A SYSTEMATIC APPROACH FOR DEVELOPING MODULAR REHABILITATION PRODUCTS FOR FACILITATING BETTER STRENGTH RECOVERY WITH FOCUS ON STROKE PATIENTS

by

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Abstract

According advanced medical technologies have enabled ruptured brain vessels to be saved by related procedures for stroke patients. However, most patients will suffer various kinds of sequela, such as muscle atrophy, hemiplegia, and facial paralysis, etc. The purpose of this thesis is to create a systematic approach to research, design, innovate and evaluate a modular rehab-equipment on the basis of electronic techniques and mechanical structures for stroke patients. The approach will instruct designer to design modular equipment that recovers the movement of human parts and muscles for stroke rehabilitation. To develop this approach, the first thing that needs to be done is to research and collect information of stroke through books, magazines, and internet, to set up the literature review. The literature review mainly includes understanding about characteristics of stroke patients, rehabilitation exercises movement, the types of synovial joint, skeleton joints principle, current modular process and factors that should be considered in the design parameters and design criteria. Further more to develop the approach based on the literature review. At the end, the elbow and wrist will be two examples, to which this approach is applied to examine whether it is effective. The result of the design approach will provided to hospitals and rehab-equipment sellers, and user feedback will be researched for future designer so that this approach can improved continuously.

Acknowledgments

After a stressful period of two semesters, today is the day: writing this page of thanks is the finishing touch on my thesis. It has been a period of intense learning for me, not only in the design arena, but also on a personal level. Writing this thesis has had a big influence on me. I would like to reflect on the people who have supported and helped me so much throughout my graduate student life.

I would like to thank Professor Tin Man Lau, Professor Jerrod Windham, and Professor Suwen Tseng for guiding and supporting me over the last 3 years. You have set an example of excellence as a researcher, mentor, instructor, and role model. Your discussions, ideas, and feedback have been absolutely invaluable.

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Introduction

1.1 Problem Statement

This study will create an approach that will help designers to develop modular rehabilitation products for stroke patients. This approach will aid in solving movement exercise, joint contracture and skeleton recovery problems for those patients who have suffered stroke. "Stroke is a leading cause of death and disability. Annually, about 16 million first-ever strokes occur in the world, causing a total of 5.7 million deaths "(Neurol 2007). In the US, someone suffers a stroke less than every minute (Heart Disease and Stroke Statistics 2015). The widespread nature of stroke means that the illness ranks second in causes of deaths (Human and economic burden of stroke 2015). Treatment and rehabilitation of stroke is extremely costly to society, with long-term care costing approximately 34.5 billion US dollars per year; this equates to two to four percent annual worldwide healthcare costs (Dombovy 2009). Because of the prevalence of strokes and need for rehabilitation of stroke patients, this thesis puts forward a design approach of wearable rehabilitation equipment on the basis of modularization, electronic technique and mechanical structure, so that we can improve rehabilitation training efficiency, allowing patients timely and effective rehabilitation training, and ease the financial burden of treatment on the family and the society.

Modularized products derived from this approach will help recover the movement of different parts of muscles in the body. These product will be convenient, economic, wearable, and particularly designed for family use, improving efficiency of patient rehabilitation training without increasing the burden of clinical medical workers and minimizing health care costs.

For patients of stroke and cerebrovascular diseases, earlier rehabilitation training can not only maintain joint range of motion and prevent joint contracture, but also significantly improve the final recovery extent of patients' movement. According to traditional rehabilitation, a therapist will conduct one-to-one rehabilitation training with the patient, hand-in-hand. It is hard to secure the training efficiency and strength in this way, and the training effect is subject to the expertise of the therapist. Besides, it is almost impossible to achieve the optimum therapeutic schedule by improving the training parameters due to the lack of objective appraisal data on the correlation between training parameters and rehabilitation effects. On the other side, rehabilitation equipment in the therapeutic center is not frequently available in a timely fashion for patients for the reason that current rehabilitation equipment is too big and hard to integrate into daily life. Therefore, this study will create an approach which utilizes modularization to analyze, develop, and assemble a totally new medical product for stroke.

1.2 Need for Study

Stroke patients not only suffer due to their exercises, procedures and inconvenience activities, but also suffer psychologically from disease. The number of patients affected by this burden is creasing with an estimated 64.5 million stroke survivors who live with different levels of disability and need assistance for activities of daily living.(Roger 2010). Due to the increase in the number of stroke and cerebrovascular disease patients, and thus an increasing need of rehabilitation equipment, a new design approach and products need to be adapted to their users. In this thesis, the approach developed for this project will learn how use and analyze the information of literature review to conduct approach step by step.

This design approach should be investigated from the reason of stroke, the characteristics after stroke, the treatment means of stroke and the rehabilitation way of stroke, because the main purpose of this thesis it to develop a modular rehabilitation equipment design approach. This approach needs according to the different symptom and rehabilitation of stroke patients to establish the therapy direction of rehabilitation equipment, and then carry on research and analysis based on how to develop the usability modular rehabilitation equipment, which will define the design factor of the product in this approach.

1.3 Objective of Study

- The objective of this thesis is utilize books, magazines, internet resources and industrial design knowledge to develop an approach that can instruct designers to design modular rehab-equipment for provide better strength recovery for stroke patients.
- Research characteristics of stroke patients
- Research current treatment theory
- Research how stroke affects people
- Research modularization process of existing industry
- Research how to improve the application of medical product appearance design
- Research how to improve the application of medical product usability design
- Research how to improve the application of medical product interface design

1.4 Definition of Key Terms

ADL – Activities of daily living (Kelly-Hayes M 2003).

Approach – The systematic method used in dealing with or accomplishing a goal.

Ball-and-Socket Joint Movement – The rounded head of one bone (the ball) fits into the concave articulation (the socket) of the adjacent bone (Types of Synovial Joints Mechanical Motion Analysis 2015).

CAD Model – A solid model created by Computer-aided design (CAD Definition).

Condyloid Joint Movement – The shallow depression at the end of one bone articulates with a rounded structure from an adjacent bone or bones (Types of Synovial Joints Mechanical Motion Analysis 2015).

Connection Module – A link component to connect different function modules.

Criteria – A standard, rule, or test on which a judgment or decision is made.

Explored View – An exploded view drawing is a diagram, picture, schematic or technical drawing of an object, that shows the relationship or order of assembly of various parts.

Hinge Joint Movement – The convex end of one bone articulates with the concave end of the adjoining bone. This type of joint allows for only bending and straightening motions along a single axis, and thus, hinge joints are functionally classified as uniaxial joints (Types of Synovial Joints Mechanical Motion Analysis 2015).

Keyshot – A solid model rendering software by simulate different materials, light and scene.

Linear Motion – A motion along a straight line by the type of synovial joint.

Modular Equipment – A equipment that subdivides a system into smaller parts called modules or skids that can be independently created and then used in different systems Are Modular (Medical Devices the Future? 2015).

Modules Base – Classify all modules into different function list.

Pivot Joint Movement – A rounded portion of a bone is enclosed within a ring formed partially by the articulation with another bone and partially by a ligament (Types of Synovial Joints Mechanical Motion Analysis 2015).

Plane Joint Movement – The articulating surfaces of the bones are flat or slightly curved and of approximately the same size, which allows the bones to slide against each other (Types of Synovial Joints Mechanical Motion Analysis 2015).

Power-driven Module – A module component that operated or controlled by mechanical or electrical energy.

Protect Module – A module component designed to protect stroke patient to use the modular rehabilitation equipment.

Prototype – A model suitable for evaluation of design, performance and production potential.

Rehab-Equipment – An equipment designed to treatment and rehabilitation injured limbs by exercise movement.

Saddle Joint Movement – Both of the articulating surfaces for the bones have a saddle shape, which is concave in one direction and convex in the other (Types of Synovial Joints Mechanical Motion Analysis 2015).

SolidWorks – A solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) computer program that runs on Microsoft Windows. SolidWorks is published by Dassault Systèmes (SolidWorks Definition 2015).

Synovial Joint – Joins bones with a fibrous joint capsule that is continuous with the periosteum of the joined bones, constitutes the outer boundary of a synovial cavity, and surrounds the bones' articulating surfaces (Types of Synovial Joints Mechanical Motion Analysis 2015).

The Physio Therapy eXercises – A website is primarily for the use of physiotherapists responsible for prescribing exercises. It may also be of interest to other health professionals including occupational therapists as well as people with injuries and disabilities (The Physio Therapy eXercises 2015).

Using Process – A process demonstrating how to use the equipment.

1.5 Assumptions of Study

Most information and resources utilized in this study comes from the Internet, magazines and books, and therefore all the information is authentic but somewhat subjective. Specific assumptions are explained below:

- It is assumed that no rehabilitation equipment for stroke patients in the market is in between low economic cost and convenient application.
- It is assumed in this paper that for stroke patients the only objects that need physical therapy rehabilitation are muscles, ligaments and joints.
- It is assumed that the research and development approach of all the current products are uniform.
- It is assumed that all electronic assistive rehabilitation devices are overlarge and expensive, and all mechanical structure-based assistive rehabilitation devices are too simple and cannot be employed in a timely enough fashion to provide the most benefit to patients.

1.6 Scope and Limitations

The rehabilitation of stroke patients involves physical recovery, psychotherapy and daily care.

The study will develop guideline aspects including mechanical control, circuit design, appearance modeling, man-machine interaction, operation method, etc. of current rehabilitation equipment for stroke patients.

The study will redesign rehabilitation equipment for stroke patients in mechanical control, circuit design, appearance modeling, man-machine interaction, operation method, etc. The discussion in this study covers Chinese and American stroke patients, who are also the research basis of all data and information. This means that information is limited to best practices in these two countries.

The whole research direction in this study is divided into user, market and technical factors.

The limits of this study are as following:

- This study will analyze the research and development processes of currently designed and sold rehabilitation equipment for stroke patients.
- This study will develop and summarize a new systematic approach to the improvement and redesign of rehabilitation equipment for stroke patients
- The initial models are limited to exhibition of the appearance and operation of basic functions.

1.7 Procedures and Methods

Procedure One: Search exercise programs for stroke patient

Method: Research a treatment plan through practical websites, software or books for creating an exercise movement program. Participants will learn how to establish client's aim, client's instruction, precautions and treatment time table.

Procedure Two: Exercise movement classification by types of synovial joints

Method: To research and analyze the types of skeleton synovial joints to divide the different exercises movement

Procedure Three: Individual human part design criteria for module creation

Method: To confirm main treatment human part after division synovial joints, then create design criteria for each human part by three factors: human factor, technology factor and production factor.

Procedure Four: The structure and function realization of synovial joint equipments

Method: According to analysis of design criteria, the synovial joint principal and existing products structure, the basic structure and basic support structure components will be created for equipment modularization.

Procedure Five: Module creation

Method: When the basic structure and basic support structure are completed, the different kinds of components will be classified into different areas. Based on these different properties, components to develop the rehab-equipment that stroke patient need.

Procedure Six: Concept sketch for each module

Method: Each module from rehab-equipment needs be improved to increase-practicality, function, appearance.

Procedure Seven: Modules base construction

Method: All concept modules created by 3D software. And a module base will be built to provide optional resources for stroke patients.

Procedure Eight: Evaluation checklist for concepts

Method: Each module assembly equipment will evaluated by three factor design criteria parameter, and the final score will grade these equipment modules. A qualified equipment will be developed in the final model.

1.8 Anticipated Outcomes

The primary outcome of this study will provide a new systematic design approach for the equipment of rehabilitation of stroke patients. The combined information of the development and appraisal of existing rehabilitation products will rule out some irrelevant reference factors in research and development. The study will cover information that is related to enhancement of interaction between the users and rehabilitation equipment, patient's independence in product use, cost of the product, and safe operation by the user. All reference factors of the information will improve the actual usage rate of the final design approach. A practical model will be developed from the preliminary sketch and 3D model according to various requirements of the systematic approach.

Chapter 2

Literature Review

2.1 Overview

The main purpose of this chapter is to derive a systematic approach to stroke rehabilitation equipment. In order to develop a more effective design approach, the following matters will be used to create, inspire, and limit the design approach. Firstly, it is required to learn what a stroke is, the main characteristics of patients who have strokes, and how to create and search for the correct exercises for stroke patients. Secondly, it is required to learn about the types of synovial joints in the human skeleton and each joint's mechanical principals, which will be the main orientation of the design approach. The approach needs to use these skeleton joint principals in order to limit and require the number and specification of rehab-equipment for individual exercise movement. Thirdly, it is required to consider what factors will improve the efficiency of rehab-equipment. The medical equipment interaction design and usability design factors will be considered and used to develop the design criteria. Finally, the current modularization products will be analyzed in order to create a modular approach. These materials are the basis of important innovations of the design approach, which derives the design steps and design contents of the approach through a more in-depth understanding of these various factors.

2.2 Characteristics of Stroke Patients

Life is extremely precious for a person. We require timely treatment and active prevention in cases of injury if we want to return to a healthy life. Normally, the human body will be changed in a negative manner after a disease. After a stroke, all parts of the human body are likely to be affected, causing damage to brain blood vessels. “Stroke is the leading cause of serious, long-term disability in the United States” (MMWR Morb Mortal Wkly Rep 2001), with permanent disability affecting between 15 and 30 percent of stroke survivors (Lloyd-Jones 2009). Data shows that at six months after a stroke, 19% of elderly survivors had aphasia, 50% had hemiparesis (weakness on one side of the body), 30% were unable to walk unassisted, and 26% were dependent in activities of daily living (ADL), and35% had depressive symptoms (Kelly-Hayes M 2003). Therefore, an assistive product that can realize accurate treatment and prevention, especially for muscular rehabilitation is needed for stroke patients.

Stroke has various cause, but there are two main types of stroke. The first one isischemic stroke, and the second one is hemorraghic stroke. An ischemic stroke occurs when an acute occlusion of a brain vessel causes a reduction in the blood supply to the brain, leading to dysfunction of the brain tissue in that area. The second one is hemorrhagic stroke. This occurs when a weakened blood vessel ruptures and bleeds into the surrounding brain (Centers for Disease Control and Prevention 2007). However, muscle exercises and movement are preventive measures in daily life, and muscle that has been shrinking or incapacitated can be rebuilt. There are three exercises movement methods. They include resistive exercise movement, passive exercise movement, and assistive exercise movement.

“A stroke is an abrupt onset of a neurologic deficit due to a sudden alteration of the blood supply to the brain, usually caused by a blocked artery or a burst blood vessel” (Lloyd-Jones 2009). Accurate medical treatment concerning which human part has been injured must be considered in the first step of any approach. “Symptoms depend on the part of the brain that is affected. People who survive a stroke often have weakness on one side of the body or trouble with moving, talking, or thinking”(US Agency for HealthCare Research and Quality 1995).

Active rehab exercise movement will aid in rebuilding cerebral tissue and with muscle regrowth. In this study, the types of exercise movement and the types of skeleton joints are considered.

2.3Rehabilitation Exercises Movement Creation

In order to develop an effective rehabilitation equipment approach, the direction of recovery to take in order to solve the problem is the most important. After a stroke, there will be different symptoms in the patients. In order to develop practical equipment and detailed solutions, the designer should understand the person's general health, how severe the injury is (US Agency for HealthCare Research and Quality 1995), and the extent to which the brain is affected. "The brain is an extremely complex organ that controls various body functions," and will be damaged if blood flow cannot reach it, resulting in impaired function. For example, if the back of the brain is damaged in a stroke event, "it's likely that some disability involving vision will result" (Facts About Stroke 2010). Other impairments depend on the location and extent of injury. If a correct exercise movement program is applied during stroke rehabilitation, it will assist stroke patients in recovering quickly. Thus, different human parts require individual rehabilitation programs.

The Physio Therapy eXercises is a website that contains over 1,000 physiotherapy exercises appropriate to treatment, improving strength and fitness for the human body injuries. This website program is primarily for the use of physiotherapists, health professionals, occupational therapists, injured people, and those with disabilities (The Physio Therapy eXercises 2015). The PTX website is a good start to search for correct exercise movements to assist the body recovery of stroke patients. The designer can search the exercises within different categories, including condition, exercise type, body part, available equipment, exercise difficulty, age, and image orientation(The Physio Therapy eXercises 2015). The exercise illustrations and photographs will be the primary design references with which to confirm the injured human part and design an approach. The designer will choose the injured part of the stroke patient from within these categories in order to create an exercise movement booklet that includes each action and its instructions, aims, and precautions.

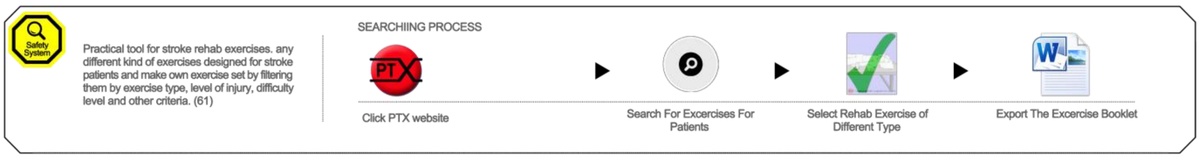

Figure 1. Exercises Movement Booklet Create Process (The Physio Therapy eXercises 2015**)**

2.4 Types of Synovial Joints and Joint Principal Analysis

The stretching and contraction exercises of human muscles depend mainly on the skeleton and ligaments. The direction and angle of the exercise movement depend on the types of synovial joint between two bone structures. “There are several treatment philosophies that provide different recommendations for the progression of treatment, type of movements to use, and the context of the activities”(Carr, -Shepherd 1983). Each type of movement is derived from the type of synovial joint, which are “subdivided based on the shapes of the articulating surface of the bone that form each joint. The six type of synovial joint are pivot, hinge, condyloid, saddle, plane, and ball-and socket-joints”(Types of Synovial Joints 2015). The direction and angel of each synovial joint can be adjusted on one or multiple axes. Therefore, the mechanical structures and electronically driven systems can stimulate synovial joint movement. Here is an example (Figure 2).The hinge joint consists of the cylinder part and the trough part. When combined, the model parts will do a hinge movement on the side axis. If two power-driven components are added to each side, then they will control the model.

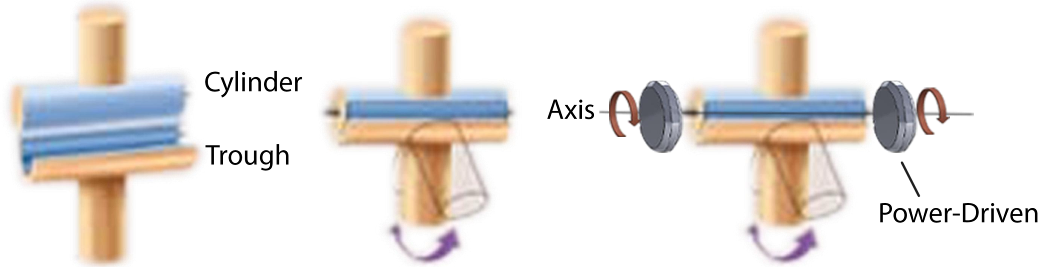

Figure 2. Hinge Joint Mechanical Structure Analysis (Types of Synovial Joints Mechanical Motion Analysis 2015**)**

During the practical application of the design approach, the movement principle of each synovial joint needs be analyzed in order to develop the rehab-equipment. The exact quantity of power-drives will be created in this step when innovating module equipment. The power-drive is intended as a driving system to mainly control the rehab-equipment for the muscle treatment of stroke patients. Each module of modular rehab-equipment has an individual function, and it can be converted for the treatment of different human parts. For example, a power-driven module can be assembled into hinge joint rehab-equipment as well as used for ball-and-socket joint rehab-equipment. Converting the same function module for the treatment of different human parts is an important foundation for design approach.

