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Hiking Backpack Design Development with Integrated Splint Feature for Fracture Injuries

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Abstract: *The background of this design is the risk of fracture injury to climbers when mountaineering. According to the International Alpine Trauma Registry (IATR), there were 306 mountaineering accidents resulting in fractures in 2019. First aid for fractures requires standardized equipment and methods to assist the rescue process. The problem studied is the difficulty of climbers in utilizing climbing equipment as splints when treating fracture victims on the mountain. The purpose of this design is to develop climbing equipment so that it can be converted into a means of bandaging to perform first aid for fracture injuries. The design method used is Quality Function Deployment (QFD), to determine the priority aspects related to the specifications of the means of massaging that users want. The result of the design is a backpack product with an internal frame that applies a collapsible mechanism so that it can be quickly accessed in an emergency and can be adjusted according to the dimensions of the body part that has a fracture injury. The developed splint design successfully meets the criteria for dimensional customization to the user's body and can immobilize the fracture according to standard first aid procedures.*

Keywords: *Climber; Fracture; Mountain; Splint; Quality Function Deployment*

INTRODUCTION

Mountain climbing in Indonesia is a popular and exciting activity for nature lovers and adventurers. According to the Association of Indonesian Mountain Guides (APGI), in 2020, the number of mountain climbers in Indonesia reached 3.15 million people, with 150 thousand of them being foreign nationals [1]. Correspondingly, mountaineering tripsin the world's mountains are also growing significantly every year [2]. The global mountaineering market has grown significantly in recent years, due to the increasing availability of mountaineering products, rising public interest inoutdoor activities, and increasing disposable incomeworldwide. The hiking market is projected to grow from $5.21 billion in 2023 to $8.72 billion by 2030, with a 6.5% annual increase [3]. However, mountaineering is a high risk activity for accidents that can cause foot injuries ranging from sprains, fractures, to bleeding due to impact.

The risk for climbers is the possibility of fracture injuries. Such injuries commonly occur in mountainous regions with difficult terrain [4]. According to the International Alpine Trauma Registry (IATR), there were 306 mountaineering accidents resulting in closed fractures in 2019 which accounted for approximately 37% of all mountaineering accidents [5].

Fracture is a condition when the bone is crackedor broken [6]. The procedure performed in handling fracture cases is examination and immobilization using a bandage. Bandaging is the use of aids to avoid movement (immobilization), protect oneself, and stabilize the injured body part. Bandaging uses a toolin the form of a splint to help stop bleeding, reduce pain, and prevent further damage or injury [7].

Fracture injuries are serious cases that must be treated quickly due to the risk of increased damage and bleeding experienced by the victim [8]. Mountain climbers are not equipped with medical splints to treat fractures on the mountain. The condition of the mountain forest, which varies by altitude zone [9], makes it difficult for climbers to find alternative splints. Long distances and extreme environmental conditions require climbers to improvise in immobilization by using the available climbing equipment.

Climbers typically use mountain bags with a capacity exceeding 40 liters to carry all their necessary equipment [10]. These bags often feature internal frames that can serve as a makeshift splint in case of injuries. However, the internal frame in mountain bags has limitations in terms of its dimensions so that treatment cannot be carried out inthe event of a thigh fracture in a climber. This is because fractures in climbers tend to occur in the body part, namely the legs [12].

The splinting procedure in the case of a thigh fractureis that the length of the splint needs to pass through two joints from the pelvis to through the knee, asshown in Figure 1.

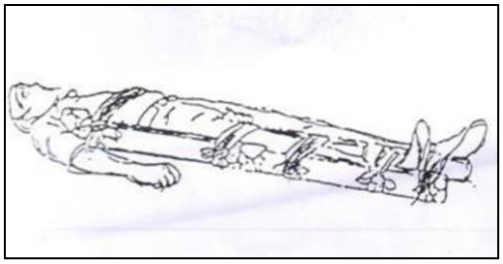

Figure 1: Illustration Of the Dressing Method for a Femur Fracture Injury
(Source: https://www.dictio.id/, 2023)

Average hip height dimension of Indonesia society is 102.06 centimeters, while the internal frame dimension of the mountain bag is 55 centimeters. Therefore, we developed a mountain bag design with an internal frame feature that can be adjusted so that the handling of thigh leg fractures inclimbers can be carried out in accordance with the procedure, and the splint tool can be integrated with the mountain bag.

