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Design Evaluation of Crutches from an Engineering Perspective

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ABSTRACT: *Crutches carry a physiological and psychological benefits especially when they're compared to the wheelchair. However, traditional crutches could yield a large number of problems to the user which may overshadow its benefits. Furthermore, Engineers found that forearm crutches are suitable for the majority as it has minimum disadvantages comparted to the other crutches. Previous researches recommend vertical motion of the upper body to be minimized, the shock absorption at the crutch tips be minimized, and the lateral motion of the crutch tips should be minimized.*
Keywords: *Crutches Design, Vertical Motion, Lateral Motion, Forearm Crutches, Biomechanical Considerations.*

I. INTRODUCTION

People with disabilities face numerous challenges in their daily lives. Our job as engineers is it to solve problems so we could make their life easier. Crutches are one of the solutions that assist people with disabilities in standing and walking which in return will improve the growth of bones, circulation of blood, reduce bladder infections and reduce pressure lesions (Shortell, Kucer, Neeley, & LeBlanc, 2001). Furthermore, crutches carry a physiological and psychological benefits especially when they're compared to the wheelchair. However, traditional crutches could yield a large number of problems to the user which may overshadow its benefits.

For instance, traditional axillary crutches tend to transfer vibrating forces to the shoulders and wrists of the user which could case injuries and irritation. Also, a common condition associated with crutches usage is Palsy, which is basically when the outer edge of the crutch saddle, as shown in figure 1, damages nerves the the axilla. This might result in total or partial paralysis in some of the upper extremity muscles (Subramony, 1989). Nonetheless, a quick recovery can be achieved by discontinuing the use of the crutches.

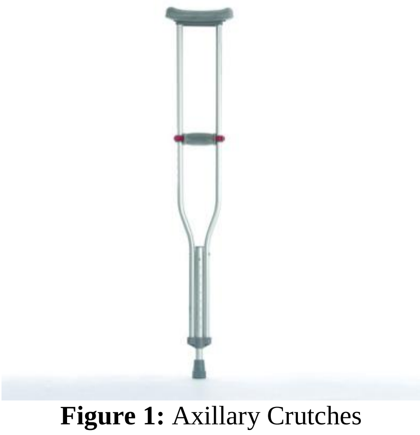

Figure 1: Axillary Crutches

Crutches have been there for years and they're still unchanged (LeBlanc, Carlson, &Nauenberg, 1993). They still make loud noises when the user walk which could make him/her feel uncomfortable. Studies show that using crutches requires twice as much the energy required for walking without assistance. People with injuries don't want to waste a lot of energy on daily basis just to walk. Engineers need to study crutches in-depth as several attempts to improve the design of crutches didn't succeed due to the lack of rigorous experimentation, ergonomically effective design and innovation.

II. LITERATURE REVIEW

Traditional Crutches and other walking aids have been used for over 5,000 years (LeBlanc, Carlson, &Nauenberg, 1993). Mankind has always used crutches of one form or another to get around when injury or illness made walking difficult or impossible. The use of crutches dates back to prehistoric times as is evident in the drawings that exist from ancient Egyp. The Pharaohs of Ancient Egypt used these devices to help them get around. The basic design of crutches has not changed much since these ancient times. Those who needed crutches cut off branches of trees or fashioned them from timber and added padding to the underarm support to make them more comfortable. Emile Schlick patented a walking stick in 1917 that could be called the first commercially produced form of crutches (figure *2*). In the design there was a support for the upper arm to rest on. However, it was A.R. Lofstrand, Jr. who patented the first deign for crutches that could be adjusted to suit the height of the user (figure 3).