2.4.1 Hinge Joint Movement

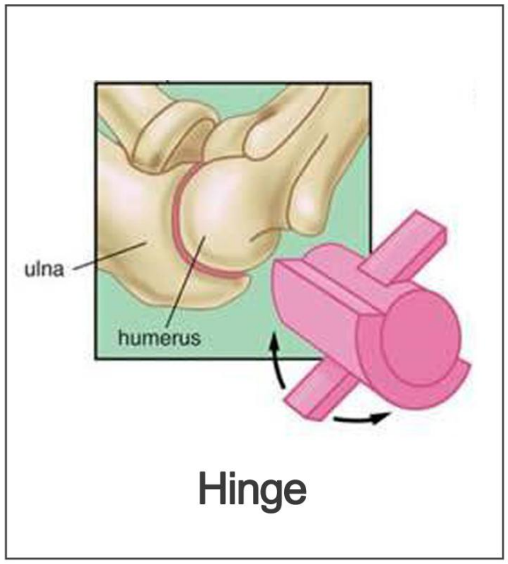

Figure 3. Hinge Joint (Types of Synovial Joints 2015**)**

In a hinge joint, the convex end of one bone articulates with the concave end of the adjoining bone. This type of joint allows for only bending and straightening motions along a single axis, and thus, hinge joints are functionally classified as uniaxial joints. A good example is the elbow joint, with the articulation between the trochlea of the humerus and the trochlear notch of the ulna. Other hinge joints of the body include the knee, ankle, and interphalangeal joints between the phalanx bones of the fingers and toes(Types of Synovial Joints 2015).

2.4.1.1 Mechanical Motion Analysis of Hinge Joint Movement

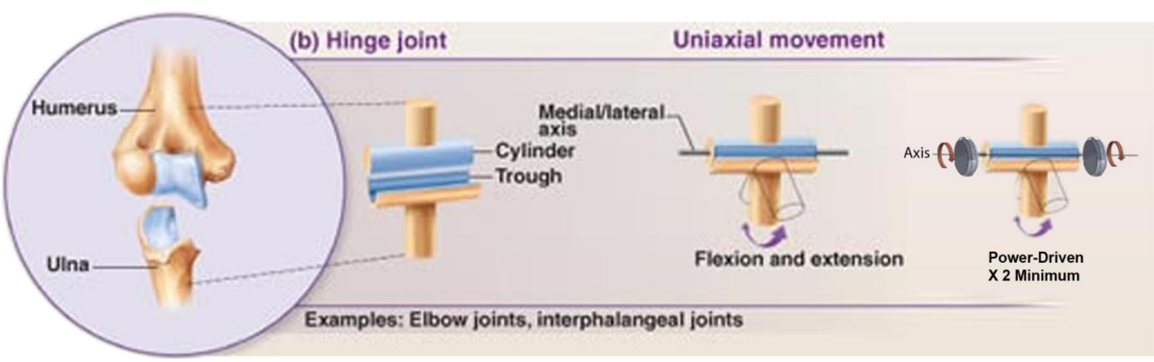

Figure 4. Mechanical Motion Analysis of Hinge Joint Movement (Types of Synovial Joints Mechanical Motion Analysis 2015)

Hinge joint movement consists of two parts, which include a cylinder skeleton and a trough skeleton. When they are connected together and follow the media axis to do the flexion and extension motion, if this skeleton wants to move by machine instead of muscle and ligament, then two power-driven systems are required in order to complete this motion (Types of Synovial Joints Mechanical Motion Analysis 2015). Hence the development of rehabilitation equipment for the hinge motion can begin with such power-driven systems. From there, researchers can figure out how to fix this equipment, how to adjust the control range of this equipment, how to ensure patients use it safely, etc. This provides a good basis for modular rehabilitation products for hinge joints.

2.4.2 Ball-and-Socket Joint Movement

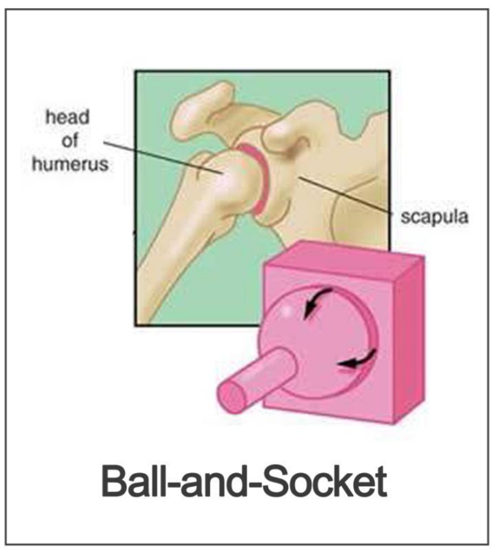

Figure 5. Ball-and-Socket Joint Movement (Types of Synovial Joints 2015**)**

The joint with the greatest range of motion is the ball-and-socket joint. In these joints, the rounded head of one bone (the ball) fits into the concave articulation (the socket) of the adjacent bone. The hip joint and the glenohumeral (shoulder) joint are the only ball-and-socket joints of the body. At the hip joint, the head of the femur articulates with the acetabulum of the hip bone, and inthe shoulder joint, the head of the humerus articulates with the glenoid cavity of the scapula (Types of Synovial Joints 2015).

2.4.2.1Mechanical Motion Analysis of Ball-and-Socket Joint Movement

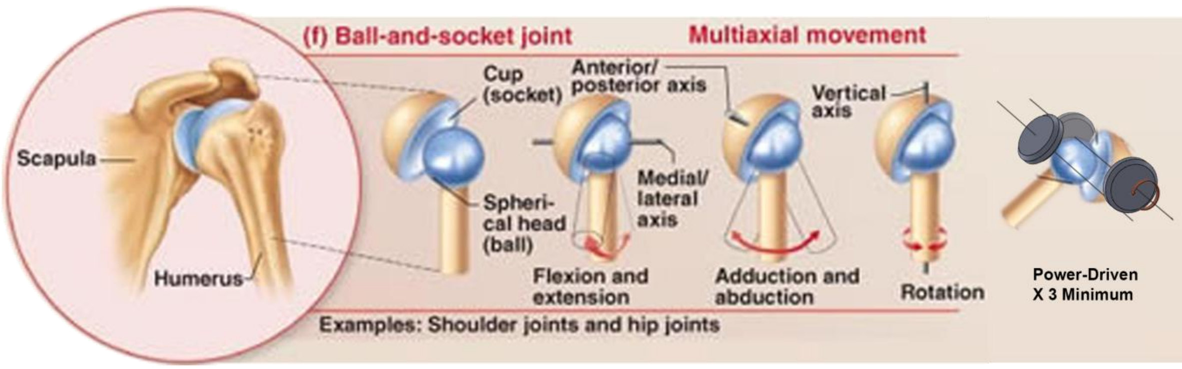

Figure 6. Mechanical Motion Analysis of Ball-and-Socket Joint Movement (Types of Synovial Joints Mechanical Motion Analysis 2015)

Ball-and-socket joint movement consists of two parts, a spherical head and a socket. When they are connected together and follow the multiple media axis for rotation, flexion, extension, adduction, and abduction motions, if this joint needs to be moved by a machine instead of muscle and ligament, then a minimum of three power-driven systems are required to complete this motion. Through the sequential control of these three power-driven components, 3D movement can be achieved (Types of Synovial Joints Mechanical Motion Analysis 2015). Hence developing rehabilitation equipment for hinge motion can begin with these power-driven systems. Then researchers can figure out how to fix this equipment, adjust its control range, ensure patients use it safely, etc. This is a good basis for modular rehabilitation products for ball-and-socket joint.

2.4.3 Condyloid Joint Movement

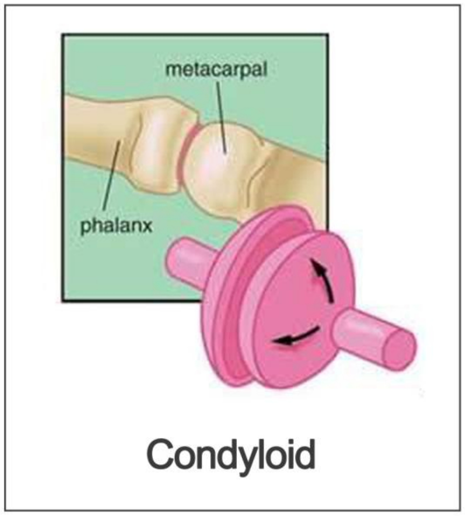

Figure 7. Condyloid Joint Movement (Types of Synovial Joints 2015**)**

In a condyloid joint (ellipsoid joint), the shallow depression at the end of one bone articulates with a rounded structure from an adjacent bone or bones. The knuckle (metacarpophalangeal) joints of the hand between the distal end of a metacarpal bone and the proximal phalanx bone are condyloid joints. Another example is the radiocarpal joint of the wrist, between the shallow depression at the distal end of the radius bone and the rounded scaphoid, lunate, and triquetrum carpal bones (Types of Synovial Joints 2015).

2.4.3.1Mechanical Motion Analysis of Condyloid Joint Movement

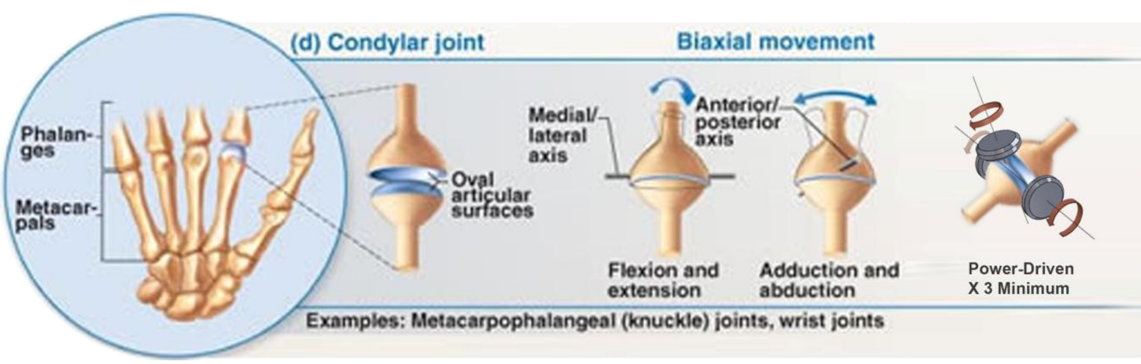

Figure 8. Mechanical Motion Analysis of Condyloid Joint Movement (Types of Synovial Joints Mechanical Motion Analysis 2015)

Condyloid joint movement consists of two parts, which include an oval articular head and an oval articular socket. When they are connected together and follow the multiple media axis do the flexion, extension, adduction, and abduction motions, if this skeleton needs to be moved by a machine instead of muscles and ligaments, then a minimum of three power-driven systems are required to complete this motion. Sequentially controlling these three power-driven components can achieve 3D movement (Types of Synovial Joints Mechanical Motion Analysis 2015). Hence developing rehabilitation equipment for the hinge motion can begin with these power-driven systems. Then researchers can figure out how to fix this equipment, adjust its control range, ensure that patients use it safely, etc. This provides a good basis for modular rehabilitation products for condyloid joint.

2.4.4Pivot Joint Movement

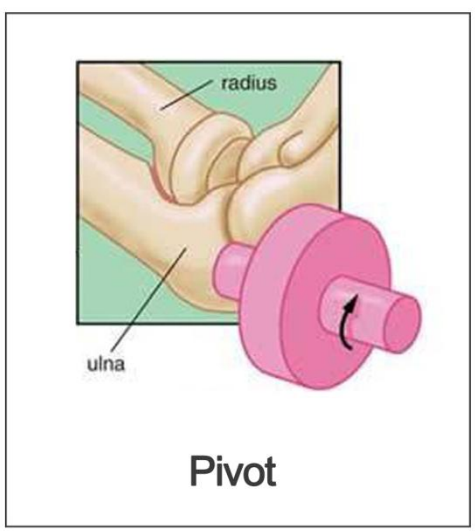

Figure 9. Pivot Joint Movement (Types of Synovial Joints 2015**)**

"At a pivot joint, a rounded portion of a bone is enclosed within a ring formed partially by the articulation with another bone and partially by a ligament. The bone rotates within this ring. Since the rotation is around a single axis, pivot joints are functionally classified as a uniaxial diarthrosis type of joint"((Types of Synovial Joints 2015)).

2.4.4.1Mechanical Motion Analysis of Pivot Joint Movement

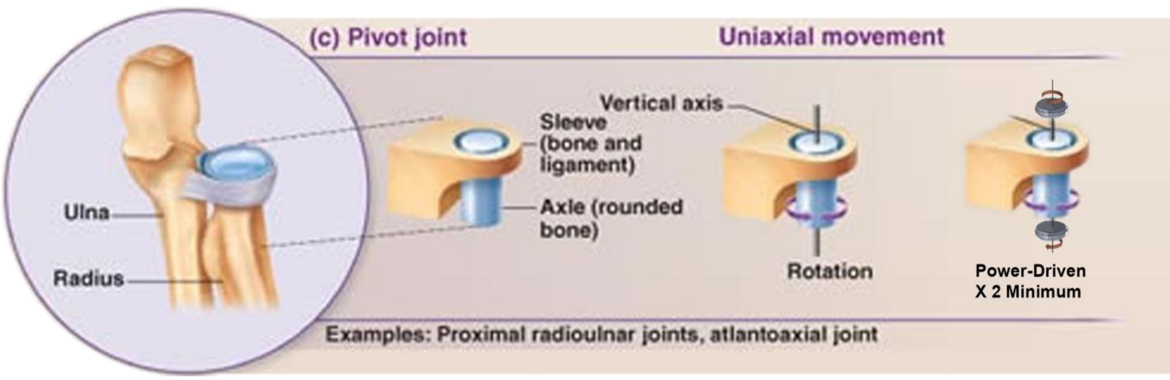

Figure 10. Mechanical Motion Analysis of Pivot Joint Movement (Types of Synovial Joints Mechanical Motion Analysis 2015)

Pivot joint movement consists of two parts, a sleeve skeleton and a rounded skeleton. When they are connected together and follow the media axis for the rotation motion, if this skeleton needs to be moved using a machine instead of muscles and ligaments, then a minimum of two power-driven systems are required in order to complete this motion (Types of Synovial Joints Mechanical Motion Analysis 2015). Hence developing rehabilitation equipment for the hinge motion can begin with these power-driven systems. Then researchers can figure out how to fix this equipment, adjust its control range, ensure that patients use it safely, etc. This is a good basis for modular rehabilitation products for pivot joint.

2.4.5 Saddle Joint Movement

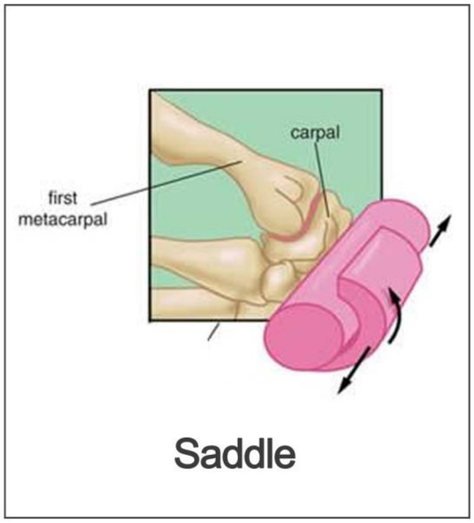

Figure 11. Saddle Joint Movement (Types of Synovial Joints 2015**)**

"At a saddle joint, both of the articulating surfaces for the bones have a saddle shape, which is concave in one direction and convex in the other. This allows the two bones to fit together like a rider sitting on a saddle. Saddle joints are functionally classified as biaxial joints. The primary example is the first carpometacarpal joint, between the trapezium (a carpal bone) and the first metacarpal bone at the base of the thumb"(Types of Synovial Joints 2015).

2.4.5.1Mechanical Motion Analysis of Saddle Joint Movement

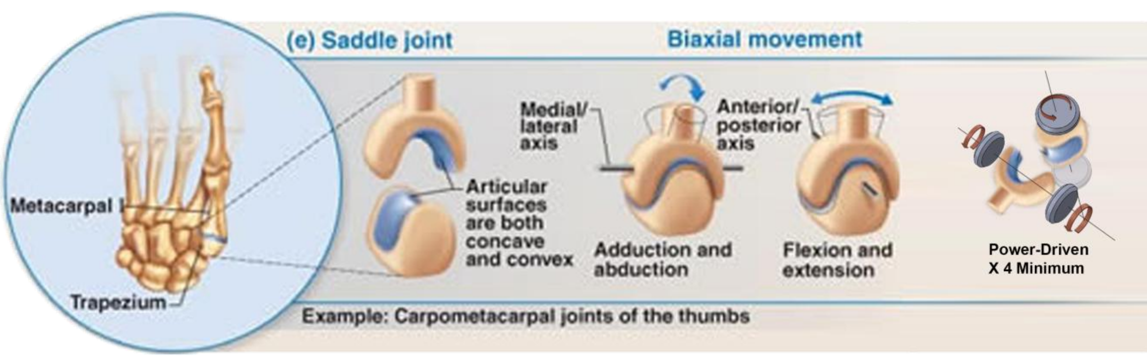

Figure 12. Mechanical Motion Analysis of Saddle Joint Movement (Types of Synovial Joints Mechanical Motion Analysis 2015)

Saddle joint movement consists of two parts, a concave articular surface and a convex articular surface. When they are connected together and follow the multiple media axis for flexion, extension, adduction and abduction motion, if this skeleton must be moved by a machine instead of muscles and ligaments, then a minimum of four power-driven systems are required in order to complete this motion (Types of Synovial Joints Mechanical Motion Analysis 2015). Hence developing rehabilitation equipment for the hinge motion can begin with these power-driven systems. Then researchers can figure out how to fix this equipment, how to adjust its control range, ensure that patients use it safely, etc. This provides a good basis for modular rehabilitation products for saddle joint.

2.4.6 Plane Joint Movement

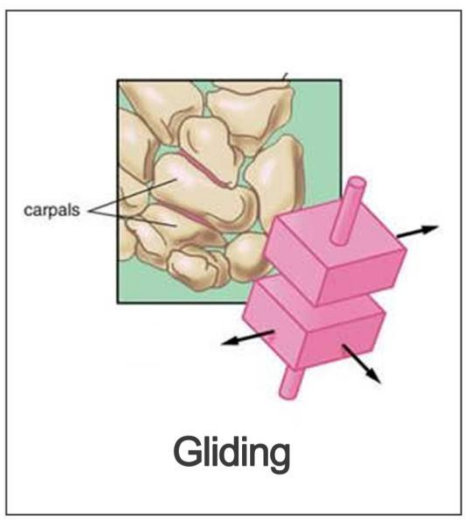

Figure 13. Plane Joint Movement (Types of Synovial Joints 2015**)**

"At a plane joint (gliding joint), the articulating surfaces of the bones are flat or slightly curved and of approximately the same size, which allows the bones to slide against each other (see Figure). The motion at this type of joint is usually small and tightly constrained by surrounding ligaments. Based only on their shape, plane joints can allow multiple movements, including rotation. Thus plane joints can be functionally classified as a multiaxial joint"(Types of Synovial Joints 2015).

