DESIGN ENGINEERING

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CONTENTS

1. INTRODUCTION

Spinal injuries have afflicted humanity for millennia with the first documentation appearing in a Egyptian document published approximately 2500 BC, named the *Edwin Smith Surgical Papyrus* after its initial discoverer, Edwin Smith, an early Egyptologist. Within this document, the original author (who is unfortunately not known), describes damage to a person's spine and the resulting 'unconsciousness' of their arms and legs. The author proclaims the described condition as 'an ailment not to be treated' (Hughes, 1988). Fortunately, throughout history, attitudes towards spinal cord injuries were becoming less pessimistic. By the 20^{th} century, doctors such as Sir Ludwig Guttman and Donald Munro had adopted a more optimistic approach (Bodner, 2009) and recognised the need for a comprehensive care of the entire person; rehabilitation with a commitment to the entirety of the patient's needs. (Donovan, 2007). The wheelchair is key item in the rehabilitation of spine injuries.

According to the National Health Service, there are 1.2 million wheelchair users in the UK alone (NHS, n.d). This is approximately 1.8% of the population, a striking proportion. It is approximated that there are 1200 new cases of spinal cord injury, one that may necessitate wheelchair use, every year (McDaid et al., 2019). 35% of these injuries cause tetraplegia, a severe form of paralysis that affects most or the entire body.

Tetraplegia is caused by damage to the spinal cord and or brain, a result of diseases, conditions such as multiple sclerosis and muscular dystrophy and physical trauma such as sporting accidents, the latter cause is the most common (NSCISC, 2020). People with tetraplegia will often rely on the use of wheelchairs, or powerchairs when referring to motorised types rather than self-powered, to aid their mobility and support them throughout the day. Unfortunately, reports show that wheelchairs are lacking in their function, extended use bringing about a number of sitting-related problems (Valent et al., 2019).

2. AIMS

The aim of this project is to examine how the seat of a chair for a wheelchair can be improved to better support a person with tetraplegia.

The design will be realised using CAD (Computer Aided Design) software, namely Solidworks. Animations will be used to simulate the designs workings and FEA (Force Element Analysis) will be used to demonstrate how certain sections of the design will react when is use. FEA will also be used to examine how any unnecessary material can be removed with the intent of creating a lighter and possibly cheaper final design.

3. TETRAPLEGIA

Tetraplegia commonly referred to as quadriplegia, is a paralysis of both the upper and lower body as opposed to paraplegia which effects the lower half only. It results in the loss of movement and sensitivity of all four limbs including the torso. The severity and location of the paralysis is dependent on where on the spinal cord is damaged. There are a number of causes for this damage which are as follows: traumatic injury, neurological conditions such as cerebral palsy, tumours on spine and brain and autoimmune conditions such as multiple sclerosis.

These conditions create lesions, areas of damage or change, on the spine or brain. The location of this damage on the spine correlates to the severity of consequent symptoms, namely paralysis, tetraplegia in the most severe cases. In continuing this project, it is necessary to identify a specific case that the designed solution will address.

The ASIA (American Spinal Injury Association) Impairment Scale (2016) is used internationally to define sensory impairment and extent of any suspected spinal injury. The examination involves grading muscle power and sensation in each designated section of the body as specified in the ASIA Impairment Scale document. Each of these sections are classified according to the segment of the spine they are linked to. Once these results are recorded the level of paralysis completeness can then be determined using a scale from A to E, with A being complete paralysis (no sensory or motor functions preserved at all) and E being no issues with motor and sensory functioning.

This project will focus on C5 category tetraplegia. This means there is a lesion on the C5 vertebrae located in the neck, this entails certain motor and sensory abilities that will be considered throughout the project that are stated as follows: paralysis of the trunk and lower limbs with partial paralysis of the upper limbs. Good functioning of the bicep and deltoid muscles are retained but poor functioning of triceps, shoulder muscles, wrists and hands. Manual wheelchair use may be possible for short distances, but a power wheelchair is most common (Spinal Cord Medicine, 2002).

There are 420 new cases of tetraplegia in the UK every year who require constant care at an average cost of £1.87 million per person's lifetime (McDaid et al., 2019). Improvements in wheelchair and mobility technology will provide a better quality of life and improvements in independence.

3.1. Pressure Ulcers

Immobility can cause incidental secondary health problems. One significant and pervasive health problem is pressure ulcers. Pressure ulcers, often named pressure sores, are defined by the NHS (National Health Service) as injuries to skin and underlying tissue caused by prolonged pressure on skin (2020). Although any part of the body can be affected, certain areas are more prone than others such as the lower back and buttocks.

Pressure ulcers can be a debilitating and painful condition if left unattended. They start initially as painful sores that can gradually become necrotic if not dealt with sufficiently which can eventually cause severe health problems such as blood poisoning. One high profile victim of pressure ulcers onset by tetraplegia was Christopher Reeve, best known for his role as Superman, although after a sporting accident and subsequent paralysis, became an advocate for spinal cord injury research and set up the Christopher and Dana Reeve Foundation (n.d).

