with the emergence of CAD system. CAD system mainly includes three parts: three-dimensional measurement, scanning model reconstruction, and virtual three-dimensional model of product design.

In the design processing of FCU, the fitness to people is determined by the structural anthropometric measurements and size of female physiological triangle region. In the tradition design, all the key design features need to be determined and designed based on anthropometric data. But it's difficult to design complex curve surface based on anthropometric measurement size with traditional two-dimension (2D) design method. At the same time, there will be a vast work to do customized product design with traditional method.

Although lots of FUDs have similar function and appearance in use, however, there isn't a proper design process for FUD. FUD contacts with human body directly, so human factors should play an important role in the design process, and the idea of human-centered theory should be incorporated into design. However, the fact is, there is little research incorporates ergonomics into FUD design explained. So it is necessary to develop an ergonomic-based FUD design process.

The objective of this paper was to propose and describe detailed a CAD system to the design of urine collection device, for providing computer-aided design systems for FCU customized and abundance design, set up an ergonomic design process for FUD design and demonstrate the relationship between design and human dimensions. To achieve this purpose, firstly, the ergonomics critical design features of FUD will be determined based on ergonomics analysis of FUD. Secondly, the critical body dimensions will be determined according to the FUD design features. Thirdly, the FUD is designed in the CAD system based on the female perineum structure. Finally, CFD (Computational Fluid Dynamics) simulation and ergonomics evaluation based on rapid prototyping will be done to obtain the feedback information on FUD revise.

II. Method and Tools

A. Ergonomics Design Factors Analysis

The ergonomics design factors of FUD includes the comfort and usability design. The aim of FUD is to aid a female to urinate while standing upright or confined to bed. To achieve these goals, FUD should be able to complete the task of receiving, collecting and discharging urine, and ease to use in comfort.

The usability design of FUD is that the FUD can take away the urine timely, without anti-splash and spill phenomenon when using. And the usability design is relative with the diameter of FUD outlet, the size and shape of middle part, the streamline design of sidewalls, and material of sidewalls, and so on.

The FUD design needs to meet the comfort design with ergonomics design. For ensuring the comfort when using, the shape and size of the inlet portion of the structure should be designed based on the relative size of the perineal. If there is a customized design, the design needs to be based on the shape and size of the individual. If there is mass-produced, the design needs to be designed on the basis of a large number of human dimension databases. And the size of FUD can be classified in to several types.

B. FUD Design Features

The structural design of FUD can be divided into three parts: 1) opening part; 2) middle part and 3) outlet part (Fig. 1a). They are designed to satisfy the function of receiving, collecting and discharging, respectively.

1) Opening part

Opening part is used for the entrance of urine, which is the part to receive the urine. This requires that all urine should enter the opening part without any leakage. For the purpose of this, the urethral opening must be held in the opening part completely while using. Meanwhile, the curve shape of the opening part must match the human body. In order to keep the urethral opening in the opening part completely, the dimension feature of the opening part includes four critical design features: the front part shape of opening, the rear part shape of opening, the opening length, the opening width (Fig. 1b). In the meantime, the opening curve shape is another critical design feature that needs to be considered to match the human body (Fig. 1c).

2) Middle part

After urine enters through the opening part, it will flow through the middle part, which not only leads the flow orientation but also has the function of urine store temporarily. Users need to hold the middle part while using, so the gripping comfort is also important. The middle part also plays an important role in its appearance.

The fact of that the diameter of the opening part is usually bigger than the outlet part may cause a temporary storage of urine in the middle part. In order to store the urine, two critical design features: middle part curve shape and volume need to be taken into consideration. During the flow of urine, it is necessary to limit the anti-splash to the greatest extent. This would reflect the

middle part curve shape in turn. The middle part curve shape also associates with the comfort of gripping and the appearance of the final product.

3) Outlet part

Outlet part is the place of disposing the urine, which receives the urine from the middle part and dispose it out of the FUD.

The velocity of disposing from the outlet part will affect the storage of urine in the middle part, which will in turn, affects the anti-splash of urine in the middle part. The velocity is influenced by the exit diameter of the outlet part. For the purpose of disposing the urine as quickly as possible, orientation of the urine entering and disposing should agree. And this is decided by outlet relative position to the opening. Under different circumstance of applications, the way of disposing the urine differs, which associates with the outlet part export orientation.

After analysis, three critical design features: 1) exit diameter; 2) outlet relative position to opening; 3) export orientation were determined (Fig. 1d).