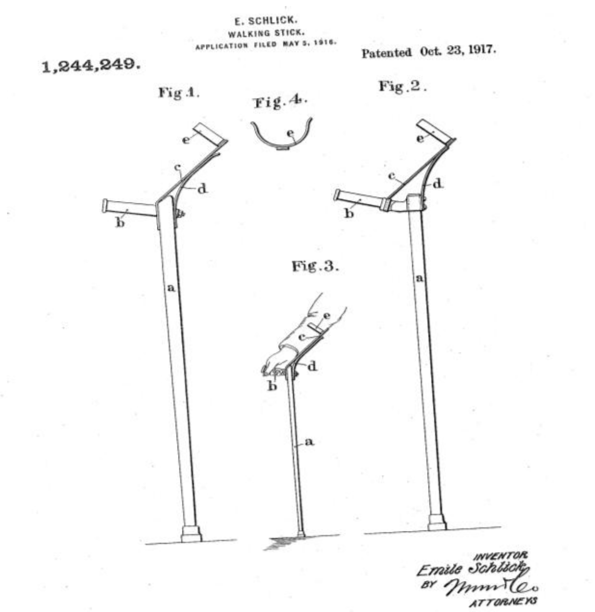

Figure 2: First Commercially Produced Crutches

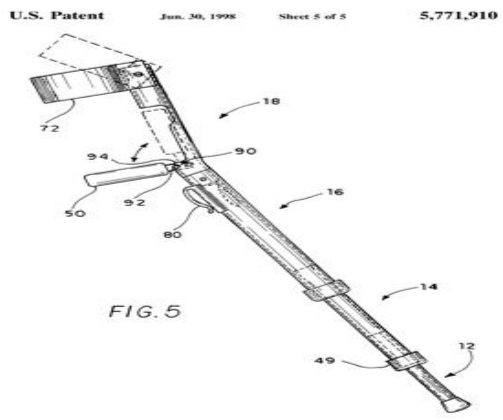

Figure 3: Adjustable Crutches

III. TYPES OF CRUTCHES

1) Axillary Crutches

Axillary crutches are a type of crutch that have a handgrip as well as a pad that rests against the side of the body just under the armpit (figure 1). This type of crutch is used mostly by temporary crutch users. Sometimes people avoid axillary crutches because of potential problems that may arise from their use such as hand, arm, and axilla problems (LeBlanc et al., 1993).

A study in the late seventies found that while subjects of their study said that ambulation with axillary crutches was less tiring than ambulation with elbow crutches, the percentage increase in heart rate from resting rate was about 20% higher for ambulation with axillary crutches compared to ambulation with elbow crutches. The researchers hypothesized that the increase in heart rate from the axillary crutches might have been due to artificial stimulation of the heart due to the contact of the top of the axillary crutch with the thoracic cage.

Instead of measuring energy expenditure by comparing heart rate, a study by Dounis, Rose, Wilson, and Steventon (1980) compared the amount of oxygen uptake for axillary crutch and elbow crutch ambulation. They found that oxygen uptake was less for ambulation with axillary crutches than for ambulation with elbow crutches. Walking with axillary crutches required less energy than walking with elbow crutches. Additionally, the subjects of the study rated the use of three types of crutches according to an effort scale provided by the researchers. However, other studies have not found significant differences in energy expenditure when subjects used axillary and elbow crutches for walking.

2) Elbow/Forearm Crutches

Elbow crutches are also known as forearm crutches. Like axillary crutches, they have a handgrip, but elbow crutches only extend to the elbow. There is no bar under or near the axilla. This type of crutch is used mostly by permanent crutch users. Without the bar under the axilla, there are no jarring forces there, but there are still forces at the hands and wrists.

Figure 4: Elbow Crutches

3) Platform Crutches

Platform crutches provide a horizontal platform for the entire forearm, which is used to bear weight rather than the hand (figure 5). They can be useful for patients with elbow contractures or with weak or painful hands or wrists.

Figure 5: Platform crutches

4) Rocker-Bottom Crutches

The idea of the rocker-bottom crutch goes back for almost 90 years. In 1918, Hall R. developed and built a modified crutch design which featured a metal rocker at the base of the crutch. He replicated the shoulder curve of the crutch as it rotates during ambulation, and applied the arc in the form of a metal rocker to the base of the crutch. In a study by LeBlanc et al. (1993), a quantitative comparison of different axillary crutches was conducted. One of the crutches used in the study was a rocker-bottom crutch. It was essentially a modified modern version of Hall's rolling crutch. LeBlanc found that the crutch provided a smooth gait and increased stride length. However, the disadvantages of the crutch were that it was awkward because of its size on stairs and aisles, it was heavy, and it was hard to stabilize.

5) Spring-loaded Crutches

The basis of spring-loaded crutches is that the extension post of standard crutches is replaced by a post with a spring mechanism in it. In a study by Pariziale and Daniels, a basic design of a spring-loaded axillary crutch was compared to a standard axillary crutch. According to the findings of the study, the spring-loaded crutches reduced both the shock and maximum load at the hand and wrist when compared to traditional axillary crutches. There was a reduction of 20-25% in the stress put on the user's wrists. In a study by LeBlanc et al. (1993) that compared spring-loaded crutches to four other modified crutch designs, advantages and disadvantages were listed. The advantages were that the crutches had a lively feel, absorbed shock, and had energy return. The disadvantages found were the moving parts, the lack of rigidity, and the difficulty in ground clearance during swing- through.

Figure 7: Spring-loaded Crutches

Another, more recent, attempt to design a new crutch was undertaken by Shortell et al. (2001). This new elbow crutch was made of carbon fiber composite material which incorporated a spring mechanism directly into the body of the crutch (figure 7). Instead of an actual spring, the researchers chose an S-curve design in which the two arcs of the S would deflect and act like a spring. Participants in the study were satisfied with the design, but felt that there was instability due to the movement in the crutch handle.