2.4.6.1Mechanical Motion Analysis of plane Joint Movement

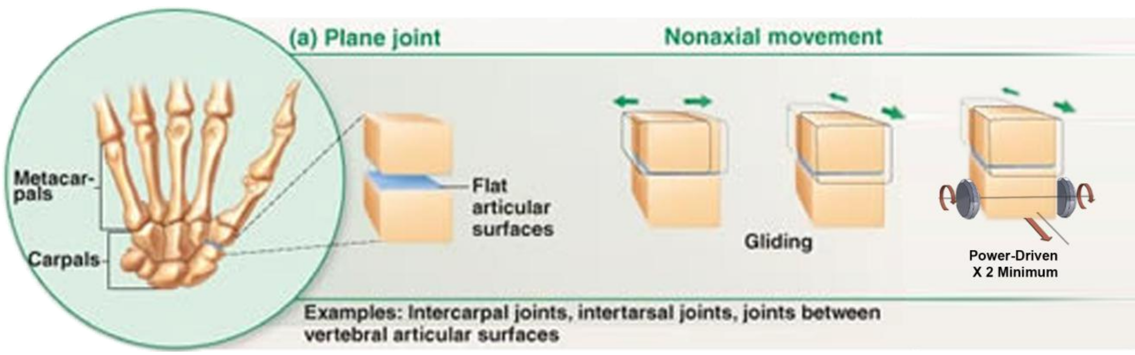

Figure 14. Mechanical Motion Analysis of plane Joint Movement (Types of Synovial Joints Mechanical Motion Analysis 2015)

Plane joint movement consists of two flat articular surfaces. When they are connected together to do a gliding motion, if this skeleton must be moved using a machine instead of muscles and ligaments, then a minimum of two power-driven systems and a gear system are required in order to complete this motion. Through control these two power-driven components to drive a gear to control the skeletons gliding (Types of Synovial Joints Mechanical Motion Analysis 2015). This provides a good basis for the development of plane joint modular products.

2.5 Factors that Should be Considered in the Design Parameters and Design Criteria of the Approach

A better understanding of related products and technologies with information related to product design factors will provide more efficient and reliable reference data for the derivation of the design criteria. The design criteria as a design limitation to limit and regulate each design parameter create the opportunities for the stroke patients design project. In the development of modular rehabilitation equipment, the human and technological factors of design methodology will be considered in order to provide better module equipment with practical applications. However, in the medical equipment interaction design research will provide the design parameters to the human factor of criteria. The usability design will provide design parameters to the technology factor of criteria. There are aesthetic parameters and practical parameters in the human factor, and the internal technical and external technical will be listed in technical factor of criteria. This section mainly presents research on human-machine interaction design and usability design information. Based on this information to create the parameters of criteria, which can be updated data by latest technology, books, and academic sources. These parameters can be used as an evaluation checklist in order to use in the evaluation of design concepts.

2.5.1Interaction Design and Usability Design Introduction

Interaction design, including product appearance design, ergonomic design, and interface design, is researched in this section in order to provide parameters for design criteria. In the industrial design field, appearance design refers to the shape of a product. The product shape is the appearance of a product, which is formed by the border lines, including the outer and inner contours of the product. The outer contour is the outside border line that can be sensed by vision, while the inner contour is the border line of the internal product structure. Product appearance is an integration of art and special structures.

User interface design is the systematic design that optimizes information communication means and communication processes between human and interface in order to improve the communication efficiency between them (Zhou 2010).

Ergonomics is also closely connected to interaction design. Products are manufactured in order to provide comfortable operation, safety, reliability, and correspondence between humans and machines. Besides the rational structure and excellent performance, the novelty product language and color harmony from mental function considerations are also important during design a product.

When designing rehabilitation products, the appearance should be considered because "Appearance is an important factor in determining the acceptability of rehabilitation products to end-users" (Hersh & Johnson 2010).The size, directions, speeds, etc. that are presented by a form may cause sensations like expressiveness or vagueness, affability or disgust, convenience or trouble, and so on. Considering ergonomics, rehabilitation equipment must be adjustable and stabile. The dimensions of equipment and environmental factors must also be taken into consideration. This parameter information will put to the design criteria to design, innovate and limit the modular rehab-equipment design concepts.

Utility refers to a product's capability to carry out an intended function. Usability refers to how easy users find it to accomplish that intended function and how to realize the technical principal in real application(Dumas, & Redish, 1993).In rehabilitation equipment usability design, the primary goal is to ensure the product does a basic function in order to realize the product's technical requirements. There are some technical factors to consider, including the internal and external technical components of a product. Designers should consider how these technical factors interrelate and influence the parameters of the design criteria. The technical function of usability generally requires effective use, high working efficiency, simplicity in learning, safety in use, and a pleasant experience for users of the interactive products.

This information of usability design were researched to create a design criteria, which were used as guidelines for design and construct the modular rehab-equipment. All parameters will also be used in order to evaluate the design concepts for a final model.

2.5.2 Interaction Design Considerations for Rehabilitation Equipment

The appearance of medical equipment may produce different psychological effects on different individuals. The appearance of different medical equipment, including its color and ergonomics, may be based on the different use behaviors, types of muscle injury, and injury conditions, in order to create the various functions for patients. Establishing performance parameters will provide design innovations for and limitations on the creation of modular rehabilitation equipment. After an analysis of the relationship between medical equipment appearance, color, use methods, and interface factors, the specific requirements of the product form raised by the use method arethe following(Wang 2001):

- Consideration of the appearance of medical product:
    1) Gentle curves should be given priority in order to establish a mellow and full shape of friendliness and affability.
    2) The overall form should be regular, stable, and decent. Space usage and layout should be reasonable and give a senses of directness and precision.
    3) The form should agree with the purpose and operation behavior of the product, providing guidance and indication for operation behaviors at the same time.
    4) Submissiveness, adaptation, and harmony should be observed in form. (Wang 2001)

- Color consideration for medical products:
  1) The best choice for the bulk of a large medical product's form is going to be one that serves as background onto which color and value contrasts can be selectively applied. White and light gray are good starting points.
  2) The best rehabilitation equipment uses warm colors, such as warm blue, warm green, warm pink, and warm yellow.
  3) Using a pure color as the main color of a medical product, such as white or warm grey, can help release the stress of the patient when they use it.(Color in Medical Products 2015)

The suggestions above will be used as parameters when designing the human factor criteria. When design modular rehabilitation equipment, these will be the basis of the innovation of concept, material, interaction, etc. Defining every parameter can elicit primary modularization equipment properly.

2.5.3 Usability Design Considerations for Rehabilitation Equipment

Different technical specification standards will affect the practical operation of rehab-equipment. A usable product consists of different technical components, materials, and production technologies. Developing modular medical rehabilitation equipment requires the use technical factors in order to set the parameters for the realization of the final, intended operation of the rehabilitation equipment.

- Internal technical consideration of medical product:
  1) Use micro controllable motors for dynamic modules as much possible, such as stepping motors and private servers.
  2) Circuit boards should use minimum control chips, such as arduino nano.

3) The rehabilitation equipment needs to have a long-distance data transmission module, such as Bluetooth or WiFi.
4) Batteries can use wireless charging, wired charging, or battery replacement.

- Material considerations for medical products:

1) In terms of selecting materials, large areas of hard-textured materials should be avoided. Metal, for example, is prone to cause the perception of hardness and distance, as well as negative emotions, like uneasiness and anxiety.
2) Plastic is frequently used in current products because it is easy to shape and process. It tends to be rich in humanity and bring about intimate usage experiences.
3) The materials should be easy to clean or bacteria resistant. Dirt and bacteria are likely to grow on the surfaces of domestic medical products because such products are mostly alternatively used by different people, which should be a key consideration in design. (Wang 2001)

The recommendations above will all be used as parameters when designing technical criteria. When design modular rehabilitation equipment, this will be the basis of the innovation of concept, material, interaction, etc. Defining every parameter can elicit primary modularization equipment properly.

2.6 Rehab Product Modularization

2.6.1Modularization Introduction

According to the classification of different exercise movements by the six types of synovial joint, designers usually create rehab-equipment based on different exercise movements, but it cannot be transfer the functions to another exercise movement. For example, recovery equipment for wrist treatment, cannot be used for the elbow because the equipment is an integral product and non-removable. Patients will spend a lot of money to purchase recovery equipment for different human body treatments. In addition, rehabilitation equipment for the human body can be very complicated to design. In general, one particular piece of equipment will correspond to one human part and cannot be used for other parts of the body. However, in order to transform the effectiveness of different equipment into one piece of equipment, the concept of modularity can be used.

Modular design, or "modularity in design," is a design approach that subdivides a system into smaller parts called modules or skids that can be independently created and then used in different systems. In particular, medical devices seem to be likely candidates for this approach because this approach can potentially save time, money, and resources, in addition to contributing to the overall goal of improved patient care(Are Modular Medical Devices the Future? 2015). A modular system can be characterized by functional partitioning into discrete, scalable, and reusable modules (Modular design definition 2015). In this section, research and analysis of current modular products are presented.

2.6.2 The Development of Modular Process for Design Approach

Google Ara is an initiative to create a completely modular and reusable smart phones. The key advantage of the Ara system is that, unlike current smartphone models, users do not have to constantly replace their entire device in order to keep up with the latest technology. Replacing individual modules base on customer requirements will realize the module update process (Modular smartphone Google Ara 2015). Different modules of the Google Ara are classified based on the various functions of the components: data processing components, including CPU modules and SD card modules; power supply components, including battery modules, USB modules, and plug-in charger modules; and display components, including LED screen modules. Modular products enable faster, easier, and more efficient customization of standard products according to unique user needs. Customers can easily assemble and release each module based on their requirements. Similarly to the Google Ara, during the development of a modular rehab-equipment design approach, all modules must be divided into different function categories based on the different requirements of patients. The module-base also supports modules to apply to the equipment assembly of different exercises movement. The use of modular design can not only be used to realize maximum benefits with fewer materials but also greatly reduce the cost of equipment.

Figure 15. Google Ara Modularization Product (Modular smartphone Google Ara 2015)

While creating the basic module process, the approach needs firstly to confirm the necessary power-driven module by the skeleton joint structure principle, with the power-driven module as the core-technology to drive other modules and the human body. Based on design the criteria, we can design, innovate, and limit other modules, such as connection, protection, strap, and support modules. After completing each basic structure, each needs be tested and simulated using 3D software. If any problem arises during the tests, then the modules can be separately improved before being reintroduced into the whole product. They do not have an impact on other assemblies, as would be the case with integral design (Modular Design Benefits 2015).

2.7 Conclusion

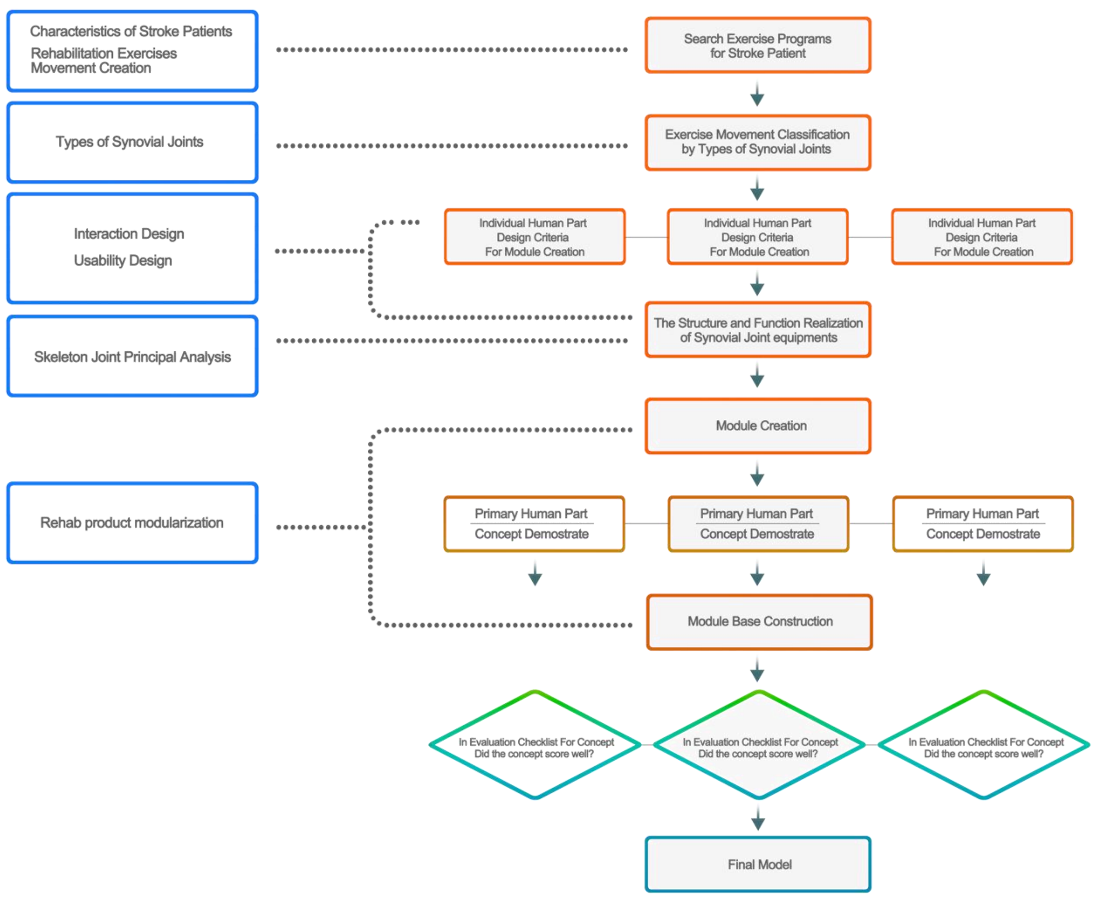

Figure 16-From Literature Review to Designing a Systematic Approach

Completing modular rehab-equipment design approach requires the use of research information in order to develop the design approach step-by-step (Figure 16). Up-to-date information and data will improve the design approach.

Based on the characteristics of stroke patients, the PTX website was used to create an exercise movement booklet for stroke patients.

When the exercise movement booklet was completed, the design objective was still problematic and too broad to start the modular rehab-equipment design. Because the human skeleton has six types of synovial joint and each joint has a similar mode of motion by the axis, mechanical equipment with rehabilitation functions can be used in different types of synovial joint. Therefore, in the second step, these exercises movements can be divided into these six types of joints in order to develop the same function module and to use each it for different skeleton joints. Each exercise movement of skeleton joint of human injured body as a design objective can be confirmed.

In the third step, design criteria will assist on the exercises movement of each injured human part in order to develop the concept module equipment for stroke patients. The design criteria will be a tool used to create, innovate, and limit modular product creation. The performance parameters will also be used to check each concept in the later approach step.

The basic structure model of exercise movement will be developed according to the design criteria and synovial joint mechanical principal. Every basic structure model has same function component. These components will be divided into different functions, such as power-driven components, connection components, and protection components. The basic structure model will be the important foundation on which to develop the modular equipment in this design approach.

During the completion of the basic modular structure equipment, these modules need be classified into different function lists. Then 3D software will be used in order to create a CAD model for each module and realize the technical function and internal structure support. Based on each exercise movement of the injured human body, these practical modules will be assembled into integrated rehab-equipment.

In order to combine and delete the unnecessary module components, these modules need be redesigned through sketch development in the next step. Each module’s appearance, material, color, and technical principle will be redesigned base on the parameters of the design criteria in order to make them more comfortable, safe, and usable for stroke patients.

Finally, the design criteria will be used in order to create an evaluation checklist for each modular rehab-equipment and confirm that all parameters are met and that they function as they should. Then we will choose the best solutions with which to develop the final model for stoke patients.

Chapter 3

Design Systematic Approach

3.1 Overview

In this chapter, a set of modularized rehabilitation products will be designed and developed in order to improve treatment effects for patients who have had a stroke. The main design procedures of the design approach are shown in Figure 17. Firstly, the designer will implement a treatment plan through the practical tool for creating an exercise program for stroke patients. The PTX will instruct the designer to learn how to establish clients' aims, instructions, precautions, treatment time tables, and exercise movements. Secondly, designers need to learn about the six types of synovial joints and the correct exercise movements for different joints. In the third step, designers need to derive design concepts with the help of the design criteria of three design factors as the design evaluation standard basis. The three factors are the human factor, technical factors, and the production factors. In the fourth step, they need to investigate and analyze the main synovial joint mechanical principles and design criteria in order to develop basic structure rehab-equipment. The concept basic structure realization and basic support structure will be listed. Fifthly, the chart will demonstrate the modularizing processes according to the classification of the basic structure components into different function lists. Then based on the exercise movement of the patient's injured part, the designer will assemble the module to be integrated rehab-equipment. In the sixth step, preliminary concept sketches should be used in order to redesign each model. In the seventh step, after completing the module concept sketches, the designer needs to create a 3D CAD model with practical functions for modules based on construction. The eighth step is the module concept evaluation and examination table, in which all sketches will be selected and evaluated in accordance with classifications. If a concept does not reach the standard, designers need to start again from the fourth step. The ninth step will derive final innovation models from qualified module rehab-equipment.