RESEARCH METHOD

The method used in this research is qualitative research method. Focuses on the context of the phenomenon, develops, and fundamentally adheres to interpretative understanding. The data collection method was carried out by means of semi-structured direct interviews to obtain answers related to the knowledge and experience of the respondents in more depth and through direct simulation in performing first aid in fracture injuries in climbers.

The research was conducted in Yogyakarta, focusing on experienced climbers who are members of a nature-loving organization or community. The study involved 27 participants. Data was collected through face-to-face interviews with 7 individuals and online questionnaires from 20 others. Field data was collected using documentation techniques in the form of photos, audio recordings, and videos. In addition, data were also collectedthrough online questionnaires distributed through social media groups of climbers in Yogyakarta. The approach in this qualitative research uses descriptive interpretation method.

The design method used in this research is Quality Function Deployment (QFD) by determining user needs related to the bedding product to be designed through questionnaires distributed so as to find out the priorities in product design. This method can translate and prioritize customer needs so that it can focus on customer satisfaction [13]. The stage begins with the process of collecting data in the formof user needs related to the product to be designed, and then processed to obtain the main priorities in thedesign using Quality of House. The priority criteria obtained are then translated through alternative design ideas to be iterated to obtain a freeze design. The iteration results are then realized into prototypesto conduct model studies and product tests. After evaluation, the prototype is then realized into a final product.

RESULT AND DISCUSSION

1. Field Data Analysis

The data we collect is critical to understanding what problems we face when designing products. Accurate data will ensure the validity of the research results and conclusions drawn [14]. Therefore, the following data was collected.

- Mountain Environment Observation

Figure 2. Mountain Environment
(Source: Lunsa, 2023)

Observations of the mountain environment were conducted on the Kledung basecamp of Mount Sundoro hiking trail, which is located between Temanggung and Wonosobo regencies, Central Java, Indonesia. This hiking trail is one of the favorite trails for hikers due to its closeaccess to Temanggung City. The environment on the mountain has a diversity of vegetation that makes it difficult for hikers to find alternative splinting tools at certain locations and altitudes. The height of the mountain, whichreaches 3150 meters above sea level, makes the sub-alpine zone the maximum limit for trees to grow [9]. The long distance and difficult access to the top of the mountain causes the need for a mountain bag with sufficient capacity to carry all equipment and supplies during the climb. Emergency equipment to perform rescue needs to be easily found by climbers.

- Interview

Tabel 1.

Splinting Criteria	Findings	Problem
Customizable size, lightweight, sturdy, straight, and multifunctional as a climbing tool	Frame carrier	Limited size, backpack load imbalance.
	Wood	There is no vegetation are, it takes more time and tools

Sumber : Lunsa, 2024

The frame is considered efficient in terms of ease of carrying and practicality of use because the backpack will always be carried by the climber, the number of pairs also meets the criteria of a splint. However, the limited length meant that the frames could not be used for splinting of upper leg fractures. The backpack will lose its stability when the frame is removed and used as a splint. Almost all hiking backpacks on the market use an internal frame model. Therefore, the back system design of the backpack needs to be strengthened to maintain stability and comfort when the frame is removed.

- Simulation of Splinting

Figure 3. Splinting Using Internal Frame
(Source: Lunsa, 2023)

The customizable size factor is important when it comes to bandaging a fracture. The number of straps as *mitela* is also very important to fulfill, which is three to four pieces. Climbers will have difficulty findingwood and roots in mountain areas where there is no vegetation and will need sharp objects to use the wood as splints.

- Online Questionnaire

In addition to field data, data was collected through questionnaires to climbing groups in Yogyakarta. The data obtained from 20 respondents resulted in several design requirements regarding the criteria for splint tools based on the knowledge andinsight of climbers, which are as follows.

a) Practical
b) Strong
c) Foldable
d) Can be assembled
e) Has another function/multifunction
f) Brief
g) Easy to use/install
h) Lightweight
i) Cheap
j) Straight

2. Data Processing Using House of Quality

The field data obtained is then processed using the House of Quality. The product design process will be easier to do because the information needed can be presented in the House of Quality [15]. This process will determine the priority aspects in designing splint products for mountain climbers, as follows.