3.2. Other existing criticisms of current designs.

3.3. Wheelchair design history

The wheelchair designs most commonly seen today is based on a design from the 1930s known as ‘Model 8’ (Nias, 2019), a design that has not changed much in its ninety years of existence resulting a design that looks particularly dated in comparison with prosthesis. Prosthesis have seen huge advances over the decades in the same time span. This is especially evident when viewing the history of prosthesis, an artificial hand produced in the 1930s is a world away from the designs of today (Lawrence, 2019). Contemporary prosthesis features a wide variety of technologies, customisation and materials that are far more advanced than those used in currently available wheelchair designs.

4. STATE OF THE ART

Current solutions vary widely in function and price. At the highest end, designs now include standing functions. This works by the chair straightening out into a flatter angle which lifts the occupant into a standing position. There are two immediately obvious benefits to this function. Firstly, the ability to reach higher places and pressure relief. Standing avoids putting pressure on the same areas for extended periods. One current product that includes this technology is the Quickie Q700 (Millercare, n.d.) but at prices upwards of £10 000, it may often prove inaccessible for the average user.

More commonly, chairs at lower price points feature tilting abilities only. When the user wants to adjust the pressure on their body, the chair can be tilted backwards and forwards dependent on its current positioning. The leg rest and also be raised or lowered to lift the legs up. These two functions are often achieved either manually or via motors actuated by the user with buttons. A motorised approach allows the user a greater degree of freedom instead of needing to rely on a caregiver. Although these are common features for chairs catering to paralysis, two examples are the Ottobock A200 (n.d) and ID Soft (Sheen Mobility, n.d). Both of these products come at a much more affordable price point than the preceding product.

Most wheelchairs feature an adjustable headrest but adjustability of the chair itself is often limited. Indoor products such as the Kirton Duo (Premier, n.d) aim to promote correct posture via a high degree of adjustability. Not only can the degree of tilt and high of head and footrest be adjusted as is the case with the preceding wheelchair examples, but the majority of the chair back can be adjusted as well. The back comprises of several sections that can be rotated and bent to create a chair that promotes correct posture for those where this may not be so feasible, i.e. spastic and flaccid tetraplegia.

There are two main technologies for pressure ulcer avoidance that often come in in the form of either a cushion or mattress. Static solutions are ones that rely on soft materials and are often cheaper. Pressure from the user is spread evenly across the surface. This solution is often recommended for those who are not at such a high risk of developing pressure ulcers. For more at risk people, a dynamic cushion is more likely to be recommended. These work by dividing the cushion or mattress up into small cells that are inflated or deflated alternatingly. Whichever cell deflates, pressure is removed from that area. This process is cyclical allowing for all area in contact with the surface to have pressure relieved.

5. DESIGN INSPIRATION

A secondary aim of this project is to examine the aesthetic qualities of tetraplegia focused wheelchairs in comparison to more aesthetically considered mobility aids like prostheses. Prosthesis, despite being highly specified and therefore not as ubiquitous as wheelchairs, appear to be designed with much more consideration of their aesthetic qualities. One such example is Naked Prostheses (n.d), whose products are highly specialised yet utilise a beautiful design that can even be customised according to the user’s discretion, there is a range of colours and patterns to choose from. Market research of existing wheelchair designs did not point to any products that feature a similar concern for aesthetic quality.

Image 1 An example of a Naked Prostheses (n.d) device. The colours around the wrist and fingertips can be chosen by the customer.

6. ANTHROPOMETRICS

Before formulating designs, it is necessary to settle on fixed dimensions that will be referenced throughout the design. The first measurement methods this project will reference is *Ergonomics and Design: A Reference Guide* (Openshaw & Taylor, 2006) from furniture manufacturers, Allsteel. It details useful anthropometric data for both sitting and standing positions as well as data that is focused on wheelchair users. This document references several anthropometric databases. It would be beneficial if access to these databases were currently possible but they are unfortunately inaccessible with a significant cost. The one that is currently fully accessible is the ANSUR II (U.S. Army anthropometric survey II) (Gordon et al., 2014) database. A comprehensive collection of measurements from 4082 male participants and 1986 female participants. Using the diagrams from *Ergonomics and Design: A Reference Guide* as reference to understand the measurements from the ANSUR II database, this project will list appropriate anthropometric measurements.

Table 1: Averages from ANSUR II dataset.