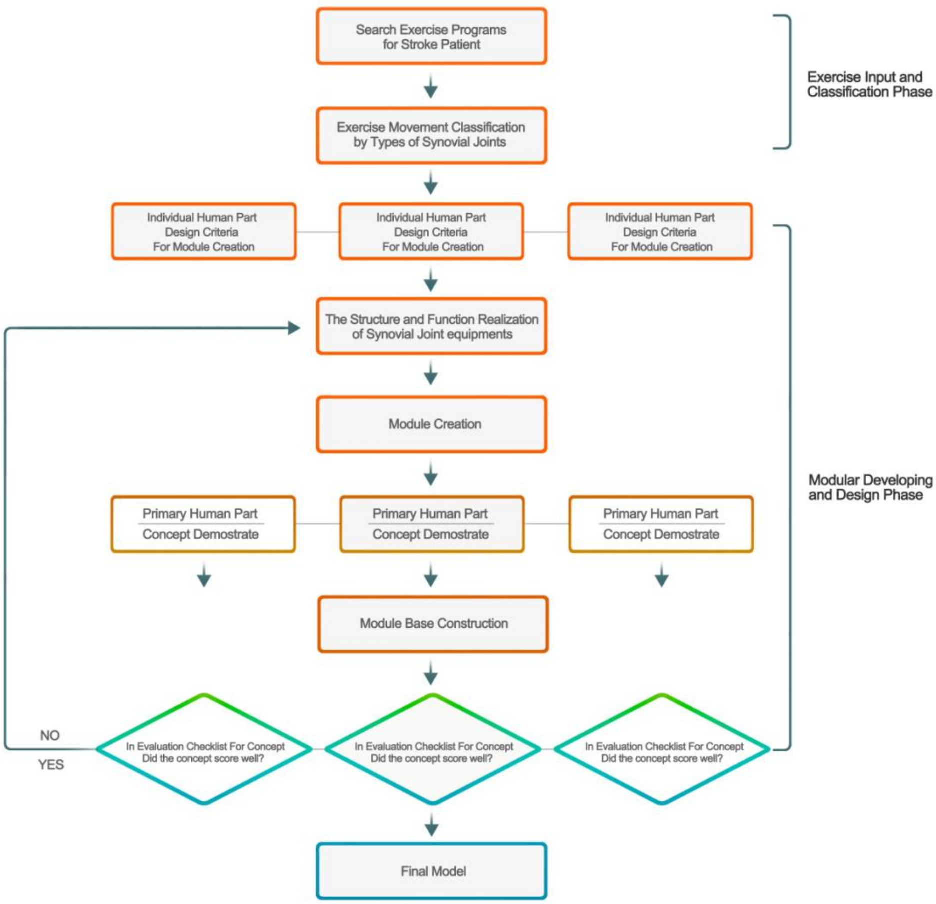

Figure 17-Design Systematic Approach Flow Chart

After the ninth step, the designer will create the design and develop the modular rehab equipment for stroke patients. This approach mainly covers the feature description of stoke patients, analysis of major functions of rehabilitation equipment, comparisons among and redesign of existing market products, and technology and process of manufacturing rehabilitation equipment. However, it allows designers to introduce design factors and survey data in the future in compliance with specific requirements; that is to say, free expansion for improvement of this approach is possible. This process may also serve current design companies or contractors engaged in the research of rehabilitation equipment, or even independent designers, for whom it can provide effective help and assistance as a design flow or evaluation system.

3.2 Search Exercise Programs for Stroke Patient

Figure 18-Demonstration of Search Exercise Programs for Stroke Patient (The Physio Therapy eXercises 2015)

In this section, based on the characteristics of stroke patients and PTX exercise movement creation program from the literature review, designers will adopt the practical tool to create exercise movement and exercise programs for stroke patients according to the type of injury, part of injury, difficulty level of injury, and other criteria. During the exercise booklet creation, the firstly the designer needs to choose the main injured part, select the exercise movements and export the exercise booklet. The exercise program booklet deliverable includes four parts: client’s aim, client instructions, precautions, and treatment time table.

3.3Exercise Movement Classification by Types of Synovial Joints

Figure 19-Demonstration of Exercise Movement Classification by Types of Synovial Joints

"After a stroke, muscles may not remember how to perform actions that were once simple, like sitting and walking. A stroke patient will need to relearn these skills with the help of physical therapy. Physical therapy retrains muscles and reminds them how to work together again"(Konkel 2015). Exercises movement will help designers to create rehabilitation equipment for stroke patients, but in modular rehab-equipment development, these exercises movements are too problematic and broad to design the modular rehabilitation equipment. However, human skeletons have six types of synovial joints that have similar modes of motion by the axis. Similar functional components of mechanical equipment can be used for different joint movements.

These exercise movements can be classified and summarized into different types of synovial joint. “The six type of synovial joint are pivot, hinge, condyloid, saddle, plane, and ball-and socket-joints”(Types of Synovial Joints 2015). In this section, all exercises movements will be classified according to the six types of synovial joint. This chart (Figure 19)will benefit the designer in terms of determining the modularization design targets, and also the design range will be reduced.

3.4 Individual Human Part Design Criteria for Module Creation

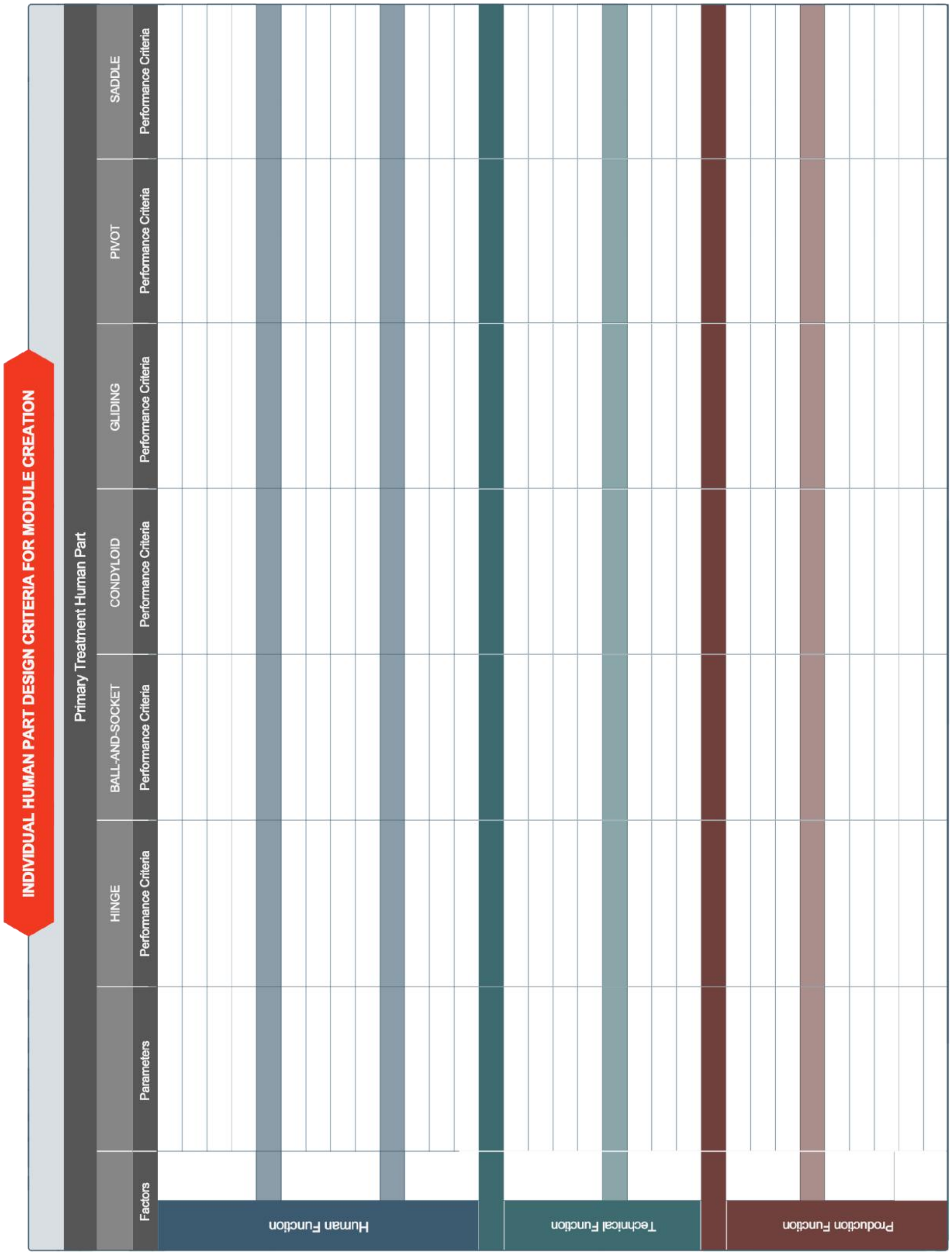

Figure 20-Demonstration of Individual Human Part Design Criteria For Module Creation

According to exercise movements that have been classified into the six synovial joints, each exercise movement of a skeleton joint of an injured human body, as a design objective, can be confirmed. This section is mainly a summary of different human body design criteria for modular product preparation. The primary treatment of one human part and one type of synovial joint will be shown in this chart (Figure 20). If stroke patients have multiple body injuries, more criteria charts will be created.

In the subset of synovial joints, previous survey data and information from Chapter Two will be managed and classified into three types, including human factors, technological factors and production factors, which will form a complete design criteria chart (Figure 20). These criteria are to be applied to the derivation of the concept, for model evaluation, and in the model manufacturing of the product in the subsequent section. Designers can achieve derivation and improvement of product concepts with intuitive reference to the design parameters of these charts.

3.5 The Structure and Function Realization of Synovial Joint Equipment

Figure 21-Demonstration of The Structure and Function Realization of Synovial Joint Equipment

Based on the criteria and synovial joint mechanical principal analysis from the literature review, designers can begin with the creation of basic rehab modular structures. According to the types of synovial joints, each exercise movement has been clearly defined. Therefore, through the synovial joint mechanical principal, each joint's main power-driven components can be developed. Then based on the parameters of the design criteria, other accessories and components can also be designed, such as connection components, protection components, and support components. Designers will mark out each component name and function for comparison and classification in the next step.

This section is intended to lay the foundation for the starting of the whole modularization design. This will enable designers to access equipment, components, and technologies that they need.

3.6 Module Creation

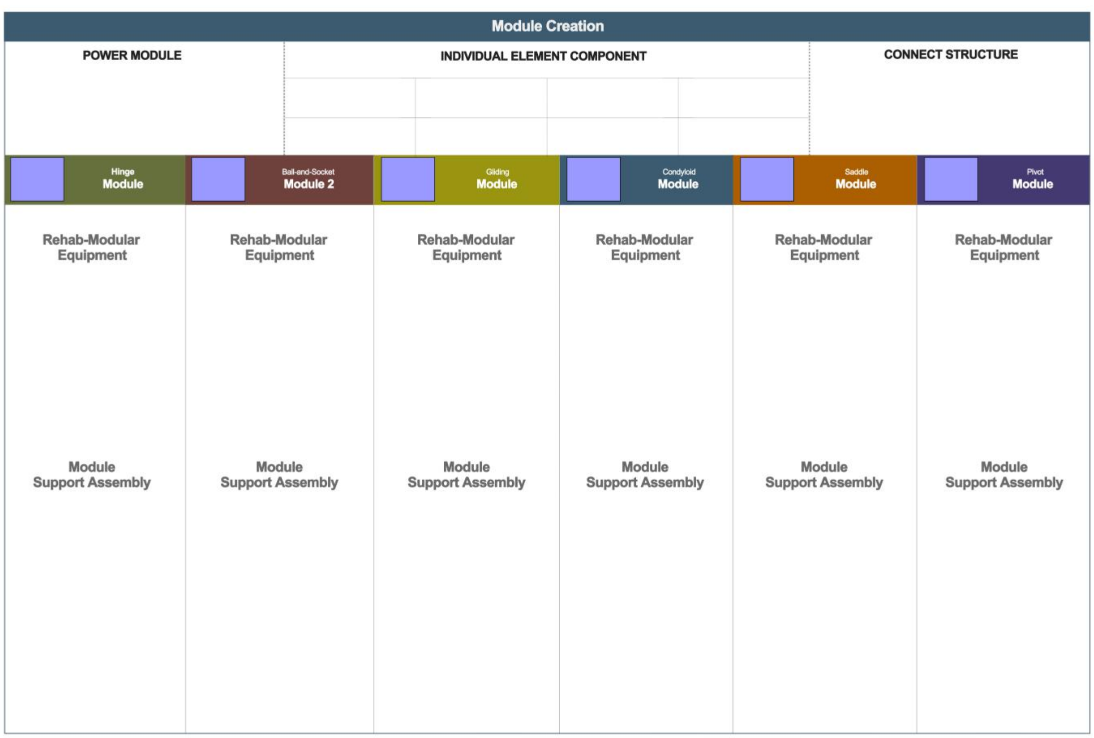

Figure 22-Demonstration of Module Creation

This section will mainly show the modularizing processes, which classifies the basic module components into different function lists. Each component will be redesigned in order to build a 3D CAD model and realize the technical function and internal structure support. When modularizing functional parts of current rehabilitation products, the following three points need to be noticed: firstly, independence of functions. A module is a standard part with specific functions, and it can achieve its functions in many different products. Thus, it has the characteristics of standardized products and can be organized into specialized production. Secondly, standardization of interfaces. A module needs to be combined with other modules in order to achieve the functional requirements of different products. Connections between modules can directly influence the quality of products as well as the design of modules and the ability of achieving functions. At the same time, the standardization of interfaces is beneficial for using new technologies inside modules, further improving abilities of modules for the convenience of updating products. Thirdly, seriation of modules. The purpose of modularization is to improve the ability of products to transform. If there is no seriation of module bases, structures of products will no change much and only the number of functions will increase or decrease. Thus, it cannot meet the changing demands of tasks. It is due to the above characteristics that currently it is mainly regarded that modules are functional modules; namely, the purpose of modularization is to determine independent, standardized or changeable functional units to achieve various functions.

In order to integrate treatment of all types of synovial joints into one piece of modular equipment that has both portability and versatility, the designer needs to divide all of the basic structural components from step four into different function lists. The designer can develop a basic modular rehab-equipment concept based on the assembly of different function modules.

3.7 Primary Human Part Concept Preliminary Sketch

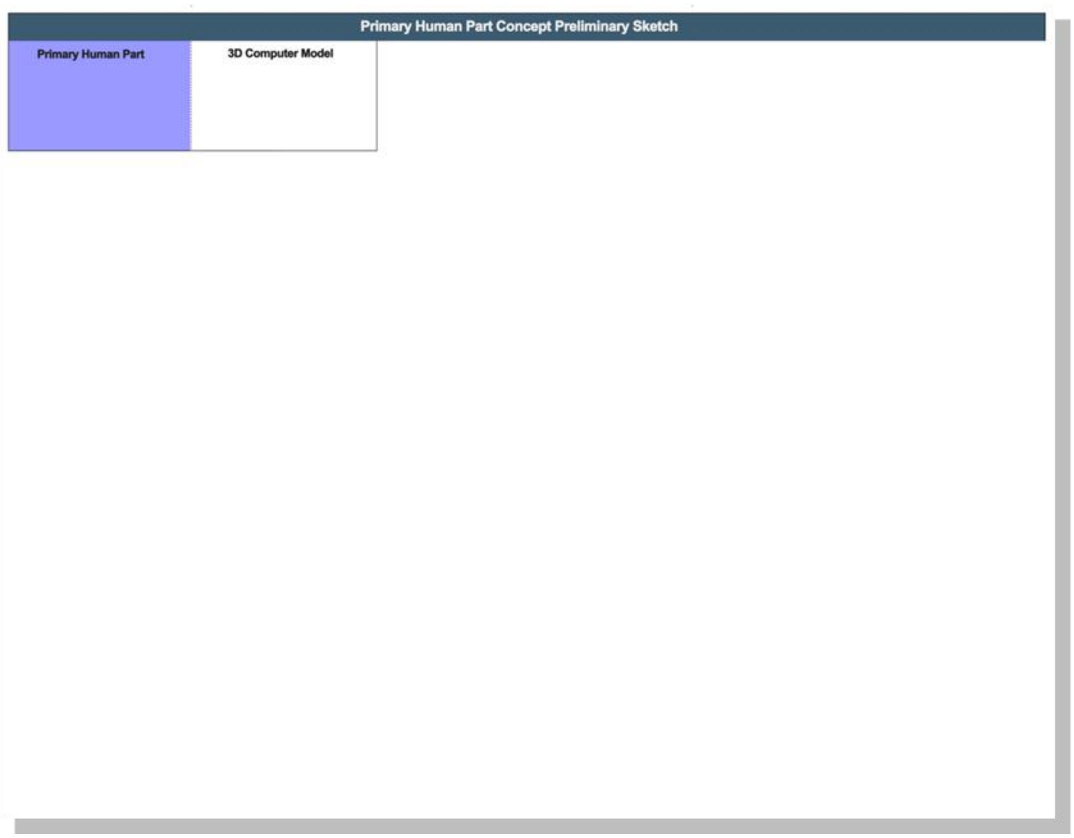

Figure 23-Demonstration of Primary Human Part Concept Preliminary Sketch

In the next step, a conceptual sketch will be derived from each rough module, which includes the appearance of the product, the operation of the product, the principle of the product, the materials analysis of the product, etc. At the same time, the actual size and processing technique will also be taken into consideration. The thinking of designers may be expanded by classifying the conceptual sketch according to the standard design drawing.

3.8 Modules Base Construction

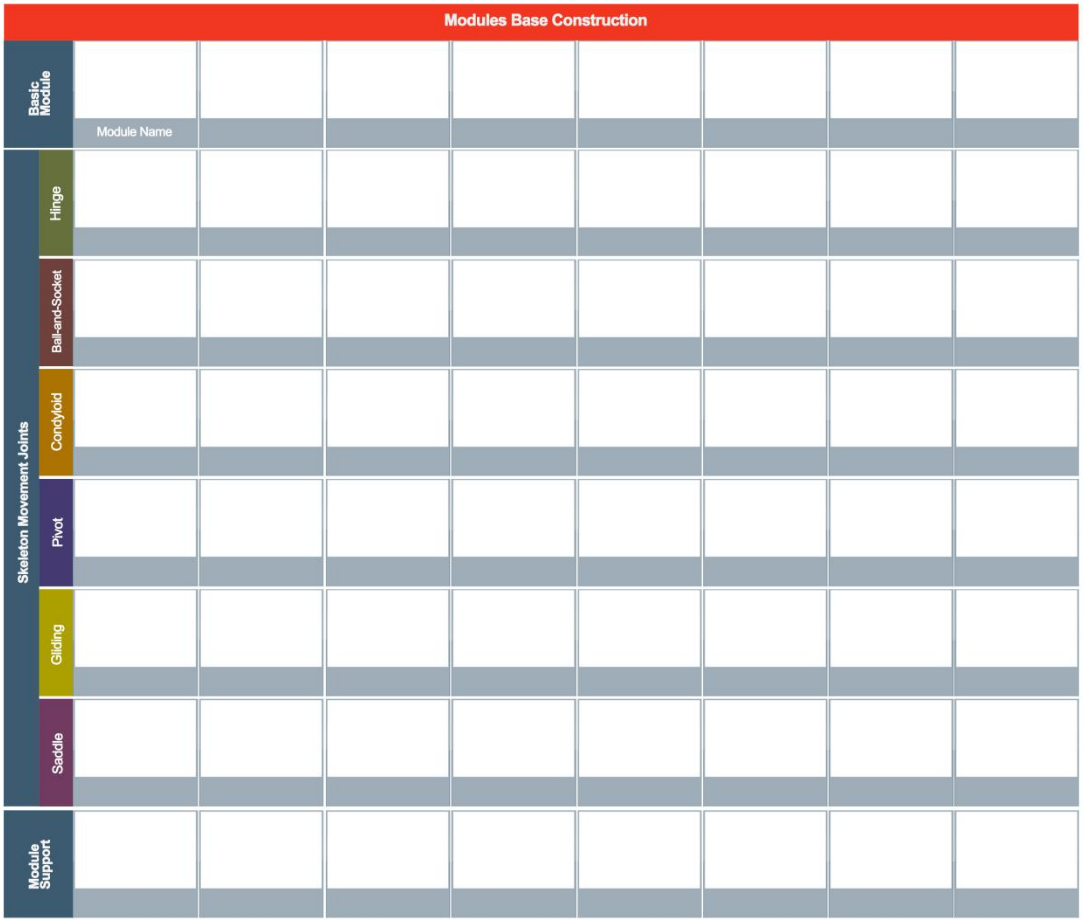

Figure 24-Demonstration of Modules Base Construction

A module is a bridge that connects the demands of customers, functions of products, and structures of products. All optional modules compose the module database, and they are the basic components of module combinations. After the standard modularization of the parts of the current rehabilitation products is finished, designers need to build a CAD model, list all modules in the following module database, and then arrange and combine these modules according to treatment kinds and functional properties. In this way, when innovating rehabilitation products, designers can choose and use modules according to the demands of customers and functions of products.

