Journal of Interdisciplinary Science Topics

Could Frodo Have Survived Moria?

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19/03/2015

Abstract
In the film '*The Lord of the Rings: The Fellowship of the Ring*', Frodo the hobbit manages to survive a cave-troll spear attack in the mines of Moria, however in the books this stab is delivered by a goblin-chieftain. Frodo is relatively unharmed due to wearing an impenetrable Mithril shirt of chain mail. This paper discusses whether it would be possible for Frodo to survive such an impact force from either the cave-troll or the goblin-chieftain without fracturing his sternum, irrespective of the finely wrought chain mail and therefore still be able to flee further from a Balrog shortly after. The conclusion of the model used is that Frodo may have been unharmed by the goblin-chieftain attack but the cave-troll attack would impart a force of 64,300 N to Frodo's chest and irrespective of dissipation of the force across his chest; this impact force is great enough to result in sternal fracture, a debilitating injury which would have made escape impossible.

Introduction
In the film '*The Lord of the Rings: The Fellowship of the Ring*', the main character Frodo is stabbed by a spear-like weapon in the chest by a cave-troll, whereas in the books this stab is delivered by a goblin-chieftain. Therefore both scenarios are modelled to see if Frodo could remain relatively unharmed by the attack, as is shown in the film [1]. The rationale is that Frodo's Mithril shirt, hidden under his tunic, prevents his body being pierced and protects Frodo. The presumptions are that the weapon is thrust into Frodo's mid chest region, the weapon appears to be a pike and that Frodo experiences no greater injury than being winded by this as he collapses but quickly regains his faculties and can sprint away from the Balrog with the rest of his party.

Sternal Fracture
From the presumptions given it is reasonable to model thoracic blunt force trauma as a consequence of the spear stab, as a considerable amount of force will be put into the jab yet Frodo's chest is not pierced. Sternal fracture is associated with internal organ damage because the sternum requires a force exceeding that, which can cause internal organ damage to break. Consequently blunt force trauma great enough to cause severe sternal fracture commonly results in serious damage, usually myocardial and pulmonary contusions or rupture [2]. Therefore if the impact force calculated exceeds the force required to break a hobbit's sternum, it can be definitively said Frodo would not have been relatively unhurt or able to run directly after.

The Force for Sternal Fracture
From analysis of the injury sustained in 'behind armour blunt thoracic trauma' there is a 50% chance of severe sternal fracture if the peak force of the impact is $24{,}900 \pm 1{,}400$ N in adult humans, depending on bone mineral density [3]. As hobbits are described as children to the eyes of humans [4], it is presumed they are the lower range for the peak force as children would be. Therefore as a hobbit, the peak force of impact which Frodo could withstand without severe sternal fracture is taken as 23,500 N.

The Goblin-Chieftain Stab
The arm weight will be approximated as the mass (m_{arm}) behind the swinging action of the underarm stab for both the goblin and cave-troll. The bodyweight of a goblin-chieftain will be presumed to be 65 kg [5] with 5% of this bodyweight being held in one of their arms [6]. This gives an arm weight of 3.25 kg for the goblin. This will be an underestimate because it doesn't take account of the forwards

momentum (*p*) of the rest of the attacker's body which will also contribute to the peak impact force.

When the goblin or the cave-troll stabs Frodo they do so with a pike. The mass of the pike (m_{pike}) is therefore a factor in determining the momentum of the stab and has been taken to be 4.25 kg, which is the average of the weight range of pikes [7]. This gives a total mass of the stab to be 7.5 kg.

The velocity (*v*) of the stab has been approximated to be the average velocity of a punch thrown by a professional boxer in the goblin's presumed weight class, which is 7.6 ms^{-1} [8]. This has been approximated as in the film the camera shots do not show the continuous motion of the thrust from the cave-troll into Frodo without cutting to different angles therefore distance per unit time could not be approximated in this way.

$$p_{stab} = (m_{pike} + m_{arm}) \times v \qquad (1)$$

This gave a value of 57 $kgms^{-1}$ for the goblin-chieftain.

To calculate the force that Frodo receives from the goblin-chieftain the momentum of the stab will be divided by the contact time (*t*) between the spear and Frodo. This will be approximated to be the average contact time between a human fist and its target during a punch. From experimental data taken over three punches to a volunteer the average contact time between the fist and the body was found to be 0.033 s [9].

$$F = \frac{\Delta p}{t} \qquad (2)$$

Dividing the overall momentum of the stab by 0.033 s gives 1,727 N of force impacting Frodo's chest. This is shown in equation 2. This force is concentrated on the tip of the pike but due to the dissipation by the Mithril rings this could perhaps be taken as the diameter of the spear shaft. However dissipation of the force is not necessary to model as this force is less than 1/10th calculated as necessary to fracture Frodo's sternum and therefore any dissipation would further lessen the impact force.

The Cave-Troll Stab

The momentum of the cave-troll stab can be modelled in the same way as that of the goblin-chieftain, shown in equation 1, scaled up to the cave-trolls size where all variables have remained the same except the mass of the punch. The mass of a cave-troll is taken to be 5,500 kg, which is the mass of an average male African bush elephant [10] as an analogous organism. Therefore the weight of its arm would be 275 kg if presumed to be of human form [6]. The mass of the pike is still 4.25 kg and the velocity of stab taken to be 7.6 ms^{-1} again as there is no data for the speed at which a cave-troll, presumed to be of elephant size, could punch. Therefore the cave-troll momentum of stab would be 2122.3 $kgms^{-1}$. Next the force is calculated presuming same contact time of 0.033 s.

Therefore the forces would be 64,300 N for a cave-troll stab. Due to the fineness and flexibility of the material that Mithril is described to be, it can be concluded that the forces could not be dissipated to significantly reduce the chance of severe sternal fracture.

Conclusion

Frodo could have been relatively unharmed by the stab of a goblin-chieftain but not the stab of a cave-troll. This is because in this model, the impact force of the cave-troll stab at 64,300 N far exceeded the 23,500 N force required to break Frodo's sternum, especially since the model underestimates the proportion of body weight that would likely have been put behind a thrusting action such as the pike stab. This result seems sensible as the purpose of the Mithril shirt is akin to chain mail which prevents penetration and, especially as the material is exceptionally fine textured, would not be able to dissipate the force to any significant degree. Therefore the only chance Frodo has of being able to run away unscathed after a cave-troll attack is magic.

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