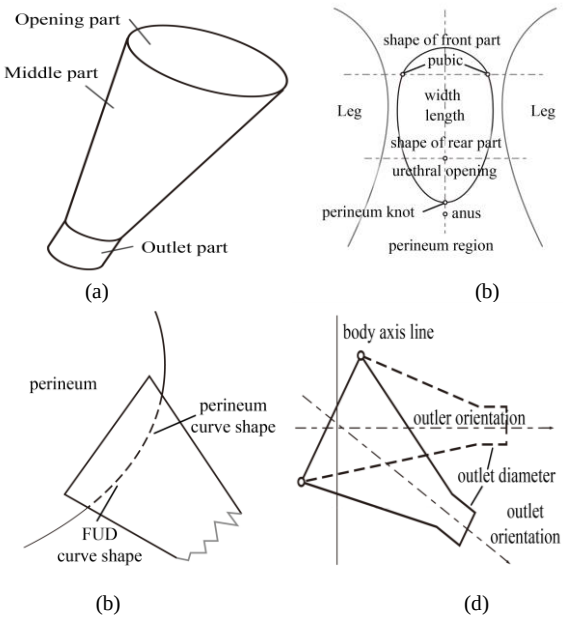

Figure 1. Description illustration of FUD design features.

C. Critical Anthropometry Dimensions

To achieve the goal of comfort and usability design, FUD design should be based on the size and surface shape of female perineum. According to the critical design features mentioned above, analysis was done to acquire the according human dimensions.

1) Opening part

The design of opening part should be based on human body because of the fact that it touches the human body directly. It is essential to analyze human body dimensions. And the shape, width and length of FUD opening should be determined according to the location, shape and size of urethral opening.

The subjective survey elucidate that the front part shape of the opening part is determined by 3D shape of perineum, so the pubic symphysis and pubics are the main dimensions in design. The length and width of the opening part is measured by the distance from exterior urethral opening to anus and the width of perineal furrow, respectively.

2) Middle part

The capacity of the middle part should be larger than the average female urine capacity. The middle portion volume of the collector is determined by two factors, human urine capacity and urinating speed.

In order to prevent the urine from anti-splash, it is necessary to take the orientation of urine entering and leaving into consideration. If the urine hit the interior wall, its flowing speed would be reduced, and chances of anti-splash to skin and leakage would increase. Ideal design is that collector outlet direction is consistent with urine incident direction, and this would avoid urine from hitting the collector interior wall directly.

In the meantime, requirements for collectors vary with application area, so the shape design for middle part should change as well. For example, if user takes a standing position, demand for convenience (handhold) requires the exit direction to move forward, but this would increase the probability of urine anti-splash.

3) Outlet portion

Urine collection would be hard to collect urine if the collector outlet diameter is too large, but urine would not discharge in time if the diameter is too small. In order to connect with other pipes conveniently, the outlet diameter should be set to standard pipe diameter. All of these factors should be considered and evaluated in the design process of collector outlet diameter.

After the analysis on the three design part of the FUD and the relevant human features, it was found that the opening part match the human body the most. Thus, four human critical dimensions: 1) distance from exterior urethral opening to anus, 2) width of perineal furrow, 3) 3D shape of perineum and 4) the angle between urethra and body axis.

D. FUD Design Flow

FUD inlet portion is intimate contact with the user's perineum area when using. So in order to achieve the comfort, the opening part design should be based on relevant perineum dimensions. So first of all in a three-dimensional scanning system, the perineum area would be scanned and reconstructed to obtain models, three-dimensional surface and related dimensions. Then, FUD opening width is designed based on the width of the vagina, curved shape design based on the perineum area surface, and opening length design based on the distance from the anus urethra mouth. The design of FUD middle and the exit part are achieved with overall consideration. They primarily are the use of the crowd, the human urethra direction and location factors.

Based on the above considerations, the FUD preliminary design models are imported into CFD simulation system for fluid simulation, then based on the simulation results, urine flow and feedback are obtained to optimize the design. The FUD design flow is shown in Fig. 2.

For the products related to human anthropometry dimensions, the CAD system is established by three computer systems, human anthropometry measurement system, 3D cloud data processing system, product design system. For FCU design, the fluid simulation part is added for the meeting of availability design, the simulation results can guide the optimization design. The explanation of each software design system is as following.

There are four CAD systems used to aid-design of FUD, 3D scanning system, Perineum model reconstruction system, Product design system, CFD simulation system (Fig. 2).