		Desired direction of improvement (↑,0,↓)
1: low, 5: high		**Functional Requirements (How)** →
Consumer Importance	Relative Weight	**Customer Requirements - (What)** ↓
5	8,62%	Lightweight
5	8,62%	Strong
4	6,9%	Foldable
3	5,16 %	Can be assembled
3	5,16 %	Multifunction
2	3,4%	Brief
4	6,9%	Easy to use/install
5	8,62%	Adjustable
5	8,62%	Practical
2	3,4%	Cheap
5	8,62%	Straight
5	8,62%	Flat surface
5	8,62%	Immobilizes
5	8,62%	Will not cause further damage

Figure 4. Customer Requirements
(Source: Lunsa, 2023)

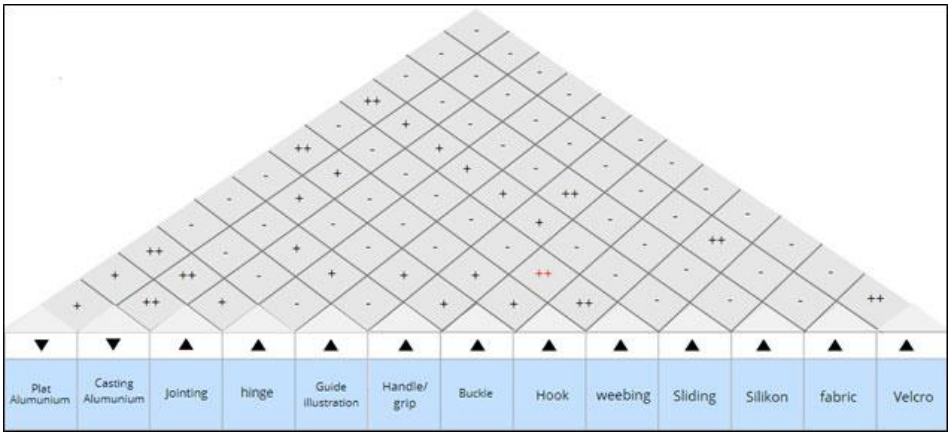

Figure 5. Functional Requirements
(Source: Lunsa, 2023)

Desired direction of improvement (↑,0,↓)	▼	▼	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
Functional Requirements (How) → / Customer Requirements - (What) ↓	Flat Alumunium	Casing Alumunium	Jointing	hinge	Guide illustraion	Handle/ grip	Buckle	Hook	weebing	Sliding	Silikon	fabric	Velcro
Lightweight	⊙	○	△	△	△	○	⊙	○	○	△	○	○	○
Strong	⊙	⊙	△	○	△	⊙	⊙	⊙	○	⊙	△	△	○
Foldable	○	○	△	⊙	△	△	△	△	○	⊙	△	○	○
Can be assembled	○	○	⊙	○	△	△	⊙	⊙	△	○	△	△	△
Multifunction	○	○	○	○	△	○	○	○	○	○	○	○	△
Brief	○	○	△	○	○	○	○	○	○	⊙	△	△	○
Easy to use/install	△	△	○	○	⊙	⊙	⊙	⊙	○	○	△	△	⊙
Adjustable	⊙	⊙	○	○	△	△	⊙	⊙	⊙	⊙	△	△	⊙
Practical	○	△	○	○	○	⊙	⊙	⊙	⊙	⊙	○	○	⊙
Cheap	○	△	○	△	△	△	○	○	○	○	○	⊙	⊙
Straight	⊙	○	○	○	△	△	○	○	○	⊙	○	△	○
Flat surface	⊙	○	○	○	⊙	△	○	○	⊙	○	⊙	⊙	⊙
Immobilizes	⊙	⊙	○	△	△	○	○	△	○	○	○	○	○
Will not cause further damage	△	△	△	△	△	△	△	△	△	△	○	○	○
Technical importance score	5.7	4	2.7	3.1	2.5	3.4	5.5	4.7	4.2	5.3	2.7	3	5
Importance %	11%	7.7%	5.2%	6%	4.8%	6.6%	11%	9%	8%	10.2%	5.2%	5.7%	9.7%

Figure 6. Importance Score
(Source: Lunsa, 2023)

The requirements that must be met in designing an internal frame that can be converted into a splint for mountain climbers are as follows:

a) The backpack frame that is converted into a splint uses stainless material combined with aluminum. This functional aspectreceived the highest Importance score of 12%.
b) Using the collapsible sliding principle withan importance value of 10.2%. This aspectcan be combined with the hinging principle.
c) Using a buckle with a webbing strap. This functional aspect received an importance score of 11%.