6) Handgrip Modifications

Complications of nerve impingement and callous formations during crutch use can be attributed to the angle of the handgrip and the contour of the wooden handle. The wrist naturally should be in slight ulnar deviation as opposed to radial deviation as it is during axillary crutch walking. A study by Yeakel and Margetis (1969) suggests that these problems can be eliminated with the use of poly (methyl methacrylate), a denture base repair resin. The material is putty-like so it can be molded to the hand of the specific crutch user. The study suggests that this allows the hand and wrist to be in their best structural alignment and that the handgrip distributes the body weight over the entire palm of the hand.

The researchers explain that when 35 people grasped free rod, the angle found was in a range from 5 to 30 degrees to the horizontal and that 73% of those ranged from 20-25%. It also suggests that similar modifications should be made to the handgrip in axillary crutches by making it sloping to an angle of 15 degrees with the horizontal. Patients who have used this angled handgrip feel that it is more comfortable than when the grip is at its traditional horizontal position.

7) Other Crutch Designs

Other designs of crutches exist and some studies have compared them to traditional designs of crutches. In a study by Hinton and Cullen (1982), traditional axillary crutches were compared to Ortho crutches (figure 7). The Ortho crutches were made of aluminum with single uprights instead of double uprights like those found in traditional axillary crutches. The researchers suggested that for walking over a short distance, the Ortho crutch would be less tiring for an inexperienced patient than axillary crutches.

Figure 7: Ortho Crutches

Wagstaff introduced a new design for a crutch called the Dublin crutch that featured a single shaft with a protruding handgrip and slightly modified axillary pad. The study found that there was a slight significant decrease in energy expenditure when walking with the Dublin crutch than when walking with a conventional axillary crutch.

8) Complications of Crutches

Crutches have many physiological and psychological benefits to individuals who use them by allowing them to walk instead of using wheeled mobility to get around. However, even though walking with crutches has many benefits, it also has many drawbacks that sometimes hinder individuals from using them. Therefore, medical experts urge inventors and engineers to approach crutches design and applications from a new perspective.

IV. BIOMECHANICAL CONSIDERATIONS & CONCEPTUAL IMPROVEMENTS

There are harsh forces on the body due to crutch walking with axillary crutches. Forces at the crutch tip are transferred directly to the hand and wrist and indirectly to the axilla. Wilson and Gilbert (1982) determined that the two important forces acting on the body during crutch walking are the horizontal forces on the axilla and the total load on the hands. The study found that the whole body weight is supported by the hands along with additional inertial forces. However, the axilla only has horizontal forces acting on it. In the study, it was determined that the peak body horizontal forces at the axilla occurred at the apex of swing-through. A force plate was used to measure the ground reaction force at the crutch tip and a force transducer system was used to measure the horizontal crutch reaction force on the axilla. According to this study, the crutch user's hands support 1.1 to 3.4 times his/her body weight, and the axilla support a horizontal load of about 3 to 11% of his/her body weight.

A similar study by Goh, Toh, and Bose (1986) found somewhat different results. The study found that the peak force at the hand during crutch ambulation was 44.4% of body weight which was less than found in Wilson and Gilbert's (1982) study. Also, the study tested the differences in the axillary forces when the subjects used the crutches correctly and incorrectly. When the crutches were used correctly, the axillary load was about 5% of body weight, but when the crutches were used incorrectly, the load was about 34% of body weight. When the subjects used the crutches correctly, the posterior upper strut of the crutch was subjected to tension while the anterior strut was in compression during crutch stance phase. While the forces on the body are greatly increased at the axilla and hands, the forces are also increased on the supporting limb during ambulation with crutches.

A study in the early eighties measured the ground reaction forces on the supporting limb during crutch walking with both axillary and elbow crutches. It monitored the forces when the subjects landed on one foot as well as when they landed on two feet. For all single-foot landings with both types of crutches, the average increase was 24.5% and for all both-feet landings with both types of crutches, the average increase was 35.1% as compared to landing during normal walking. A similar study by Stallard, Dounis, Major and Rose (1980) also found an increase on the supporting limb during ambulation. The study found increases in vertical ground reaction forces of about 16% as compared to normal walking. A study by Shoup, Fletcher, and Merrill (1974) consisted of a literature search and a displacement analysis of swing-through crutch gait in order to make recommendations for further crutch modifications. The researchers suggested three developments in crutch design from the results of the study. They recommended that the vertical motion of the upper body be minimized, the shock absorption at the crutch tips be minimized, and the lateral motion of the crutch tips should be minimized.

V. CONCLUSION

From the previous discussion, it cannot be determined whether it is better to use Axillary crutches or other type of crutches. However, engineers found that forearm crutches are suitable for the majority as it has minimum disadvantages comparted to the other crutches. Nonetheless, people should try different alternatives and consider different factors in their experiments with crutches in order to decide on the best choice. Furthermore, crutches manufacturers should consider the feedback of the user in order to develop and improve their product design.

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