ANSUR II results			
Measurement (Mean)	No.	Female (mm)	Male (mm)
Abdominal Extension Depth	12	230	255
Bideltoid Breadth	10	450	510
Cervicale Height		624	679
Chest Height (distance between sitting surface and chest point)		400	453
Elbow Rest Height (distance from sitting surface to olecranon)	17	232	245
Eye Height	15	748	805
Forearm Length (elbow – centre of grip)	18	318	349
Forearm - Forearm Breadth		495	579
Head Breadth		148	154
Hip Breadth (whilst sitting)	13	399	379
Knee Height (whilst sitting)		511	554
Leg Length	22	1044	1130
Popliteal height (back of knee to sole of feet)	23	388	430
Seat Depth (Buttock-Popliteal length)	20	485	503
Sitting height	14	857	918
Suprasternale – Waist length	16	350	382
Thigh Clearance	11	168	180
Waist Back length		425	478

Waist Breadth		299	326
Weight (kg)		67.8	85.5

Using this dataset rises one issue being that it is populated by individuals employed by the US Army. This data may not be representative of the wider, general population. This concern is alleviated when reading that Openshaw and Taylor (2006) review both ANSUR (and earlier, smaller iteration of ANSUR II) and CAESAR when approaching ergonomic design and share that many ergonomic textbooks reference these two datasets.

The measurements above are applicable when designing a chair although all of them may not be entirely necessary during design phases. A number of measurements have been portrayed on a anthropometric illustration below. This data is vital for proceeding onto preceding steps; deciding chair dimensions.

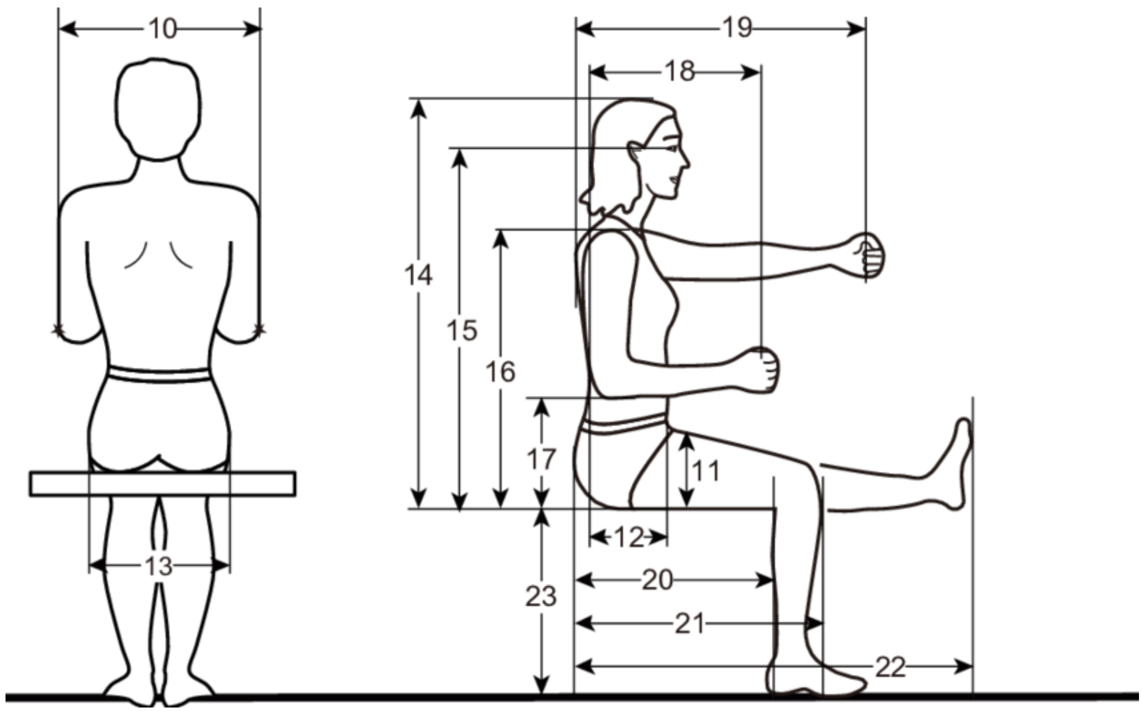

Image 2 courtesy of Karuppiah et al., 2011.

6.1. Profile of Individual

To simplify the design process, this project will focus on one particular person's profile, i.e. deciding on their dimension and condition. Tetraplegia can affect any individual but according to the National (US) Spinal Cord Injury Statistical Center (NSCISC, 2020), 78% of new spinal cord injuries cases are male. Men are therefore at a higher risk of tetraplegia. Furthermore, available datasets have much larger male sample sizes. For these reasons the chosen individual profile will be male. All required measurements will be taken from the averages in the male column from table 1.

The level of paralysis that will be focused on is C5 tetraplegia. This specific category was chosen as patients' mobility is severely reduced yet they do not often require a chair that is highly adapted. Patients with more complete paralysis often require apparatus in conjunction with mobility aids, a respirator is one such device. If focusing on higher paralysis levels it is then necessary to examine how a chair can incorporate these devices, something that is beyond the scope of this project.

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