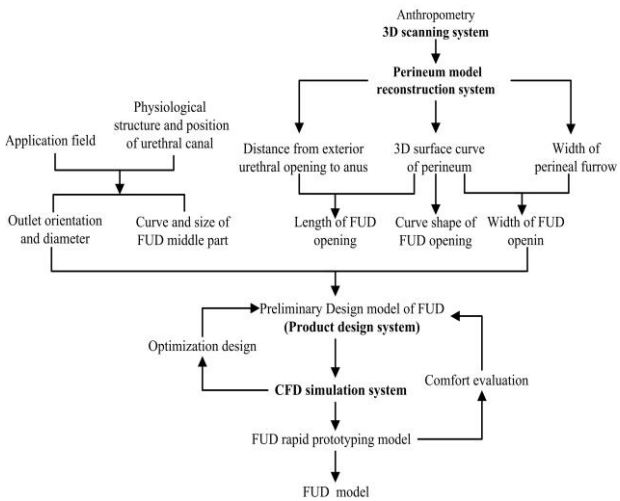

Figure 2. The design flow of FCU with CAD system.

3D scanning system: The dimensions and 3D shape related to the FUD design are need to be scanned and measurement by 3D scanner. Digital database of 3D perineum was established by the related dimension. E.g. Scanner: 3D CaMega (PCP-300, China) three-dimensional optical scanning portable system, measurement precision 0.025, data precision 0.02mm. Scanning technology: Optical grating was projected onto the object surface to be measured. The streak image are captured by the CCD (Charge-coupled Device) and inputted into the computer, and then the surface space coordinates (X, Y, Z) were calculated by phase method and triangulation method based on the shape change in curvature.

Perineum model reconstruction system (Reverse engineering software): The result of the 3D scan was a set of spatial points with their corresponding 3D coordinates named the point cloud. Several steps were employed to model the acquisition process. Firstly, the point cloud was entered into reverse engineering software (e.g. Geomagic, USA), where the point objects were linked to form triangles after sharping the objects and removing the vitro isolated points. The point cloud of the 3D scan was imported into reverse engineering software (Geomagic), obtaining the point-cloud model. Such model was then converted to Nurbs surface, with marking the position of anus, ischial tubersi ties, and symmetry planes. The Nurbs surface of female perineum was directly employed to reconstruct the 3D surface model of perineum.

Product design system: The perineum model was import the model into 3D model design system (e.g. CATIA) to build the surface and model after being reconstructed in the Geomagic Studio. Based on the relevant perineum size and three-dimensional structure model, the FUD model was designed in CATIA.

Fluid simulation system: In order to design FUD which can fully meet its use, let urine timely drain away without anti-splash phenomenon, and reduce design costs, design optimization should be placed in the preliminary design stage. The preliminary FUD model based on body size and functional analysis was imported into fluid simulation software (e.g. Computational Fluid Dynamics, CFD) to carry out the fluid simulation under gravity case. Through the simulation of users, based on the urine situation and anti-splash case simulation results, the optimal design advice for the FUD are provided to give feedback to design section.

III. Results

A. 3D Scanning System for Human Dimensions

Since the fact of there is no human dimensions of perineum in today's anthropometry database, we need to measure the human body first. Direct and 3D measurement methods were both used. Direct method was used to measure the distance from exterior urethral opening to anus and the width of perineal furrow. 3D shape of perineum was scanned by 3D scanning.

To measure the four critical design dimensions mentioned above. The measurement process consisted of four phases: (1) orientation of the study purpose and measurement process; (2) attachment of stickers to the designated landmark locations on the perineum; (3) direct measurement using a Martin-type anthropometry and (4) 3D measurement using a 3D scanner.

In the orientation phase, the purpose and process of face measurement were explained to the subjects. Then, the participants were lying on the measurement chair in a supine position with their legs bent. For convenient measurement on 3D perineum, the stickers need to be marked on the designated locations on the perineum before scanning, including pubic symphysis, pubics, urethral opening, and anus (See Fig. 3). In the direct measurement phase, two critical body dimensions: the width of perineal furrow and the distance from exterior urethral opening to anus were measured. In the end, the 3D shape of perineum was scanned by 3D scanner, to obtain the point cloud data of perineum 3D surface model.

Then, the 3D point cloud data was imported into reverse engineering software Geomagic Studio (Geomagic, USA). Perineum surfaces were created with characteristic points (all mark-points) after the dealing of stitching, noise removal, smoothing. The perineum model was established in reverse engineering software after being dealt.