3.9 Evaluation Checklist for Concept

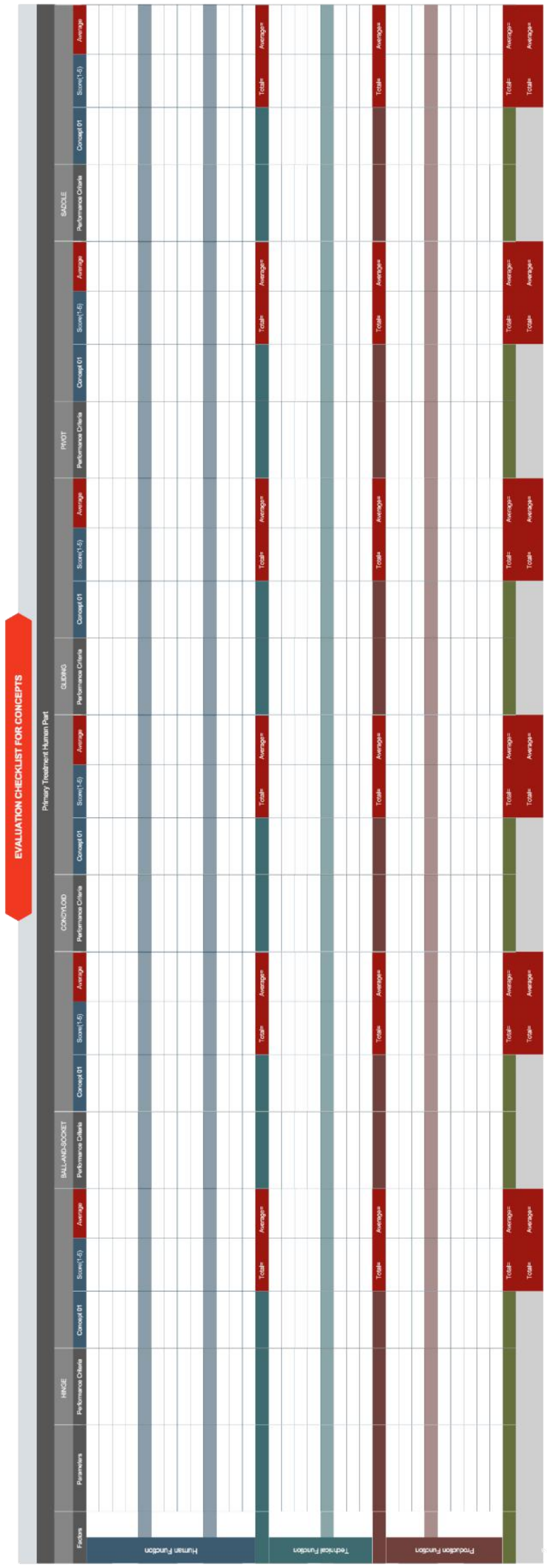

Figure 25-Demonstration of Evaluation checklist for concept

A model evaluation system will be accomplished in this step. It is intended to lay a better foundation for the final model of the finished product by evaluating and selecting from all the product concepts through this standard design drawing. Then a product prototype will be manufactured according to the data in the charts after the selected concept is established.

The evaluation system will evaluate how the product performs in the execution of all the design standards. The product is expected to have employed all the data collected, including all the subset items of human factors, technological factors, and factors of production. When the evaluation is finished, the designers are required to draw a full conclusion from these evaluation results.

Each item selected for evaluation will receive its own independent score, and the “total” below each item refers to the final score of the product. Each score can range from 1 to 5, and 5 will be a full score.

3.10 Final Model

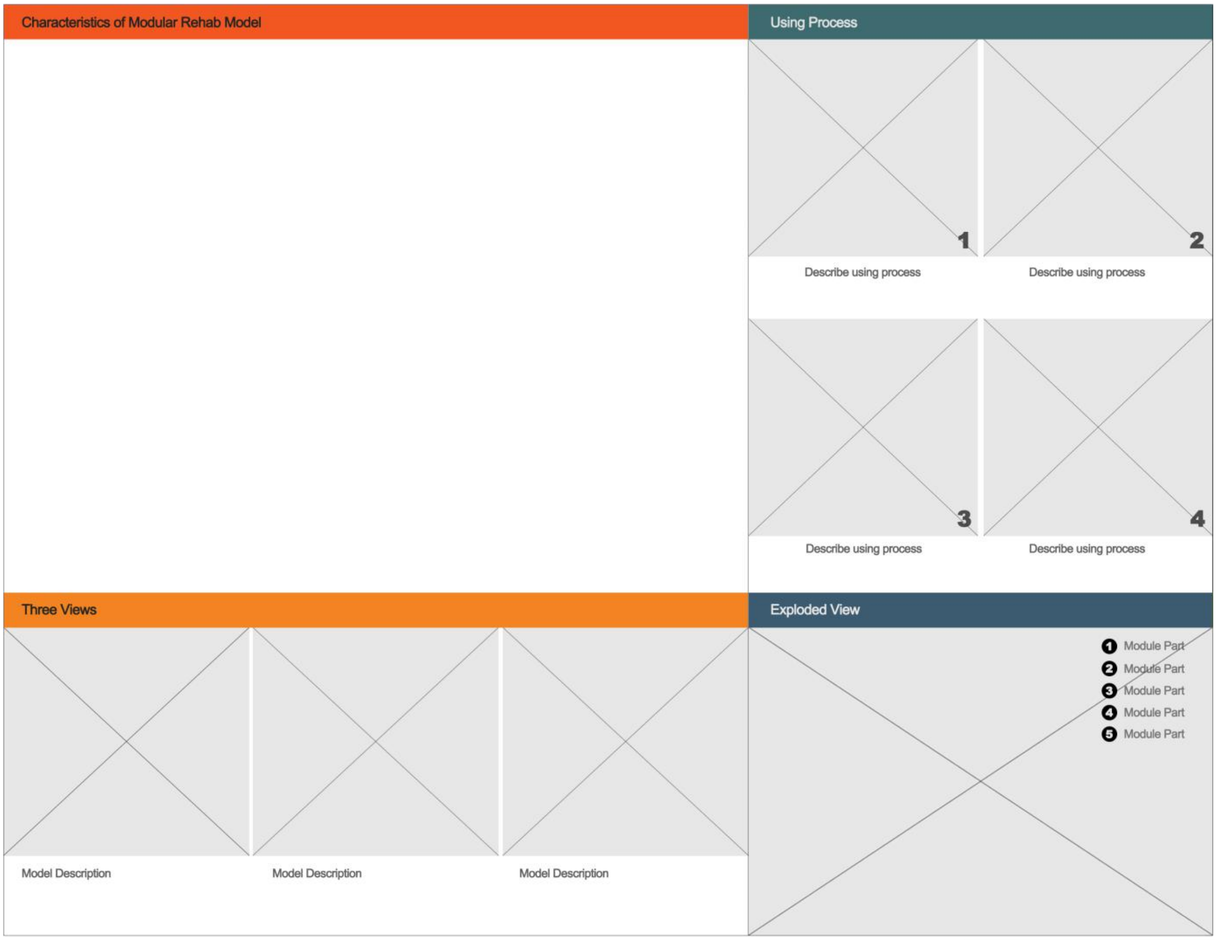

Figure 26-Demonstration of Final Model

In the closing step, the designer will use 3D software to create a CAD model according to the previous evaluation checklist results. The rendering figures will be demonstrated in this chart in order to let patients know the appearance of this rehab-equipment. Under the figure, there will be instructions, showing how to correctly use and assemble all modules of the rehab-equipment. At the same time, an exploded view of the modules needs to reveal how many modules will be used for patient rehabilitation. In additional, the model's front view, side view, and top view with dimensions will also be shown in the chart.

Chapter 4

Application of the Developed Approach

4.1 Overview

This chapter will execute the previous designed approach, to assist to develop a modularized rehabilitation equipment for stroke patients. This rehab-equipment mainly aims at the patients who lose their muscular capacity of wrist joints and elbow joints because of stroke to carry out the active, passive, assistant rehabilitation training. Designers can realize the ultimate modularized products according to the set design approach and design requirements of every step. And all the modules that are developed in the end will be stored in the module database, so orthopedists and therapists can directly select modules to assemble and use according to the rehabilitation demands of the next patient.

4.2 Search Exercise Programs for Stroke Patient

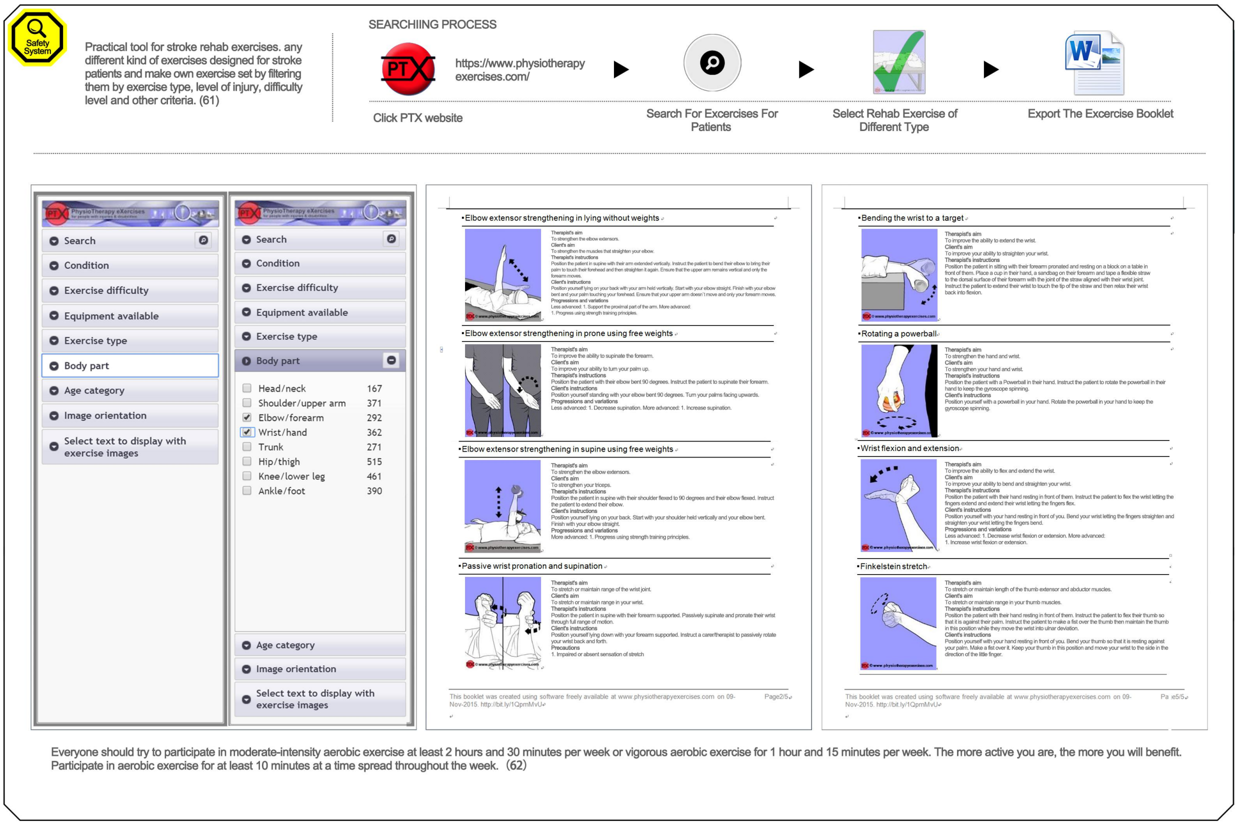

Figure 27 - Search Exercise Programs for Stroke Patient (The Physio Therapy eXercises 2015)

Stroke patients cannot always control limbs because of the rupture of blood vessels in the brain, leading to muscle atrophy. After stroke patients received cerebrovascular procedure, limb muscles are still in the atrophic or uncontrolled state. However, exercise movement practice of limbs can make muscles get rehabilitation and prevention effectively. The application of the approach in this chapter, will assume that stroke patients lose muscle motility of elbow and wrist because of the rupture of blood vessel of brain, so a set of modularized rehabilitation equipment is needed to conduct rehabilitation training of wrist and elbow.

In the first step of the design approach, a designer should obtain accurate rehabilitation exercise movements through the use of the steps of the PTX program. Firstly, a designer enters the PTX program, and chooses main symptoms and main rehabilitation body parts in the leftmost column. Then her or she chooses wrist and elbow in the list of body parts, and clicks to generate the rehabilitation exercise movement booklet. Consequently, a set of instructions, which includes the list of rehabilitation exercise movements and detailed movement guidance of four wrist joints and four elbow joints, will be established. A set of modularized rehabilitation equipment will be developed according to these eight rehabilitation movements.

4.3 Exercise Movement Classification by Types of Synovial Joints

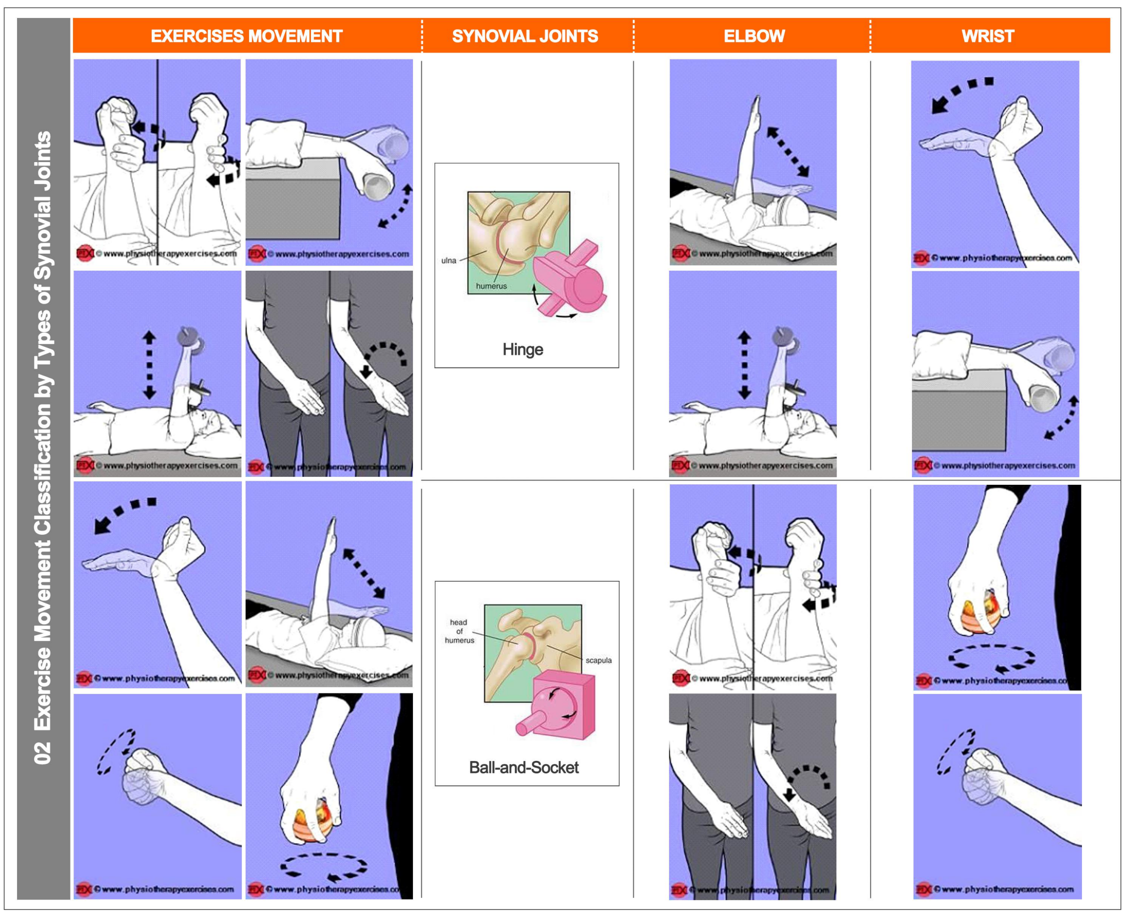

Figure 28 - Exercise Movement Classification by Types of Synovial Joints

Every synovial joint of the body can move in the connection of one or several fixed axis. These joints can be divided into hinge, pivot, gliding, condyloid, saddle and ball, six categories of connection movements. And these regular movements can assist patients to conduct rehabilitation training by taking advantage of the mechanical structure, and following this principle will not cause secondary injury of patients' bones and muscles. In this section, the rehabilitation exercise movements of eight wrist and elbow joints generated by PTX program should be divided according to the ways that skeletons connect. This study will mainly classify according to hinge joints and ball joints.