3. Design Recommendations

Based on the results of the research and data analysis, the product design recommendations for splints for mountain climbers are as follows.

- Splints should be easy for climbersto carry and find.
- Hiking splints are straight and can be customized to fit the injured bodypart.
- The hiker's splint is equipped withfour strands of rope.
- Climbers' splints have another function when not in use
- The hiking splint is a development of the frame on the backpack used when hiking. The frames on hiking backpacks are detachable and use strong, light weight materials, and have a straight shape.
- Apply a collapsible mechanism to the frame to meet the size criteria in accordance with the procedures in the dressing of fracture injuries.
- Backpack products have additional frames to maintain the shape of the product.

4. Design

- Iterations

The following are alternative product sketches generated from the iteration stage of product sketch ideas.

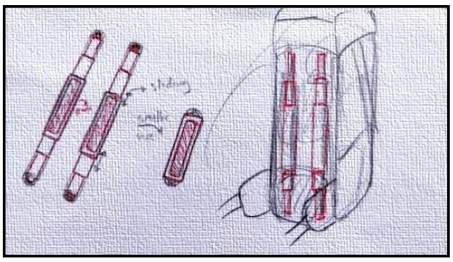

Figure 7. Internal Frame Sketch Iteration
(Source: Lunsa, 2023)

The design iteration in Figure 5. Applies the principle of multilevel sliding. In this concept, the frame does not feature a strap.

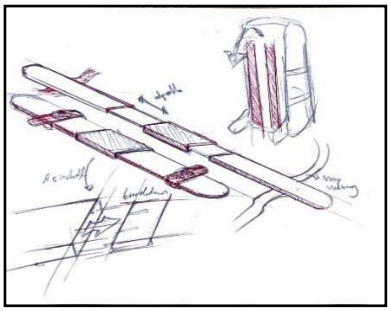

Figure 8. Internal Frame Sketch Iteration
(Source: Lunsa, 2023)

The design iteration in Figure 6. Combines the sliding and assemble principles. The operation of the assemble or detachable feature is by unplugging, while sliding is by pulling. The webbing feature is modular.

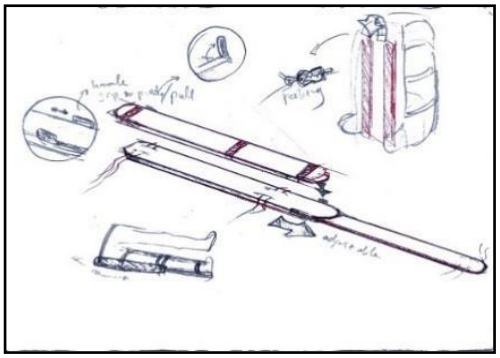

Figure 9. Selected Internal Frame Design Sketch
(Source: Lunsa, 2023)

The design iteration in Figure 7. Applies a sliding mechanism to each frame blade. Sliding operation by pushing from the side, there is a strap that has been integrated into the splint.

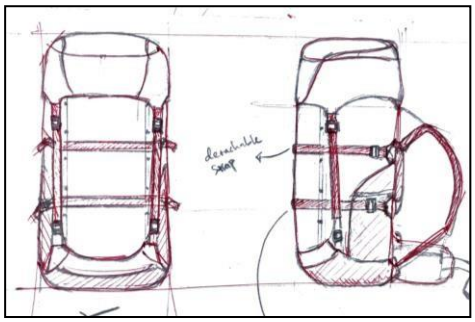

Figure 10. Bag Design Sketch
(Source: Lunsa, 2023)

Exploration design of the mountaineering bag according to the standard equipment of mountaineers. With a capacity of over 40 liters, it features a top lid to store small-sized equipment that needs to be used whileon the hiking trail, two straps to lock the lid, and two more straps for compression straps on the sides. The mountaineering bag is equipped with an internal frame.