B. Computer Aided Product Design

FUD are designed in CATIA based on 3D structure and anthropometry of perineum which is obtained

through 3D scanner. Firstly, the reconstructed three-dimensional perineal surface model was imported into CATIA. FUD was designed based on relevant perineal area size and three-dimensional surface model.

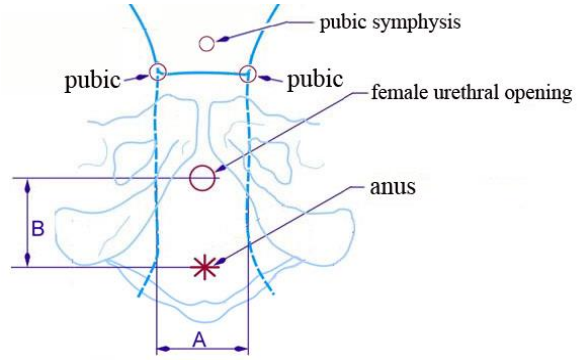

Figure 3. Feature points on perineum

In CATIA environment, the opening shape of FUD was designed based on 3D perineum and land markers. To ensure the opening curve shape satisfying human body, more space points between land markers need to be chosen to establish opening curve shape of FUD, including two points on perineum model between pubic symphysis pubic and pubics, four points between pubics and perineum knot, ensuring all these coordinate points on perineal furrow. Then the 3D model for the three-dimensional coordinates of these points the value of (x, y, z), and exported as a TXT file.

For customized design, FUD opening design is based on the space coordinate of user. For quantity production design, fiftieth percentile value or average value of the space coordinate of these landmarkers from several subjects. The processed data was used to establish space curve of FUD opening (Fig. 4).

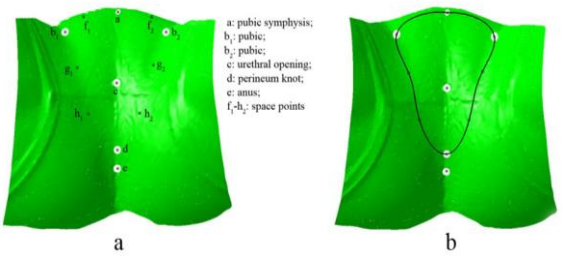

Figure 4. a) Land markers and space points on 3D perineum model; b) Curve design of FUD based land markers.

The FUD opening shape is designed based on human 3D perineum, which not only achieves a great conformability, but also ensures usability of FUD, completely package urethral opening in the collector.

Width of FUD opening: The width of perineal furrow through urethral opening was used as the representation for the width of FUD opening.

Length of FUD opening: The length of the opening are the determined by size from the front end to the tail end. First of all, the length of collector should be longer than the distance between the urethra mouth to the anus, and the tail end should between the urethra mouth to the anus, instead of wrap the anus. Perineal knot is the joint point of the perineal furrow located between the urethra mouth to the anus, and 1cm away from the anus. To achieve the comfortability and fitness, the tail end of the collector is located at the perineal knot, and front end starts from the public symphysis area.

Outlet orientation and diameter: First make sure body axis is fixed, and then based on the perineal three-dimensional model; fix the collector and human body. Then determine the urine direction by the angle of the urethra and the body axis. The angle of urinating incidence into collector is 15-30 degrees between female bladder urethra and body axis. 22.5 degree is taken as the degree between urinating direction and body axis for the FUD outlet orientation design.

Curve fitting: After the opening shape, opening direction and opening diameter has been determined, fit the middle part curve to achieve a smooth and glossy appearance. Meanwhile, calculate the volume of the collector after the fitting the curve surface and make appropriate amendment (Fig. 5).

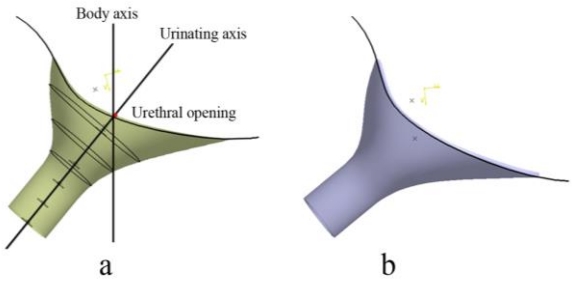

Figure 5. a) 3D curve shape of FUD design; b) substance model design based on curve model.