4.4 Individual Human Part Design Criteria for Module Creation

INDIVIDUAL HUMAN PART DESIGN CRITERIA FOR MODULE CREATION

Primary Treatment For **ELBOW**

Factors			Parameters	HINGE (Type of Synovial Joint) Performance Criteria	BALL-AND-SOCKET (Type of Synovial Joint) Performance Criteria
Human Function	Aesthetic	1	Product Retail Price	$200 — $250	$250 — $300
		2	Color of Power-Driven Housing	Grey / White / Black / Blue	Grey / White / Black / Blue
		3	Color of Straps	Dark Grey	Dark Grey
		4	Color of Module Connect Part	Grey / Blue	Grey / Blue
		5	Entirety Visual Appearance	Grey / White	Grey / White
	Practice Practical	6	Adjustability	Allow For People Personal Adjustment of Width and Height	Allow For People Personal Adjustment of Width and Height
		7	Ergonomics	Each Module Must Fit The Patient Comfortable	Each Module Must Fit The Patient Comfortable
		8	Stability	Can Not Movement From Elbow	Can Not Movement From Elbow
		9	Method of Control	Remote / Android App	Remote / Android App
		10	Assembly Speed	Must Simple and Fast	Must Simple and Fast
		11	Use Environmental	Home / Outdoor / Travel	Home / Outdoor / Travel
		12	Weight of Equipment	Less Than 20 lbs	Less Than 25 lbs
		13	Height of Equipment Collapsed	200 Millimeter or Less	200 Millimeter or Less
		14	Height of Equipment Extended	300 Millimeter or Less	300 Millimeter or Less
		15	Width of Equipment Collapsed	100 Millimeter or Less	100 Millimeter or Less
		16	Width of Equipment Extended	150 Millimeter or Less	200 Millimeter or Less
		17	Width of Straps	25.4 Millimeter or Less	25.4 Millimeter or Less
Technical Function	Production	18	Assembly Method	Automated or Manual	Automated or Manual
		19	Color Application	Digital Print	Digital Print
		20	Prodution Process	3D Print for Final Model	3D Print for Final Model
	Internal Tech	21	Material for Main Power Motor	Stepper Motor or Servo Motor	Stepper Motor or Servo Motor
		22	Material For Signal Receiver	Wireless Wifi or Bluetooth Receiver Board	Wireless Wifi or Bluetooth Receiver Board
		23	Power Supply	Tiny Battery	Tiny Battery
		24	Main CPU	Atmel Atmega328p or Atmel Atmega328	Atmel Atmega328p or Atmel Atmega328
		25	Circuit Board	Arduino Nano Board or Arduino Uno	Arduino Nano Board or Arduino Uno
		26	Material For Connect Module	ABS Plastic	ABS Plastic
		27	Material For Straps	Nylon Velcro	Nylon Velcro
		28	Material For Padding	Soft Rubber or Polyethylene Foam	Soft Rubber or Polyethylene Foam
		29	Material For Power Housing	ABS Plastic	ABS Plastic
		30	Material For Connect Element	ABS Plastic or Strong Magnet	ABS Plastic or Strong Magnet
		31	Material For Light	Tiny LED	Tiny LED
	External Tech	32	Durability	Withstand Long Periods of Exercise Movement	Withstand Long Periods of Exercise Movement
		33	Cleaning of Equipment	Hand Wash	Hand Wash
		34	Emergency Detachment System	Quick Release	Quick Release
		35	Number of Module Part	Less Than 14	Less Than 14
		36	Number of Power-driven	Less Than 5	Less Than 5
		37	Rotating Rate	Adjustable Speed	Adjustable Speed

Figure 29 - Individual Human Part Design Criteria For Module Creation For Elbow

INDIVIDUAL HUMAN PART DESIGN CRITERIA FOR MODULE CREATION

Primary Treatment For **WRIST**

Factors			Parameters	HINGE (Type of Synovial Joint) Performance Criteria	BALL-AND-SOCKET (Type of Synovial Joint) Performance Criteria
Human Function	Aesthetic	1	Product Retail Price	\$200 — \$250	\$250 — \$300
		2	Color of Power-Driven Housing	Grey / White / Black / Blue	Grey / White / Black / Blue
		3	Color of Straps	Dark Grey	Dark Grey
		4	Color of Module Connect Part	Grey / Blue	Grey / Blue
		5	Entirety Visual Appearance	Grey / White	Grey / White
	Practice Practical	6	Adjustability	Allow For People Personal Adjustment of Width and Height	Allow For People Personal Adjustment of Width and Height
		7	Ergonomics	Each Module Must Fit The Patient Comfortable	Each Module Must Fit The Patient Comfortable
		8	Stability	Can Not Movement From Elbow	Can Not Movement From Elbow
		9	Method of Control	Remote / Android App	Remote / Android App
		10	Assembly Speed	Must Simple and Fast	Must Simple and Fast
		11	Use Environmental	Home / Outdoor / Travel	Home / Outdoor / Travel
		12	Weight of Equipment	Less Than 20 lbs	Less Than 25 lbs
		13	Height of Equipment Collapsed	200 Millimeter or Less	200 Millimeter or Less
		14	Height of Equipment Extended	300 Millimeter or Less	300 Millimeter or Less
		15	Width of Equipment Collapsed	100 Millimeter or Less	100 Millimeter or Less
		16	Width of Equipment Extended	150 Millimeter or Less	200 Millimeter or Less
		17	Width of Straps	25.4 Millimeter or Less	25.4 Millimeter or Less
Technical Function	Production	18	Assembly Method	Automated or Manual	Automated or Manual
		19	Color Application	Digital Print	Digital Print
		20	Prodution Process	3D Print for Final Model	3D Print for Final Model
	Internal Tech	21	Material for Main Power Motor	Stepper Motor or Servo Motor	Stepper Motor or Servo Motor
		22	Material For Signal Receiver	Wireless Wifi or Bluetooth Receiver Board	Wireless Wifi or Bluetooth Receiver Board
		23	Power Supply	Tiny Battery	Tiny Battery
		24	Main CPU	Atmel Atmega328p or Atmel Atmega328	Atmel Atmega328p or Atmel Atmega328
		25	Circuit Board	Arduino Nano Board or Arduino Uno	Arduino Nano Board or Arduino Uno
		26	Material For Connect Module	ABS Plastic	ABS Plastic
		27	Material For Straps	Nylon Velcro	Nylon Velcro
		28	Material For Padding	Soft Rubber or Polyethylene Foam	Soft Rubber or Polyethylene Foam
		29	Material For Power Housing	ABS Plastic	ABS Plastic
		30	Material For Connect Element	ABS Plastic or Strong Magnet	ABS Plastic or Strong Magnet
		31	Material For Light	Tiny LED	Tiny LED
	External Tech	32	Durability	Withstand Long Periods of Exercise Movement	Withstand Long Periods of Exercise Movement
		33	Cleaning of Equipment	Hand Wash	Hand Wash
		34	Emergency Detachment System	Quick Release	Quick Release
		35	Number of Module Part	Less Than 12	Less Than 14
		36	Number of Power-driven	Less Than 4	Less Than 5
		37	Rotating Rate	Adjustable Speed	Adjustable Speed

Figure 30 - Individual Human Part Design Criteria For Module Creation For Wrist

After research on the rehabilitation exercise movements of elbow and wrist, a design criteria with a parameter list needs to be established, and then the design criteria used to develop a set of brand new conceptual products. In the application of the approach in this chapter, it is necessary to build design criteria separately for elbow parts and wrist parts. Every body part is classified according to the ways that synovial joints move.

As a utility, the design criteria require that new product concepts must satisfy all parameter data. The parameter data should take human factors, technology factors and production factors into consideration. The human factors include aesthetics parameters and practical parameters, which can effectively control and improve the man-machine interaction of concepts, such as the influences of product color parameters on patients, influences of product appearance on patients, and influences of product size on patients. When a conceptual product meets all these conditions at the same time, then this product is proved to be able to apply to patients well. In terms of science and technology factors, requirements on technology realization are set for conceptual products, so designers realize the applicability of products through the internal technical requirements and external technical requirements of products.

4.5 The Structure and Function Realization of Synovial Joint Equipment

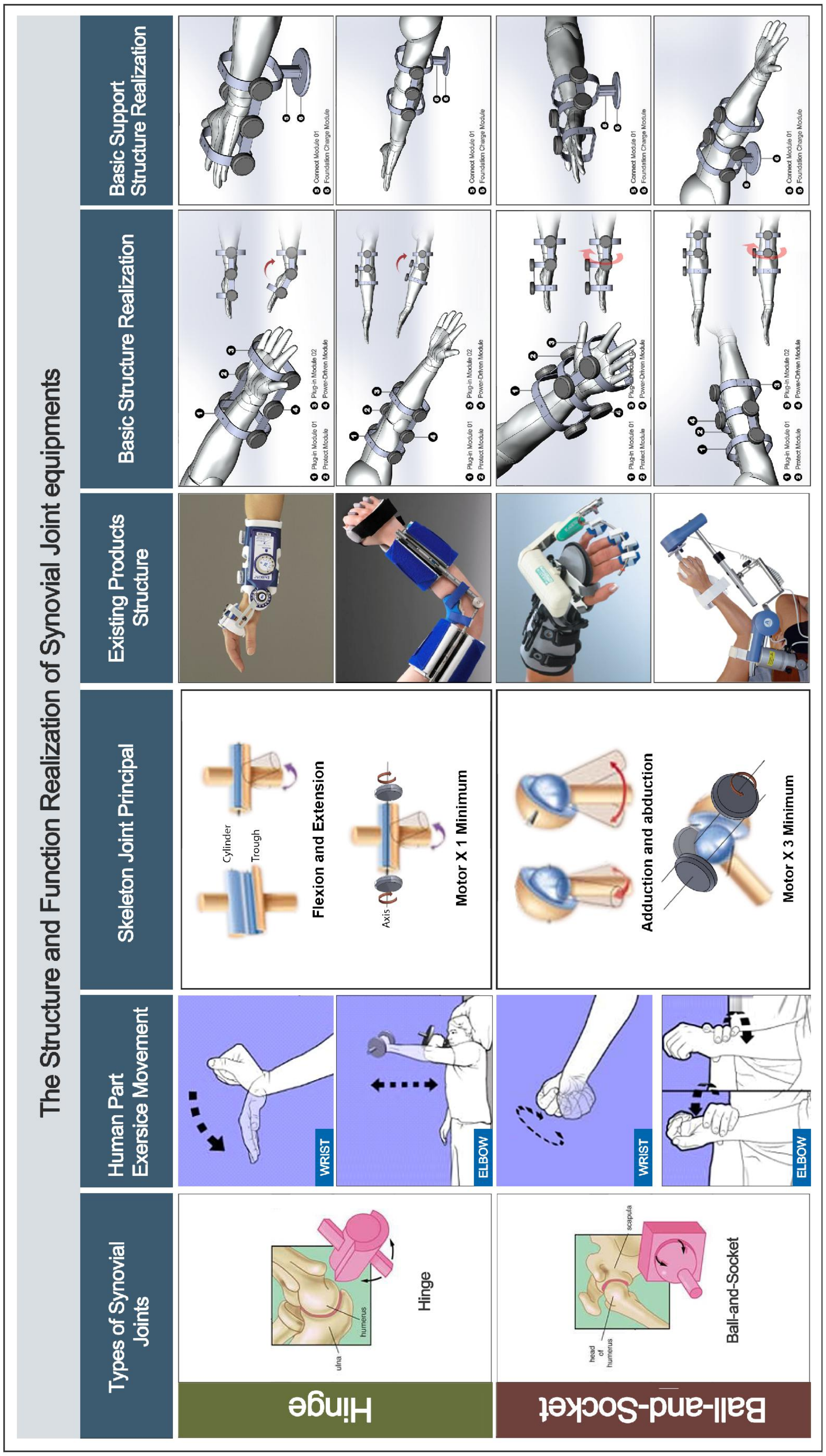

Figure 31 - The Structure and Function Realization of Synovial Joint equipments

After finishing the establishment of the design criteria, we can carry out the initial structural design of concepts according to the design parameters in it. During the process of structure realization, designers should find the things in common among conceptual products of every body part and every bone and joint, and then classify them to serve as the primary basis for developing modular rehabilitation equipment. In the unit of bone connection principle, the principle of bone connection and needed amount of kinetic energy has been listed. Designers need to use bone connection principle, analysis of existing product structure and parameters of design criteria to design the initial structural model.

In this section, according to the hinge connection and ball connection in the ways of bone connection, two rehabilitation movement patterns of wrist and elbow are entered separately. And the structural principle of conceptual products and support structural principle through the analysis on the central axis of skeleton movement and analysis on the structure of existing rehabilitation products are obtained. At last, the name of every main part is marked with sequential numbers. Therefore, designers can clearly find the common parts of four conceptual products. These parts will be listed into different module types based on different functions.

4.6 Module Creation

Figure 32 - Module Creation

After the main parts of four rehabilitation conceptual products are classified, we should start to carry out modularized processing on every type of parts. And the modularized process needs to carry out secondary classification on all parts according to the realizability of functions, and use SolidWorks and other computer software is used to conduct 3D modeling, which can modify and analyze the structure and appearance of models more intuitively.

In this chapter, all components are divided into three categories, including module of motor drive, independent element and support structure module, and connection module. After having the library of these three kinds of modules, we can assemble rehabilitation equipment according to the specific demands of stroke patients. In the application of the design methodology, module assembly for wrist and elbow is conducted separately according to hinge connection and ball connection of bones. And the support structure of the equipment is listed at the bottom of completely assembled rehabilitation equipment. This makes it more convenient and effective for patients to use the equipment.

