Prototype of a low-cost post-stroke wrist splint in Ghana

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INTRODUCTION

Stroke is a leading cause of death and the third leading cause of disability in adults globally, with up to 80% of survivors reporting short- or long-term disabilities [1; 2]. The impairments caused by stroke create challenges in participating and completing activities of daily living (ADLs), significantly lowering a survivor's quality of life. However, with appropriate intervention, significant strides towards recovery can occur as early as three months after stroke [3].

In Ghana, a low-middle income country (LMIC) in West Africa, stroke is ranked as a leading cause of death not attributed to communicable diseases [4]. However, there are very few centers that provide stroke care in Ghana, particularly Accra, the most populated city in Ghana [4]. Further, when stroke survivors are discharged from the hospital, they are faced with extraneous challenges, namely geographical and financial barriers, preventing them from continuing the rehabilitation services they require [5; 6]. Patients may lack the funds to travel long distances to reach a treatment site, much less pay for the rehabilitation services provided there.

One of the main goals of stroke rehabilitation is continued treatment for spasticity, or abnormal increases in muscle tone and stiffness, to improve functional recovery for the stroke survivor [7-9]. The main treatments for spasticity include physical therapy, electrical stimulation, pharmacologic and surgery [9]. With the aforementioned barriers to outpatient care, the purpose of this study was to design a rehabilitation aid that would improve health outcomes for stroke survivors with resultant spasticity who live in low-middle resource communities, like Ghana.

METHODS

Given the COVID-19 pandemic, and the geographic distance to the target audience, semi-structured interviews were conducted via Zoom to elicit design requirements. Four participants were all recruited from the Korle-Bu Teaching Hospital Stroke Unit in Accra, including one occupational therapist and three physiotherapists. The sample of participants represented 25% of clinicians within the stroke unit, all with an average of 5 years of experience. All participants were guided through questions regarding stroke and spasticity management. From there, results were collated to elicit design requirements for a rehabilitation aid for stroke spasticity rehabilitation. These requirements were then used to prototype an Appropriate Paper Tech (APT) wrist splint. Building this splint requires water, paper, glue, and gauze, and only uses bowls and LTTP in a warm water bath as tools.

DESIGN REQUIREMENTS

The interview participants reported that upper limb spasticity was most commonly seen in the elbow, wrist, proximal interphalangeal joint, and shoulder. Moreover, they reported spasticity to be a lasting condition post stroke. In regard to management, participants reported that massage therapy, passive movements, and stretch exercises were used to relax the muscles, followed by splinting, reducing the likelihood and severity of the spasticity. However, with no way to maintain the relaxed state, the effects were temporary.

"For upper limb spasticity, we do passive mobilizations and stretches, then afterwards, maintain the ranges we have obtained with a splint, when the patient can afford a splint… When you add the splinting, it is able to sustain the stretch or relaxation achieve after a physical therapy session. Without the splinting, the effects of the passives is for only a very short time." – Participant 1

The preferred means for doing this is using a custom resting hand splint, usually made from Low Temperature Thermoplastic (LTT). The resting hand splint maintains the extended state of the spastic joints and is usually worn at night when the patient retires for the day. One clinician described how the cost of the splint depended on how much of the material was required based on the size of the patient and in 2021 ranged from 150- 300 Ghanaian Cedi (GHS, $20-$50USD). Some patients who can afford it purchase premade splints from global market sites such as Amazon. That purchase is often made by family members outside Ghana who then bring it with them when next visiting. However, over 60% of patients are unable to afford either means of the hand splint and patients use hard cardboard as a resting hand splint.

Diving deeper into the design criteria and constraints of splints in Ghana, we were able to elicit design requirements, shown in Table 1.

Table 1. Verification & Validation Testing

#	Design Specification	V&V Test
1	Low cost	Less than 150-300 GHS ($20-$50 USD)
2	Easy to manufacture	Does not require specialize machining tools, equipment, or materials
3	Adjustable	
4	Resistant to flexion forces	Withstand >3.4N (hand flexion force) [10]
5	Durable	Withstand >1 month of wear
6	Comfortable	

PROTOTYPING

Using the design specifications listed above we were able to design a low-cost splint solution. The first barrier was materials. Low temperature thermoplastic (LTTP) is the standard for making simple hand splints around the world due to its stiffness, strength, and the shapes it forms. In Ghana this poses a problem as it is imported, thereby making the product more expensive.

