Cameron Fisher-Gomez
12/06/2024

Individual Component Analysis: Anchor Point Placement

The Halo Helmet project focuses on developing an advanced safety system designed to protect the head and upper body from high-impact forces. This system incorporates a rigid connection between the head protection unit and a chest piece to restrict neck movement and prevent extreme angular displacements during sudden impacts. By distributing forces across the entire system, the design minimizes localized forces at the point of impact, significantly reducing the risk of severe injuries.

Functional Requirements

The anchor points (APs) of the Halo Helmet system are critical components that securely join the roll cage to the vest. These points must withstand forces transmitted through the roll cage during high-impact events while minimizing bodily harm to the wearer. For example, an 81kg (180lb) rider experiencing a worst-case deceleration of 200G would generate forces of up to 160kN that need to be dispersed. To mitigate this pressure and enhance user safety, the design increases the surface area of contact between each AP and the body, distributing forces more effectively and reducing the risk of localized injuries. Assuming a typical AP surface area of $0.0225m^2$ (6”x6”), this corresponds to a pressure of approximately 711kPa.

The majority of strong, low-movement areas on the human body are located around bony prominences, which provide stability and support. Human bones can be broadly classified into two types: cancellous and cortical. Cancellous bones, often referred to as 'spongy bones,' are porous and less dense, making them relatively fragile and unsuitable for withstanding large impacts. Despite their fragility, they play a critical role in marrow production. In contrast, cortical bones are denser, stronger, and more stable, making them far better suited for force dissipation. Given their prevalence in the human skeleton and their superior ability to handle stress, our design prioritizes cortical bones for anchor point placement to ensure maximum strength and impact resistance

In addition to strength, the APs must preserve near-full articulation of key joints, including the glenohumeral (shoulder) joint, atlanto-axial (neck) joint, lumbar spine (lower back), and scapulothoracic (scapula) joint. Achieving this balance ensures the system provides effective protection without significantly restricting movement during activity. To evaluate this, OpenPose software can be employed to measure ranges of motion both with and without the Halo Helmet in place. While individual variability poses a challenge to quantifying movement accurately, for the purposes of this assignment, a successful range of motion is defined as 70–80% of the baseline range. This baseline is captured via camera systems and analyzed using OpenPose to ensure precise and repeatable measurements.

The placement of APs must balance strength and mobility. Strong areas that can resist impact forces without compromising safety include the ilium (hip) bone, humerus, thoracic cage, erector spinae, and scapulae. Each potential location presents unique benefits and trade-offs:

- **Ilium**: The ilium provides a stable, robust surface capable of withstanding forces up to 18kN without fracturing [1]. Its minimal rotation and translation during most activities make it an ideal location for a rigid anchor point.
- **Thoracic Cage**: Utilizing the frontal chest area, including the clavicle and sternum, offers a broad surface for force dissipation. Additionally, the thoracic cage provides minor natural damping due to its flexibility. However, internal stress waves generated by quick impacts increase the risk of internal contusions and lacerations, which can be mitigated by extending the impact duration or incorporating advanced damping materials beyond traditional foam [2].
- **Humerus**: The humerus is a strong bone, withstanding up to 180MPa that could serve as an anchor point [3]. However, its close connection to scapular movement would significantly impair glenohumeral mobility, making it less suitable for AP placement for activities that require frequent arm motion [4].
- **Erector Spinae**: The erector muscles surrounding the lumbar vertebrae offer excellent force dissipation. While this location reduces pressure at impact points, it introduces the risk of transmitting excessive forces to the spinal cord.
- **Scapulae**: The scapulae provide large, strong surfaces capable of withstanding substantial forces. However, their critical role in arm movement necessitates a more forgiving attachment method to preserve mobility.