4.7 Primary Human Part Concept Preliminary Sketch

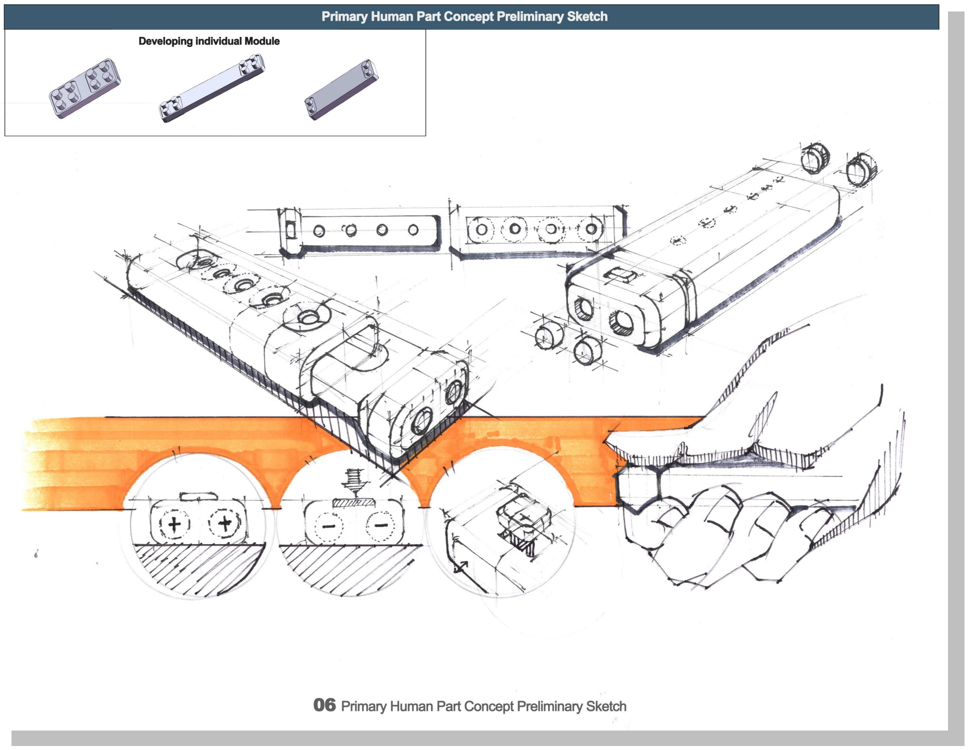

Figure 33 - Concept Preliminary Sketch 01

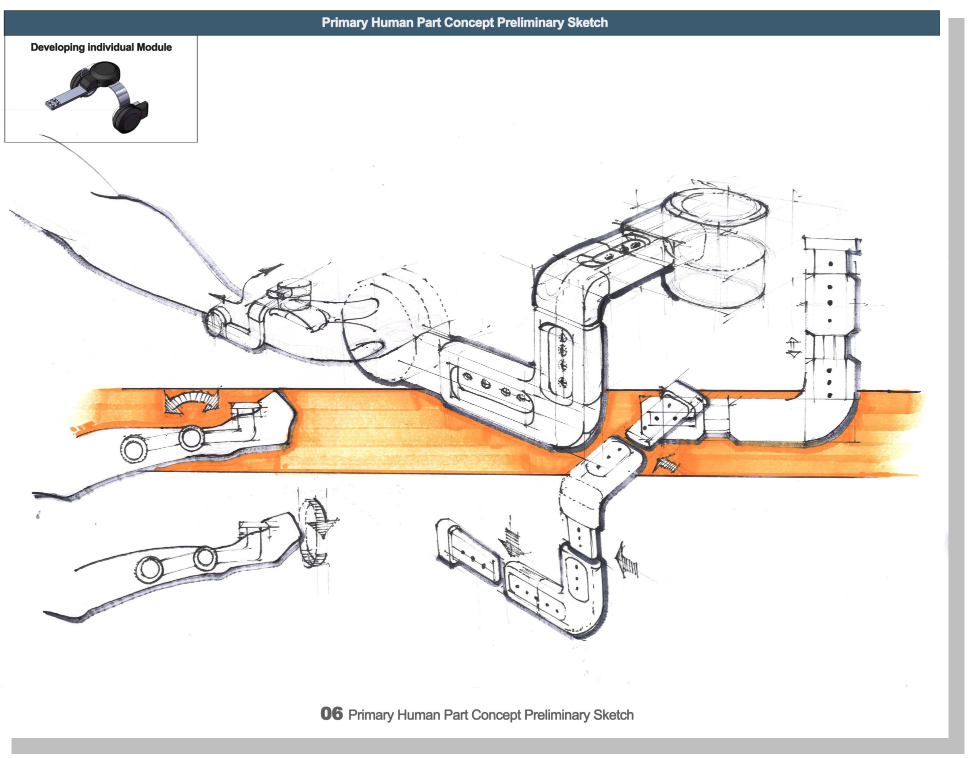

Figure 34 - Concept Preliminary Sketch 02

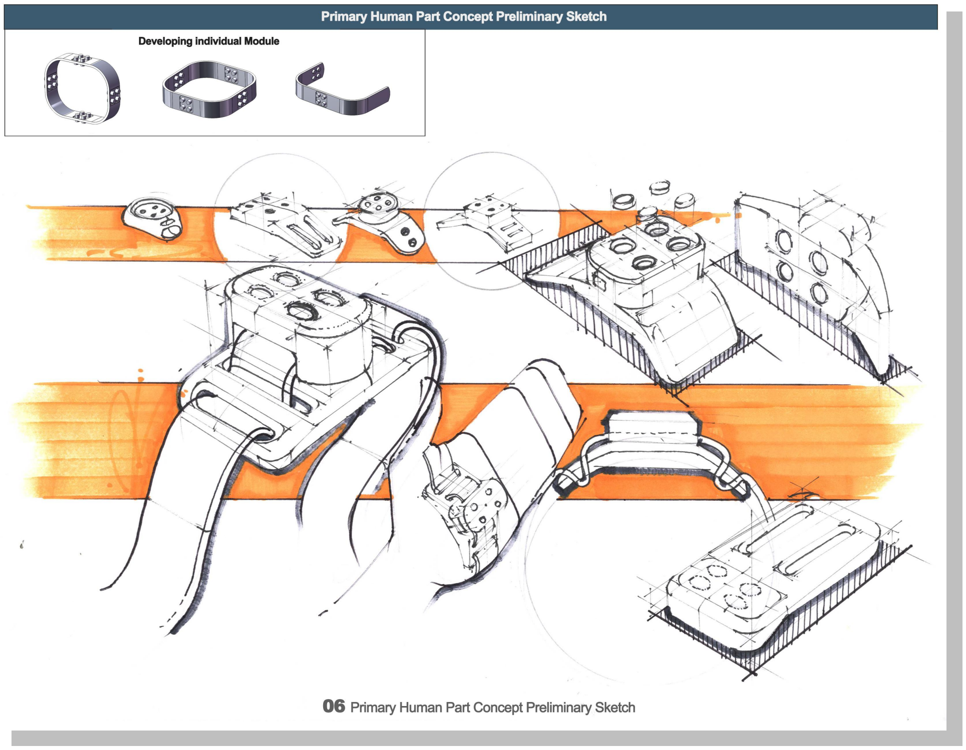

Figure 35 - Concept Preliminary Sketch 03

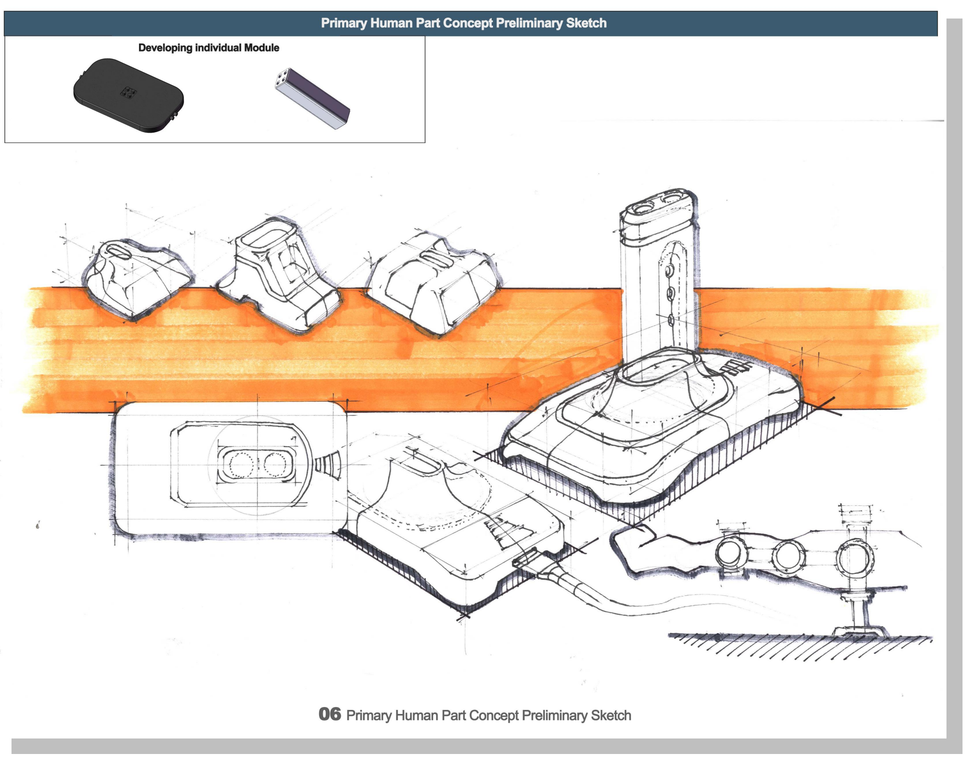

Figure 36 - Concept Preliminary Sketch 04

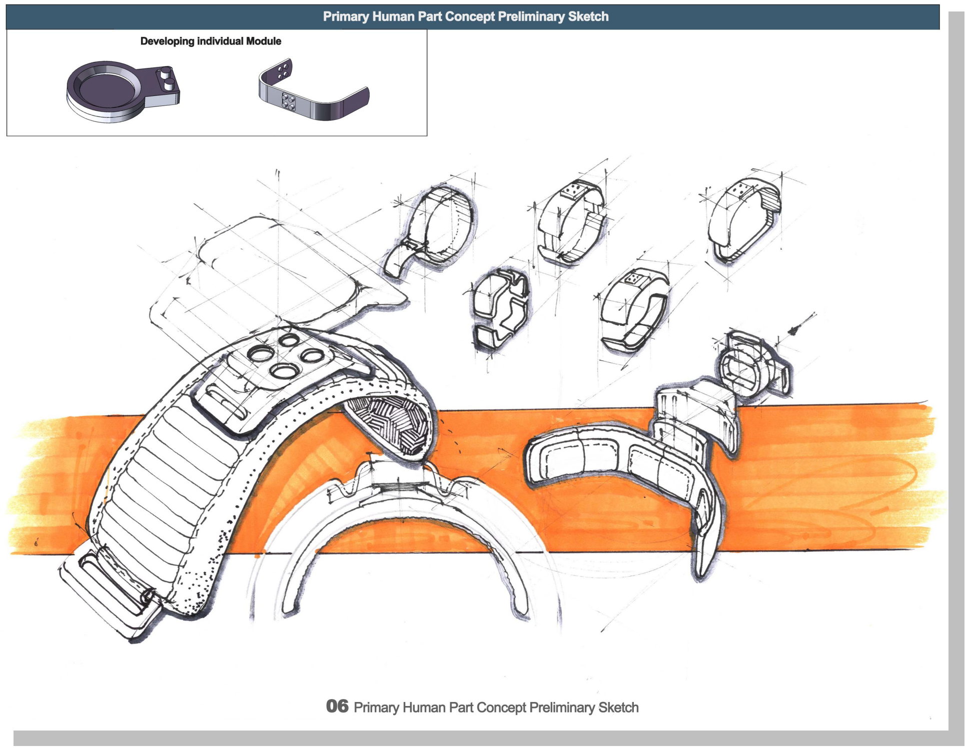

Figure 37 - Concept Preliminary Sketch 05

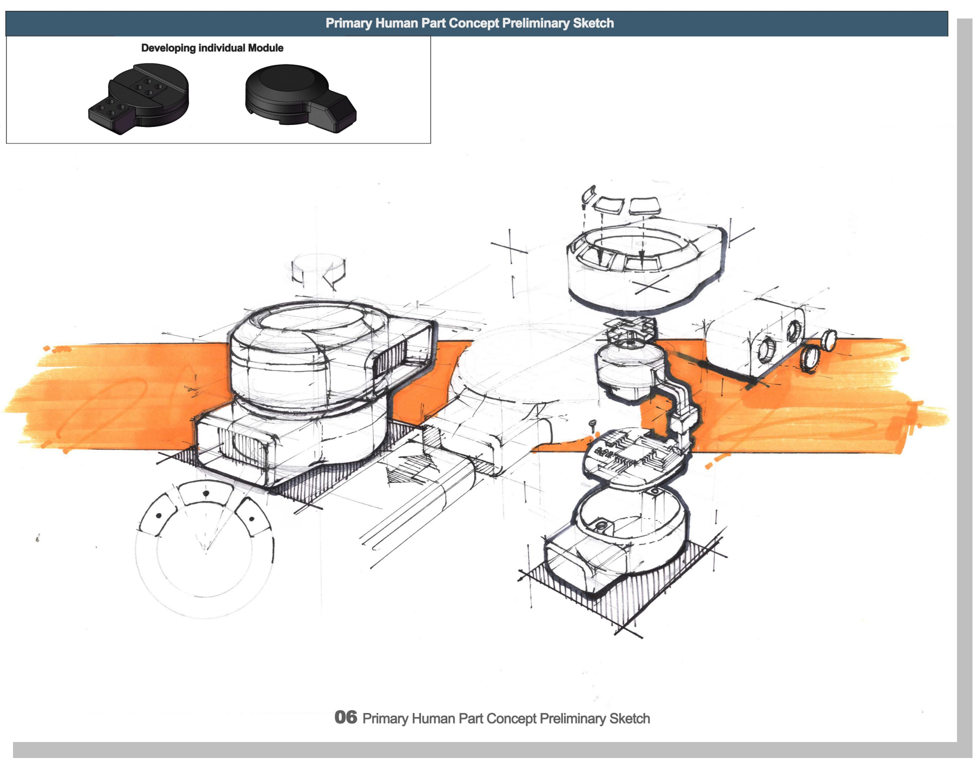

Figure 38 - Concept Preliminary Sketch 06

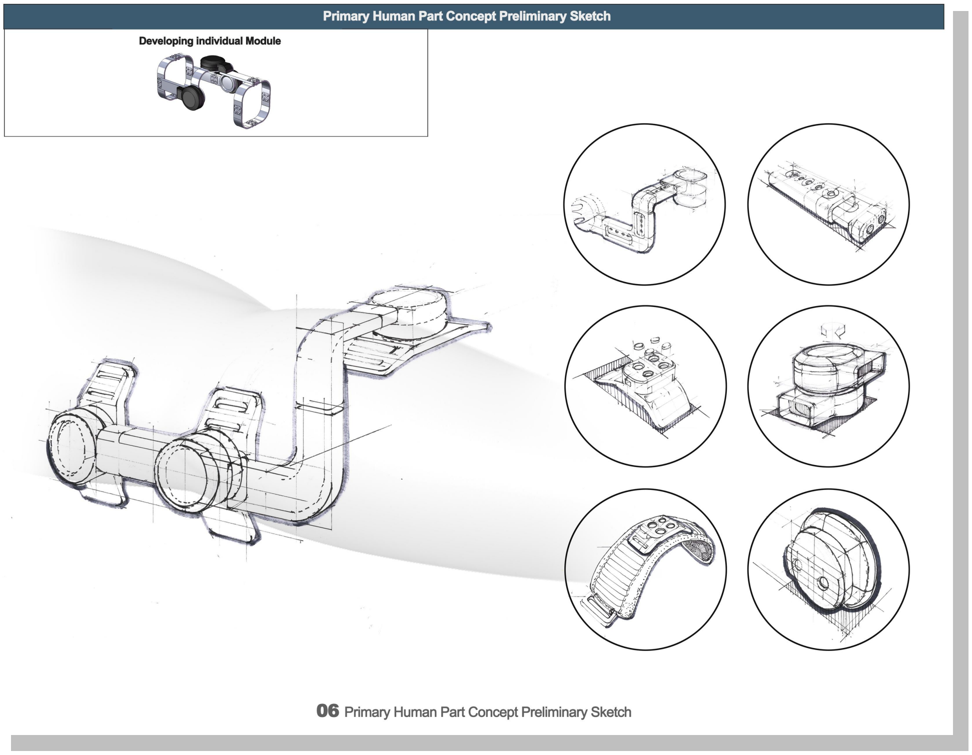

Figure 39 - Primary Human Part Concept Preliminary Sketch 07

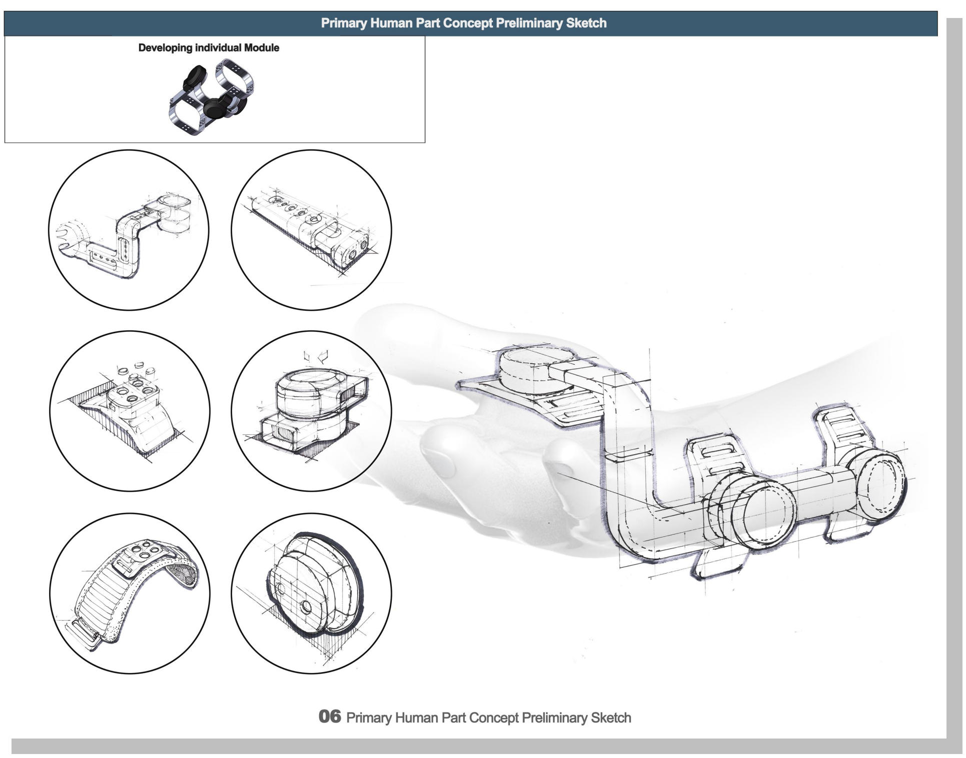

Figure 40 - Primary Human Part Concept Preliminary Sketch 08

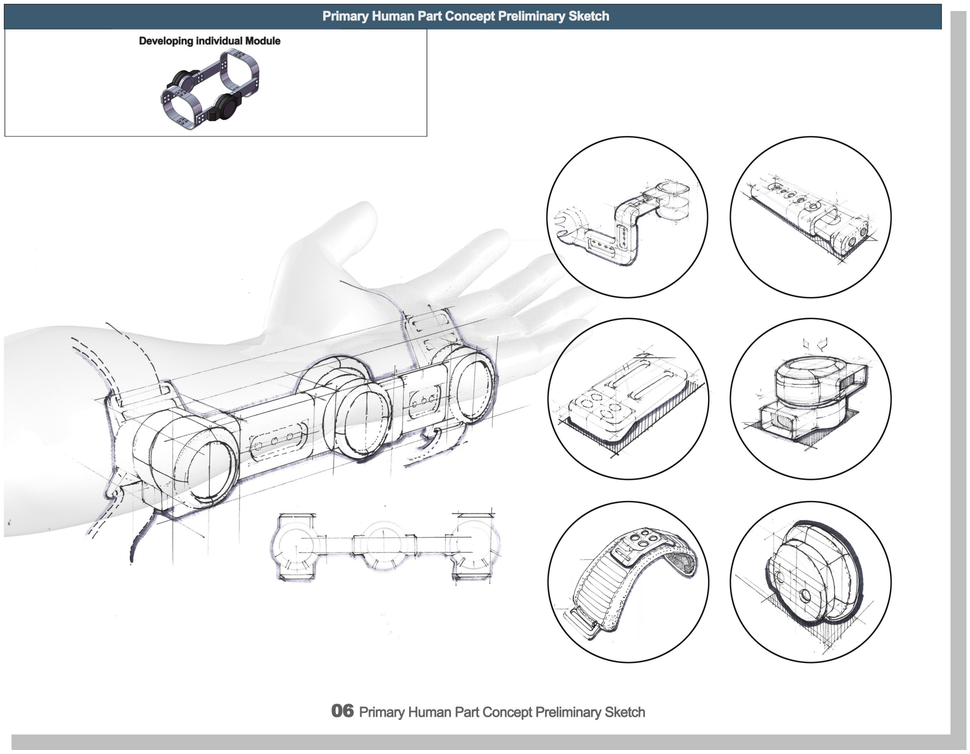

Figure 41 - Primary Human Part Concept Preliminary Sketch 09

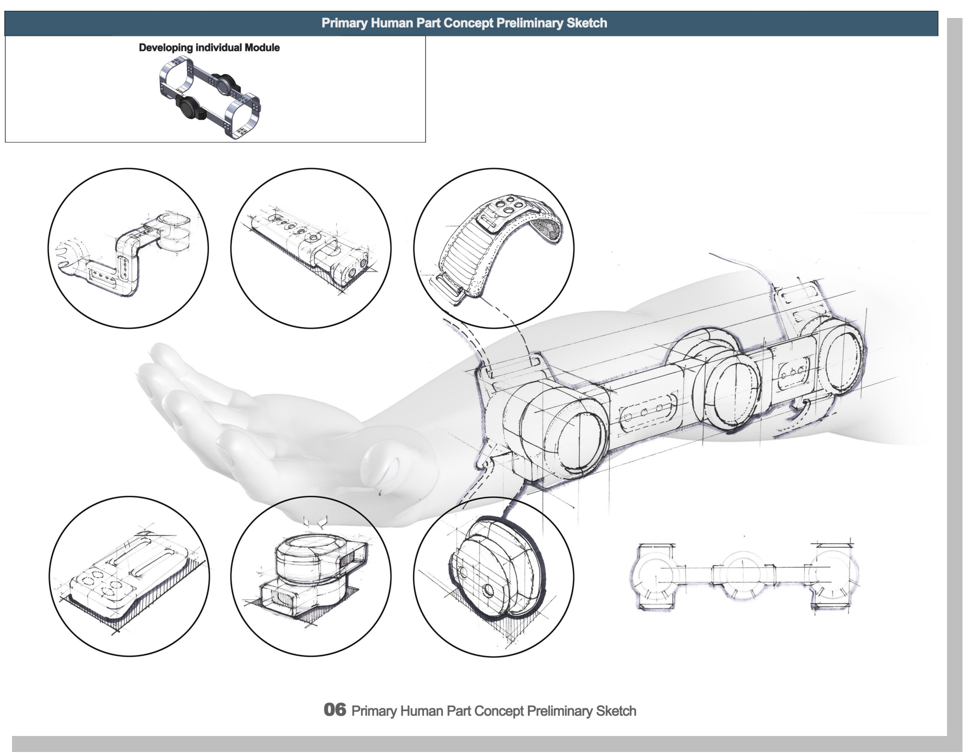

Figure 42 - Primary Human Part Concept Preliminary Sketch 10

In this step, designers need to sketch all determined module units and then design. The concept sketches will make every module more multi-functional by combining and decreasing the unnecessary parts. The sketches are used to show the internal and external technology application of modules. Each concept sketch is discussed here Concept sketch 1: the interior of motor drive module consists of servo motor, circuit board, Bluetooth Receiver, bearings, these four parts, can use remote control to control its direction of rotation, rotation angle and rotation dynamics. Concept sketch 2: the original three connection modules have been designed to be retractable connection structure through merging, and using fasteners can fix its length. Concept sketch 3: this is the inserted module, mainly applied to the connection between each module as the base. It is fixed on each part of the body by a bandage. Concept sketch 4: merge three driver modules and two connection modules to get a retractable connection module. This module can effectively help realize the connection movement of spherical bones and is suitable for wrist and elbow. Concept sketch 5: the protection module is composed of a protection pad and linker, and its main function is to make every module fit the body parts of patients comfortably. Concept sketch 6: it is the module equipment assembled by more than 6 modules for the rehabilitation of hand elbow. It consists of 3 driver modules, 2 connection modules and 3 protection modules, can realized the passive, active and assistant rehabilitation exercise of hand elbow. It is mainly controlled by a cellphone app. Concept sketch 7: it is the module equipment assembled by more than 6 modules for the Ball-and-socket exercise movement rehabilitation of hand wrist. Concept sketch 8: it is the module equipment assembled by more than 6 modules for the hinge exercise movement rehabilitation of hand wrist. Concept sketch 9: it is the module equipment assembled by more than 6 modules for the hinge exercise movement rehabilitation of hand elbow.