The ergonomics assessment of FUD includes usability and comfort evaluation. The usability assessment can be obtained by subjective evaluation and fluid simulation, comfort assessment evaluation by subjective evaluation. The fluid simulation and subjective evaluation method in the ergonomics assessment are descripted as following.

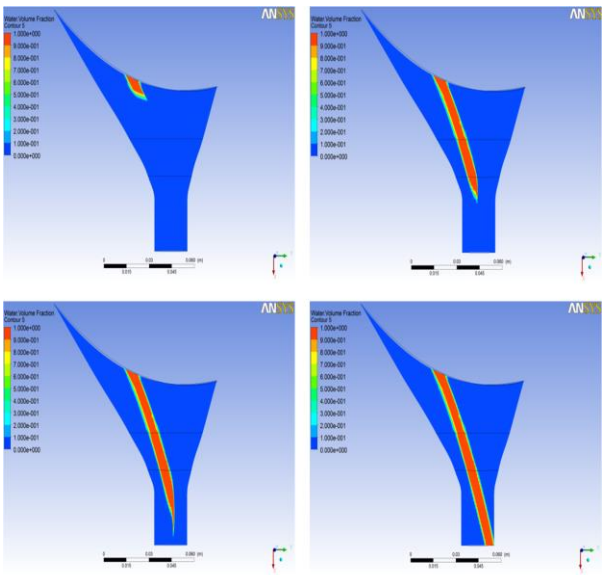

Figure 6. The simulation result of permitting urination using FUD.

C. FUD Ergonomics Evaluation

1) CFD simulation evaluation system

Based on the designed FUD model, urine collection procedure was simulated in fluid simulation software to test the efficiency, effect and safety of the FUD. The three indexes were reflected by the effect of collection, the time of urine collection and the anti-splash and spill of the urine respectively.

Import the 3D model built in CATIA into CFD, set the initial parameters, then simulate the using process. Observe and analyze the simulation results, see if the urine flows smoothly, anti-splash happens or not, side spill or not. Then based on the simulation results, revise the collector pipe-flow and curvature.

The simulation results from Fig. 6 showed that during the usage of the FUD, the urine didn't anti-splash. And the collection of urine completed 0.1s after the urine stopped.

2) FUD subjective evaluation

Subjective assessment was used to obtain the feelings of users in the comfort evaluate of the FUD. Feedbacks from users were also collected for revise of the product. The evaluation was divided into two parts: 1) static evaluation and 2) dynamic evaluation. The index for the static evaluation was comfort and the indexes for the dynamic evaluation were efficacy, efficient, comfort, usability and safety.

After model optimization, the urine collector was rapid prototyped to obtain several rapid prototyping models. Then five target users were selected to try the collector. After using the products, each of the five participants was asked to fill a comfort evaluation form of FUD.

Through the assessment on key parts of the collector and collector size design was evaluated, and then testing results are given as feedback to revise the original design.

Feeling evaluation is mainly concerned with comfort evaluation on the collector shape and size, including the overall comfort; whether collector aperture width and opening length is appropriate, whether surface switch is comfort, and other indexes.

Urine collector usability evaluation mainly includes: whether the overall shape, front end size and tail end size is conductive to urine excretion ;whether urine anti-splashes; whether two sides size is a hindrance to the urine; whether the export is a smooth defecation; whether handheld collector is comfort and other indexes.

The final evaluation of each index needs to a note, invite each participants to evaluate indexes, put forward suggestions on design.

IV. Conclusion

This paper proposed an ergonomics design method and procedure with computer-aided design for female urine collector. The contribution contained four points: Firstly, ergonomics design factors of FUD include mainly availability and comfort. Secondly, The female perineum dimensions were determined with the ergonomics design factors, which is relevant with the collector design. Thirdly, the four subsystems used for FUD design in the CAD system: 3D scanning system (for anthropometry), 3D model reconstruction system, product design system, CFD fluid simulation system. Finally, the evaluate method and index of FUD, in the model preliminary design stage, was introduced.

This paper proposed the female urine collector design method based on computer aided design system. This method is not only the first introduction of the design of female urine collector; also integrate computer aided design to the design. The FUD computer aided design can make the design more convenient, also make the collector more comfortable, and better meet their usability in the meantime.

This method can provide guidance for the design of female urine collector. Female urine collector design mainly includes three parts: the opening part, the middle part (side wall surface design), the export part. For the female urine collector applied in different fields, design should base on different intended use, and this can be optimized in CAD system.

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