- Freeze Design

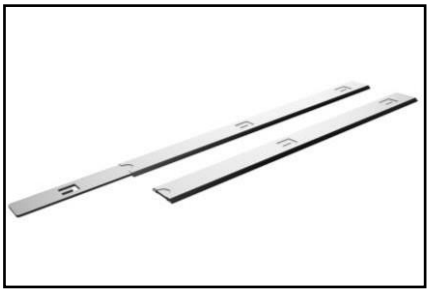

Figure 11. Freeze Design Frame
(Source: Lunsa, 2023)

The internal frame uses stainless material on the outer cover. There is a feature to hook the straps at several points that are adjusted to the user's body. The frame applies a collapsible sliding mechanism, so it can be adjusted to the dimensions of the user's fractured body.

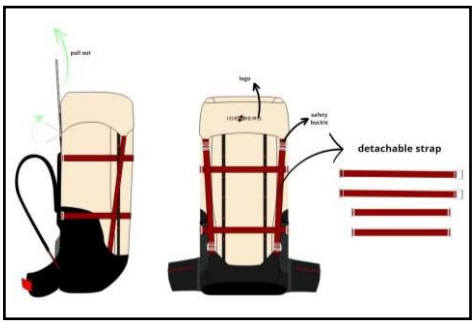

Figure 12. Bag Freeze Design
(Source: Lunsa, 2023)

The bag design features a detachable compression strap that can be used as a splintstrap. The bag is 60 liters in size so it can be used in hiking activities of sufficient duration, which is 3 - 4 days. There is a top lid section with space that can be used to store equipmentwhile traveling. It also features pockets on theside and on the hip belt.

- Model Study

Figure 13. Frame Model
(Source: Lunsa, 2023)

After the initial model study, a frame model study was developed with features that consider a sliding mechanism for ease of use, the strap is not on the frame but on the mountain, bag used, there is a hole to hook the strap when installed, the strap lock uses abuckle safety harness type.

5. Final Product

Figure 14. Model Iteration
(Source: Lunsa, 2023)

Tests were conducted on the model to determine the dimensions and mechanisms applied to the product.

Figure 15. Bag Model
(Source: Lunsa, 2023)

The next model study is to create a bagmodel by conducting discussions with vendors to produce a pattern that is suitable and easy for the production process.

- Prototype

Figure 16. Prototype
(Source: Lunsa, 2023)

Prototypes are made using actual materials. Trials are conducted to evaluate the functionof the product until the final product isobtained.

Figure 17. Final Product
(Source: Lunsa, 2023)

The production process was carried out in Yogyakarta and took 3 weeks. The mountain bag product with integrated splint feature on the *internal frame* has the following specifications.

Tabel 2.

Bag specifications		
Material	Top lid	Cordura, Furring, Nylon strap
	Body	Cordura, Furring, Nylon strap
	Back system	PVC, Cordura, Furring, Mesh, Foam
	Frame	Stainless steel, Aluminum
	Shoulder Strap	Cordura, Mesh, Foam, PE Foam, Nylon strap
	Hip belt	Cordura, Mesh, Foam, PE Foam, - Nylon strap
Dimensions	30cm x 20cm x 80cm	
Colors	Cream, black, red	
Weight	1.380gr	

Tabel 3.

Internal frame specifications	
Material	Stainless Steel 1,2mm (Cover)
	Aluminum plat 3mm (internal)
Dimensions	60cm x 5,7x 0,54 cm Maximum lenght: 110 cm
Weight	1.265gr

6. Final Product Testing

Figure 18. Climber Using the Product
(Source: Lunsa, 2023)

Figure 19. Leg Immobilized Using a Splint from the Bag Frame
(Source: Lunsa, 2023)

CONCLUSION

The developed splint design successfully fulfillsthe criteria of dimensional customizability. The *collapsible-sliding* mechanism on the *frame* simplifies the operation and installation of the product as a splint, allowing the splint to accommodate various limb sizes. The splint feature is applied to the *internal frame*, in addition there is a strap feature that is integrated with the *compression strap feature* on the bag. This integration not only saves space but also facilitates access when needed.

SUGGESTION

Suggestions given by researchers for further product development are the development of *frame* materials that can use lighter materials such as duraluminor carbon to increase product mobility with a lighter weight. Add other features related to climbing activities to further optimize the multifunctional aspect of the product.

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