4.8 Modules Base Construction

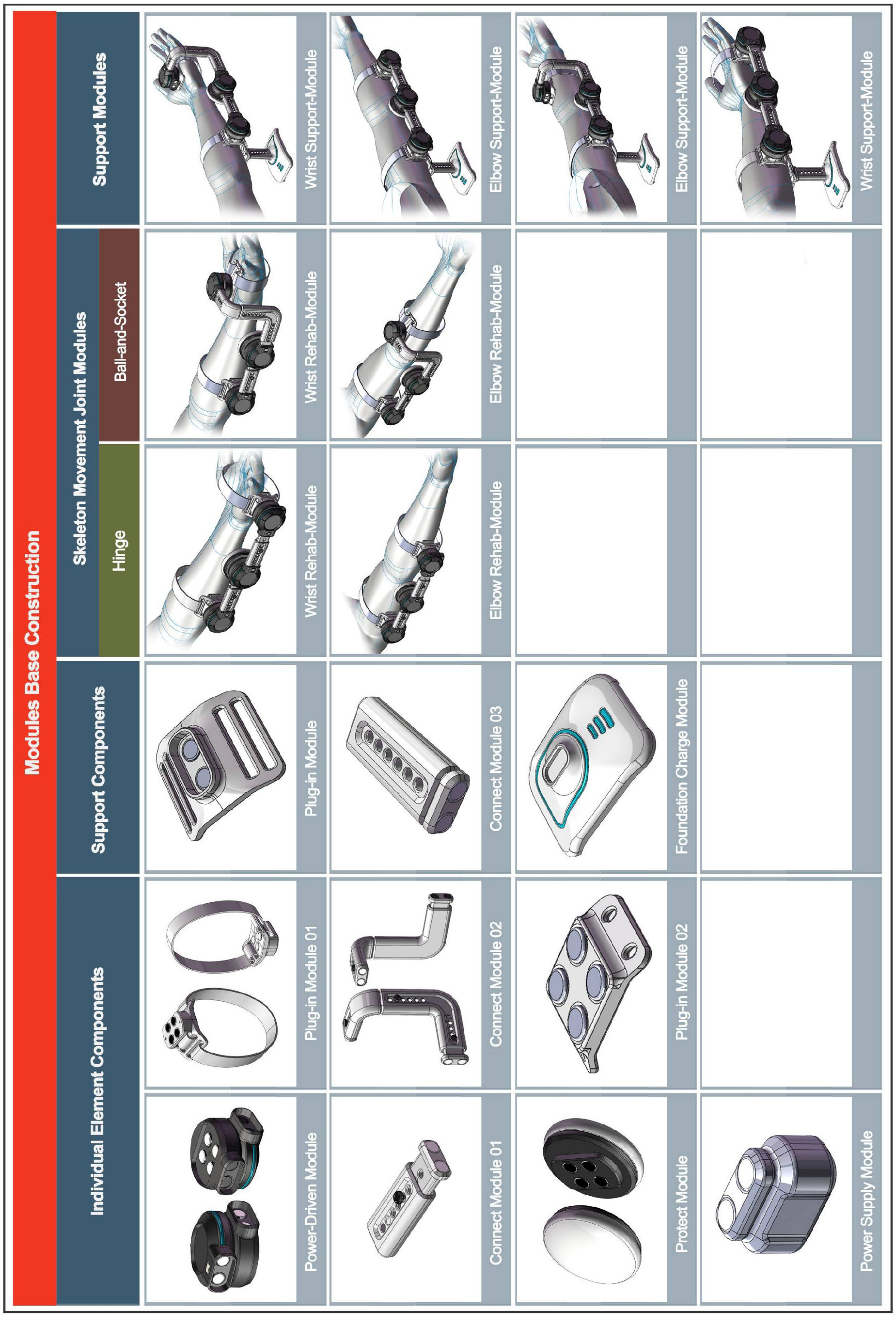

Figure 43 - Modules Base Construction

After finishing the rough draft of the design concepts, designers need to use 3D modeling software to build three-dimensional objects according to every scheme, and then put them into the module database according to their own categories. These modules would be assembled by designer, doctors and therapists on the basis of patients' requirements. In this step, the module base is classified according to four categories; respectively these are module database of independent element, module database of independent support, module database of bone connection and support module database. In the module database of bone connection, though it is perfect module equipment, it still can be assembled with other modules as a module, which greatly improves modular expansibility.

4.9 Evaluation Checklist for Concepts

INDIVIDUAL HUMAN PART DESIGN CRITERIA FOR MODULE CREATION

Primary Treatment For **WRIST**

Factors			Parameters	HINGE (Type of Synovial Joint) Performance Criteria	Module Concept 01	Score (1-5)	Average	BALL-AND-SOCKET (Type of Synovial Joint) Performance Criteria	Module Concept 02	Score (1-5)	Average
Human Function	Aesthetic	1	Product Retail Price	$200 — $250	$216 For Prototype	5		$250 — $300	$219.9 For Prototype	5	
		2	Color of Power-Driven Housing	Grey / White / Black / Blue	White	4		Grey / White / Black / Blue	White	4	
		3	Color of Straps	Dark Grey	Dark Grey	5		Dark Grey	Dark Grey	5	
		4	Color of Module Light	Warm Green / Warm Blue / Red	Warm Green	4		Grey / Blue	Warm Green	4	
		5	Entirety Visual Appearance	Grey / White	White	3		Grey / White	White	3	
						Total = 21	Avg = 4.2			Total = 21	Avg = 4.2
	Practice Practical	6	Adjustability	Allow For People Personal Adjustment of Width and Height	Adjustable Product Wieth, Length and Straps	4		Allow For People Personal Adjustment of Width and Height	Adjustable Product Wieth, Length and Straps	4	
		7	Ergonomics	Each Module Must Fit The Patient Comfortable	Form Fitting and Adjustable	5		Each Module Must Fit The Patient Comfortable	Form Fitting and Adjustable	5	
		8	Stability	Can Not Movement From Elbow And Wrist When Using Condition	Can Not Movement From Wrist When Using Module Equipment	4		Can Not Movement From Elbow	Can Not Movement From Wrist When Using Module Equipment	4	
		9	Method of Control	Remote / Android App	Android App	2		Remote / Android App	Android App	2	
		10	Assembly Speed	Must Simple and Quick	Assembly Speed is Quick by Stroke Patient	3		Must Simple and Fast	Assembly Speed is Quick by Stroke Patient	3	
		11	Use Environmental	Home / Outdoor / Travel	Home / Travel	4		Home / Outdoor / Travel	Home / Travel	4	
		12	Weight of Equipment	Less Than 20 lbs	8 lbs	5		Less Than 25 lbs	10 lbs	5	
		13	Height of Equipment Collapsed	250 Millimeter or Less	256 Millimeter	5		200 Millimeter or Less	256 Millimeter	5	
		14	Height of Equipment Extended	350 Millimeter or Less	320 Millimeter	5		300 Millimeter or Less	320 Millimeter	5	
		15	Width of Equipment Collapsed	150 Millimeter or Less	177 Millimeter	5		100 Millimeter or Less	177 Millimeter	5	
		16	Width of Equipment Extended	250 Millimeter or Less	210 Millimeter	5		200 Millimeter or Less	210 Millimeter	5	
		17	Width of Straps	25.4 Millimeter or Less	25.4 Millimeter	5		25.4 Millimeter or Less	25.4 Millimeter	5	
						Total = 52	Avg = 4.3			Total = 52	Avg = 4.3
Technical Function	Production	18	Assembly Method	Automated or Manual	Manual by Patient	5		Automated or Manual	Manual by Patient	5	
		19	Color Application	Digital Print / Manual Print	Manual Print	2		Digital Print	Manual Print	2	
		20	Prodution Process	3D Print for Final Model	3D Print for Main Module Parts	4		3D Print for Final Model	3D Print for Main Module Parts	4	
						Total = 11	Avg = 3.6			Total = 11	Avg = 3.6
	Internal Tech	21	Material for Main Power Motor	Stepper Motor or Servo Motor	Servo Motor	4		Stepper Motor or Servo Motor	3D Print for Main Module Parts	4	
		22	Material For Signal Receiver	Wireless Wifi or Bluetooth Receiver Board	Wireless Wifi or Bluetooth Receiver Board	5		Wireless Wifi or Bluetooth Receiver Board	Wireless Wifi or Bluetooth Receiver Board	5	
		23	Power Supply	Tiny Battery	EnergyShield - Rechargeable Battery with Solar Charging	4		Tiny Battery	EnergyShield - Rechargeable Battery with Solar Charging	4	
		24	Main CPU	Atmel Atmega328p or Atmel Atmega328	Atmel Atmega328p	4		Atmel Atmega328p or Atmel Atmega328	Atmel Atmega328p	4	
		25	Circuit Board	Arduino Nano Board or Arduino Uno	Arduino Nano Board	5		Arduino Nano Board or Arduino Uno	Arduino Nano Board	5	
		26	Material For Connect Module	ABS Plastic	ABS Plastic	5		ABS Plastic	ABS Plastic	5	
		27	Material For Straps	Nylon Velcro	Nylon Velcro	5		Nylon Velcro	Nylon Velcro	5	
		28	Material For Padding	Soft Rubber or Polyethylene Foam	Soft Rubber	5		Soft Rubber or Polyethylene Foam	Soft Rubber	5	
		29	Material For Power Housing	ABS Plastic	ABS Plastic	4		ABS Plastic	ABS Plastic	4	
		30	Material For Connect Element	ABS Plastic or Strong Magnet	Strong Magnet	4		ABS Plastic or Strong Magnet	Strong Magnet	4	
		31	Material For Light	Tiny LED	Warm Green Tiny LED	3		Tiny LED	Warm Green Tiny LED	3	
						Total = 48	Avg = 4.3			Total = 48	Avg = 4.3
	External Tech	32	Durability	Withstand Long Periods of Exercise Movement	Withstand Long Periods of Exercise Movement	3		Withstand Long Periods of Exercise Movement	Withstand Long Periods of Exercise Movement	3	
		33	Cleaning of Equipment	Hand Wash	Hand Wash	3		Hand Wash	Hand Wash	3	
		34	Emergency Detachment System	Quick Release	Quick Release by Release Push Button	4		Quick Release	Quick Release by Release Push Button	4	
		35	Number of Module Part	Less Than 12	10 Components	5		Less Than 14	11 Components	5	
		36	Number of Power-driven	Less Than 4	1 Component	5		Less Than 5	3 Component	5	
		37	Rotating Rate	Adjustable Speed	Adjustable Speed and Rotation	5		Adjustable Speed	Adjustable Speed and Rotation	5	
						Total = 25	Avg = 4.1			Total = 25	Avg = 4.1
						Total = 157	Avg = 4.2			Total = 157	Avg = 4.2

Figure 44 - Evaluation Checklist For Wrist Concepts

INDIVIDUAL HUMAN PART DESIGN CRITERIA FOR MODULE CREATION

Primary Treatment For **Elbow**

Factors			Parameters	HINGE (Type of Synovial Joint) Performance Criteria	Module Concept 01	Score (1-5)	Average	BALL-AND-SOCKET (Type of Synovial Joint) Performance Criteria	Module Concept 02	Score (1-5)	Average
Human Function	Aesthetic	1	Product Retail Price	$200 — $250	$216 For Prototype	5		$250 — $300	$219.9 For Prototype	5	
		2	Color of Power-Driven Housing	Grey / White / Black / Blue	White	4		Grey / White / Black / Blue	White	4	
		3	Color of Straps	Dark Grey	Dark Grey	5		Dark Grey	Dark Grey	5	
		4	Color of Module Light	Warm Green / Warm Blue / Red	Warm Green	4		Grey / Blue	Warm Green	4	
		5	Entirety Visual Appearance	Grey / White	White	3		Grey / White	White	3	
						Total = 21	Avg = 4.2			Total = 21	Avg = 4.2
	Practice Practical	6	Adjustability	Allow For People Personal Adjustment of Width and Height	Adjustable Product Wieth, Length and Straps	4		Allow For People Personal Adjustment of Width and Height	Adjustable Product Wieth, Length and Straps	4	
		7	Ergonomics	Each Module Must Fit The Patient Comfortable	Form Fitting and Adjustable	5		Each Module Must Fit The Patient Comfortable	Form Fitting and Adjustable	5	
		8	Stability	Can Not Movement From Elbow And Wrist When Using Condition	Can Not Movement From Elbow When Using Module Equipment	4		Can Not Movement From Elbow	Can Not Movement From Elbow When Using Module Equipment	4	
		9	Method of Control	Remote / Android App	Android App	2		Remote / Android App	Android App	2	
		10	Assembly Speed	Must Simple and Quick	Assembly Speed is Quick by Stroke Patient	3		Must Simple and Fast	Assenmbly Speed is Quick by Stroke Patient	3	
		11	Use Environmental	Home / Outdoor / Travel	Home / Travel	4		Home / Outdoor / Travel	Home / Travel	4	
		12	Weight of Equipment	Less Than 20 lbs	8 lbs	5		Less Than 25 lbs	10 lbs	5	
		13	Height of Equipment Collapsed	250 Millimeter or Less	256 Millimeter	5		200 Millimeter or Less	256 Millimeter	5	
		14	Height of Equipment Extended	350 Millimeter or Less	320 Millimeter	5		300 Millimeter or Less	320 Millimeter	5	
		15	Width of Equipment Collapsed	150 Millimeter or Less	177 Millimeter	5		100 Millimeter or Less	177 Millimeter	5	
		16	Width of Equipment Extended	250 Millimeter or Less	210 Millimeter	5		200 Millimeter or Less	210 Millimeter	5	
		17	Width of Straps	25.4 Millimeter or Less	25.4 Millimeter	5		25.4 Millimeter or Less	25.4 Millimeter	5	
						Total = 52	Avg = 4.3			Total = 52	Avg = 4.3
Technical Function	Production	18	Assembly Method	Automated or Manual	Manual by Patient	5		Automated or Manual	Manual by Patient	5	
		19	Color Application	Digital Print / Manual Print	Manual Print	2		Digital Print	Manual Print	2	
		20	Prodution Process	3D Print for Final Model	3D Print for Main Module Parts	4		3D Print for Final Model	3D Print for Main Module Parts	4	
						Total = 11	Avg = 3.6			Total = 11	Avg = 3.6
	Internal Tech	21	Material for Main Power Motor	Stepper Motor or Servo Motor	Servo Motor	4		Stepper Motor or Servo Motor	3D Print for Main Module Parts	4	
		22	Material For Signal Receiver	Wireless Wifi or Bluetooth Receiver Board	Wireless Wifi or Bluetooth Receiver Board	5		Wireless Wifi or Bluetooth Receiver Board	Wireless Wifi or Bluetooth Receiver Board	5	
		23	Power Supply	Tiny Battery	EnergyShield - Rechargeable Battery with Solar Charging	4		Tiny Battery	EnergyShield - Rechargeable Battery with Solar Charging	4	
		24	Main CPU	Atmel Atmega328p or Atmel Atmega328	Atmel Atmega328p	4		Atmel Atmega328p or Atmel Atmega328	Atmel Atmega328p	4	
		25	Circuit Board	Arduino Nano Board or Arduino Uno	Arduino Nano Board	5		Arduino Nano Board or Arduino Uno	Arduino Nano Board	5	
		26	Material For Connect Module	ABS Plastic	ABS Plastic	5		ABS Plastic	ABS Plastic	5	
		27	Material For Straps	Nylon Velcro	Nylon Velcro	5		Nylon Velcro	Nylon Velcro	5	
		28	Material For Padding	Soft Rubber or Polyethylene Foam	Soft Rubber	5		Soft Rubber or Polyethylene Foam	Soft Rubber	5	
		29	Material For Power Housing	ABS Plastic	ABS Plastic	4		ABS Plastic	ABS Plastic	4	
		30	Material For Connect Element	ABS Plastic or Strong Magnet	Strong Magnet	4		ABS Plastic or Strong Magnet	Strong Magnet	4	
		31	Material For Light	Tiny LED	Warm Green Tiny LED	3		Tiny LED	Warm Green Tiny LED	3	
						Total = 48	Avg = 4.3			Total = 48	Avg = 4.3
	External Tech	32	Durability	Withstand Long Periods of Exercise Movement	Withstand Long Periods of Exercise Movement	3		Withstand Long Periods of Exercise Movement	Withstand Long Periods of Exercise Movement	3	
		33	Cleaning of Equipment	Hand Wash	Hand Wash	3		Hand Wash	Hand Wash	3	
		34	Emergency Detachment System	Quick Release	Quick Release by Release Push Button	4		Quick Release	Quick Release by Release Push Button	4	
		35	Number of Module Part	Less Than 12	10 Components	5		Less Than 14	11 Components	5	
		36	Number of Power-driven	Less Than 4	1 Component	5		Less Than 5	3 Component	5	
		37	Rotating Rate	Adjustable Speed	Adjustable Speed and Rotation	5		Adjustable Speed	Adjustable Speed and Rotation	5	
						Total = 25	Avg = 4.1			Total = 25	Avg = 4.1
						Total = 157	Avg = 4.2			Total = 157	Avg = 4.2

Figure 45 - Evaluation Checklist for Elbow Concepts

The design criteria is used to restrict design factors and make designers be able to derive concepts according to every parameter, while design evaluation checklist is used to check whether this concept can completely meet every parameter in the previous design criteria and grade each concept. The detailed assessment categories, adopt the three factors, human factors, technology factors and manufacturing factors, similarly. In this step, a designer should regard the four rehabilitation equipment of the skeleton joints module as the object for evaluation from the module base. The grade of appearance and internal technology is from 1 to 5. The first evaluation checklist diagram is to assess the hinge joint module rehab-equipment and ball-and-socket joint module equipment for wrist joints, all the grades reach 4.2. The second evaluation checklist diagram is to assess the hinge joint module equipment and ball-and-socket joint module equipment for elbow joints, and all the grades reach to 4.2. As a result, these four rehabilitation equipment modules can be regarded as the ultimate model at the same time.

4.10 Final Model

The final design will selected from evaluation result of the design whose score is above the needed average 3.5. The final module equipment will created in SolidWorks which is a 3D modeling software, and rendering in Keyshot that is a 3D model material rendering software. There are two rehab-equipments from the types of synovial joint in different human bodies in this example. The wrist part and the elbow part will require two equipment modules respectively on the basis of the hinge joint and the ball-and-socket joint. The final module will be assembled by module-base.

Figure 46 - Final Model of Hinge Joint Movement for Elbow

Figure 47 - Final Model of Ball-and-Socket Joint Movement for Wrist

Figure 48 - Final Model of Ball-and-Socket Joint Movement for Elbow

Figure 49 - Final Model Final Model of Hinge Joint Movement for Wrist

Chapter 5

Conclusions

5.1 Summary of study

This study began with a stroke muscle rehabilitation problem and ends with modular rehab-equipment. In the processing, an approach was presented in an instructional manner, which is to be used by future designers. The approach has nine steps that were demonstrated through figures and charts to assist designers in understanding of the study's purpose.

Chapter One of this study began with the problem identification, the needs of study and solution method process. The primary problem is the muscle and skeleton joint injured of human body by blood vessel broken of stroke. The first chapter is beginning of the introduction to what stroke is and how to create a plan for modular product approach.

Chapter Two serves as the foundation to develop the design approach. According to the research of characteristics of stroke patients, types of synovial joints and what factors will provide better services to patients, the basic approach outline was created for the next phase of the study. Research of existing products' advantages and disadvantage also was included in this chapter.

Chapter Three outlines the nine steps approach, which is used to design rehab-equipment for stroke patients. Each step serves as a manual instruction to limit design factors. The result of modularization will be used in hospitals or by rehab equipment seller. Future designer will research the feedback of these modules to improve the product.

Chapter Four was the application of the design approach. A fictitious project about elbow and wrist of stroke patient was applied in this phase. Through the types of synovial joints, design criteria information and knowledge of existing products, four modular pieces of equipment was created for a patient. In the eighth step of the approach, this modular equipment was refined and evaluated for a final solution.

5.2 Suggestions for applications and future research/study.

In the applying of this thesis, the study only discussed the use of the elbow and wrist parts but there are so many injuries of different body parts, which are caused by stroke, so the module needs to have more detailed functions . Future designers should add more particular module designs to this approach, such as the size change of the power-driven module, the length change of connection module, keeping the protective module fitting to each other, the weight of the equipment, materials and exterior: they all still have potential development space.

In this approach now, it only determined the production pattern of power-driven module quantity. Going as far as the module connection, the quality of protective module cannot be accounted for by this approach.

The support module part cannot be in common use, but it can only apply to the support of large muscle group rehabilitation equipment. If instead it is a little muscle group that is damaged, than it needs a set of supporting equipment, which can switch sizes, to apply to rehabilitation.

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