In investigating low-cost materials, we found that Appropriate Paper Tech (APT or paper mâché) was common material used in standing frames and chairs for children with cerebral palsy in LMIC's such as Kenya, Uganda, Mexico, and Ghana. Moreover, the main ingredients for APT are paper, water, glue, cooking oil and a bowl for mixing; all of which are readily available in Ghana. Once mixed up, the APT resembles wet clay, making it easy to mold around splint forms. APT derives its strength from the fiber linkages within the paper [11] in addition to that of the dried glue[12]. However, we immediately found through initial trials that the material was brittle. To ensure that the fiber structure was long and continuous, inducing elasticity, layers of gauze were added to the APT splint. With the material chosen and validated by the interview participants, we were able to address design specifications 1 and 4-6.

The molding process was simple, not requiring any specialized machine tools, equipment, or materials that would not be available to a clinician making the splint, addressing design specification 2. However, the construction is weather and time dependent. In future work, it will be important to optimize drying time of the splint, as drying the layers of APT was the rate limiting factor. Furthermore, if the splint was not fully dry when removed from the mold, the structural durability and sizing was subject to change.

After several iterations, the final build process was as follows:

<u>Materials and Tools</u>

1.5 cups shredded paper of any type

2 sheets of newspaper

16oz Elmer's glue

2 cups of water

Cooking oil

Large Bowl

Medium Bowl

LTTP in a warm water bath

Figure 1. An image of an APT splint.

<u>Protocol</u>

1. Use the LTTP in a warm water bath to create a mold. Form the LTTP as if for making a splint itself.
2. Prepare the ATP mash
    a. In a large bowl, soak 1.5 c shredded paper and 1 c water, preferably overnight.
    b. Add 0.5 c of Elmer's glue and 0.25 c of water
    c. Mix thoroughly, allowing the paper to tear into small pieces.

3. Prepare the ATP strips
    a. Cut the two sheets of newspaper into 1-inch strips
    b. In a medium bowl, mix 1.5 c Elmer's glue with 0.75 c water to create a glue slurry
4. Spread a layer of oil on the inside of the mold to prevent the paper from sticking
5. Dip paper strips into the glue slurry and place on the outside of the mold. Because ATP tends to shrink while drying, the splint should be built on the side most resistant to shrinkage.
6. Repeat step 5 two more times, leaving time to dry in between each layer.
7. Spread a layer the ATP mash over the paper strips.
8. Dip the gauze in the glue slurry and place over the ATP mash layer.
9. Spread a layer of the ATP mash over the gauze.
10. Let the splint completely dry.
11. Remove the ATP splint from the mold and trim edges as needed.
12. As needed, dip the paper strips and gauze in the glue slurry and cover the edges of the splint to make a smooth finish.
13. Ensure the splint is completely dry before giving it to the client.

DISCUSSION

The resulting splint would be producible at minimal cost in Ghana. The materials used in building this wrist splint (water, paper, glue, gauze, cooking oil) are readily available at everyday shops. Tools required include a bowl and LTTP, both of which can be reused for multiple patients and splints.

In future work it will be important to optimize drying time. Since the majority of construction time is spent drying, optimizing drying time can have a significant impact on production rates. Furthermore, if the splint is not fully dry when removed from the mold, it will not only be less sturdy, but it will also be extremely likely to shrink. Understanding the impact of the weather, availability of electric fans, and ratio of water to paper are important conditions to investigate.

CONCLUSION

This project set out to identify a way to manage ongoing post-stroke spasticity at a low-cost for stroke survivors in Ghana. Disability from the stroke itself, proximity to rehabilitation services, and financial constraints limit access to post stroke. Interviews with clinicians provided design guidelines based on their knowledge of LTTP and the variety of makeshift alternatives that they use with clients. After addressing issues APT proved to be successful as a material since it was easily available with minimal cost.

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