<u>Summary Table</u>

Anchor Point Location	**Pros**	**Cons**
Ilium	- Very strong and capable of withstanding high forces. - Relatively stationary during most	- AP placement may interfere with arm positioning when at the sides. - Limited surface area for

	activities, minimizing risk of interference.	attachment may reduce force dissipation.
Humerus	- Exceptionally strong, capable of withstanding forces up to 180MPa. - Potential for additional structural reinforcement if necessary.	- Significantly restricts glenohumeral joint movement. - High joint mobility may reduce the effectiveness of force distribution.
Thoracic cage	- Large surface area allows for effective force distribution. - Includes the clavicle, which is anatomically designed to fracture safely in high-impact scenarios. - Natural damping properties of the ribcage can absorb some impact energy.	- Risk of internal contusions or lacerations from stress waves during impacts. - Additional damping materials may be required to mitigate injury risks, needing further research.
Erector spinae	- Does not impede lumbar motion, maintaining core flexibility. - Located near the spinal column, providing a central force dissipation pathway.	- May increase the risk of injury to surrounding soft tissues. - Proximity to the spinal cord raises concerns about transmitting excessive forces to critical areas.
Scapulae	- Offers a large, strong surface area suitable for force distribution. - Structurally robust, capable of handling significant forces.	- Placement could restrict scapular movement, affecting arm and shoulder mobility. - Scapular orientation may complicate effective force dissipation. - Requires innovative AP design to balance protection and mobility.

Among the identified options, the ilium, thoracic cage, and erector spinae provide an optimal combination of strength and stability while maintaining acceptable levels of mobility. In theory, these locations should not restrict movement beyond the desired range, but physical testing will be necessary to validate these assumptions and evaluate their real-world performance. Conversely, while the humerus and scapulae offer adequate strength, their use as anchor points is likely to impose greater restrictions on movement, potentially hindering mobility during activities.

However, the scapulae warrant further exploration due to their promising structural qualities, despite challenges in providing adequate upper, rear-facing support within the selected areas. Incorporating a secondary, less rigid AP design could be a viable alternative, offering reduced force dissipation capacity while enhancing mobility. The lack of upper-back support in the current AP placements raises concerns about overall system stability, underscoring the importance of overcoming the challenges associated with integrating the scapulae into the design.

The design and placement of APs directly influence the shape and function of the roll cage. The roll cage must stay out of the way during activities while providing comprehensive protection. Choosing appropriate materials for the APs is equally important. A strong but somewhat ductile material can minimize physical impact while maintaining durability. Incorporating additional padding or damping materials [2], especially around the thoracic cage , is an avenue for further research, one that will be explored more in 156B [5].

Research Progression

Initially, most of the search phrases were relatively broad, including terms like 'biking injuries,' 'muscular injuries,' and 'bodily impacts.' However, as the research progressed and my understanding of human anatomy and physiology deepened, the keywords evolved and became more specific. They evolved to include phrases such as 'impact fracture,' 'bone fracture properties,' 'scapular range of motion,' and 'blunt chest trauma.'

Appendix

[1] Gardner, T. N., Simpson, A. H., Booth, C., Sprukkelhorst, P., Evans, M., Kenwright, J., and Evans, J. G., 1998, "Measurement of Impact Force, Simulation of Fall and Hip Fracture," *Medical Engineering & Physics*, 20(1), pp. 57–65. https://doi.org/10.1016/s1350-4533(97)00041-6 Annotated

[2] Cooper, G. J., and Taylor, D. E., 1989, "Biophysics of Impact Injury to the Chest and Abdomen," *Journal of the Royal Army Medical Corps*, 135(2), pp. 58–67. https://doi.org/10.1136/jramc-135-02-04 Annotated

[3] Singh, D., Rana, A., Jhajhria, S., Garg, B., Pandey, P., and Kalyanasundaram, D., 2018, "Experimental Assessment of Biomechanical Properties in Human Male Elbow Bone Subjected to Bending and Compression Loads," *Journal of Applied Biomaterials & Functional Materials*, 17(1), p. 2280800018793816. https://doi.org/10.1177/2280800018793816 Annotated

[4] Massimini, D. F., Warner, J. J. P., and Li, G., 2011, "Non-Invasive Determination of Coupled Motion of the Scapula and Humerus—An In-Vitro Validation," *Journal of Biomechanics*, 44(3), pp. 408–412. https://doi.org/10.1016/j.jbiomech.2010.10.003 Annotated

[5] Engsberg, J. R., Standeven, J. W., Shurtleff, T. L., Tricamo, J. M., and Landau, W. M., 2009, "Spinal Cord and Brain Injury Protection: Testing Concept for a Protective Device," *Spinal Cord*, 47(8), pp. 634–639. https://doi.org/10.1038/sc.2009.1 Annotated