Using LS-Dyna as an Aid to the Inclusive Design of Child Resistant Closures

AUTHORS:

Joe Luxmoore
University of Sheffield
Dr. Alaster Yoxall
University of Sheffield

CORRESPONDENCE:

Joe Luxmoore
University of Sheffield
Phone +44 114 222 7878
Fax +44 114 222 7890
Email j.luxmoore@sheffield.ac.uk

ABSTRACT:

The population of most developed countries is ageing. Despite continuing medical advances, ageing brings with it a host of issues, not least a loss in strength and dexterity. One major area of concern is the ability of elderly consumers to access packaged goods such as food and medicines. In previous studies, the authors developed an LS-Dyna model of a human hand that was used to investigate the effect of physical dimensions and the choice of grip type on joint stresses and hence levels of discomfort. The work was supported by consumer ethnography studies and lead to recommendations for inclusive packaging design. In the present paper, the model is applied to a product that is known to cause particular difficulties for the elderly, the "squeeze and turn" child resistant closure, identifying the specific ergonomic issues associated with it.

KEYWORDS:

Packaging, Child resistant closure, Biomechanics

INTRODUCTION

As the average population age in developed nations increases, issues relating to strength and dexterity become ever more important. One aspect of daily life where this is very apparent is in the design of consumer packaging. Studies have shown that many elderly people experience such difficulties in opening packaging that they will abandon products altogether [1], leading to non-compliance in the case of medical packaging [2], and possibly even malnutrition in the most vulnerable individuals. The principals of Inclusive Design seek to address issues of social exclusion such as these. To quote the late Bernard Isaacs, founding director of the Birmingham Centre for Applied Gerontology: "Design for the young and you exclude the old; design for the old and you include the young".

In previous studies [3, 4], the authors developed an LS-Dyna model of a human hand. This was used to assess the effects of choice of grip type and hand dimensions on joint stresses (and hence pain or discomfort) during gripping tasks. Briefly, it was found that certain grip types and larger hand sizes result in lower joint stresses. This was supported by parallel ethnography studies which demonstrated that consumers will tend to use these grip types if the size of the packaging allows.

In this study, the model is extended to examine the opening function of a child-resistant closure, specifically a "squeeze and turn" type commonly found on household cleaning products. These are known to cause issues for the elderly, many of whom struggle to open them.

LS-DYNA MODEL

The human hand model is described in detail in a previous paper [3]. A brief outline is given here, together with adaptations made for the specific task of modelling a child resistant closure.

Bone geometry was created by 3D laser-scanning (ModelMaker W70, 3D Scanners, London) individual bones from a 1:1 scale skeletal right hand model (3b Scientific, Hamburg, Germany). The bones were meshed using temperature independent, constant stress, 8-noded, hexahedral brick elements.

The model boundary was set as the base of the four finger metacarpal bones (the long bones in the palm of the hand) and the trapezium (one of the carpal bones, at the base of the thumb). The relative movement between the four metacarpals and the trapezium is small [5] and hence this is a convenient area in which to constrain the model. Nodes in this region were constrained for all degrees of freedom using *BOUNDARY _SPC_NODE.

Joints were modelled using the *CONSTRAINED_JOINT_SPHERICAL option. Each joint was connected to its two corresponding bone sections using "spiders" of rigid beam elements. Local Cartesian coordinate systems were defined at each joint centre and rotations in the x, y and z axes were restricted using the *CONSTRAINED_JOINT_STIFFNESS_GENERALIZED card. Joint angle limits were from the median values of ranges given by Palastanga et al. [6]. The spherical joints were each arbitrarily located in the head of the more proximal bone section and positioned such that the bones did not overlap through the full range of movement. In reality, joint centres and limits of rotation are complex subjects that require further investigation.

Physical properties of bone were assumed to be isotropic and were taken from Katti [7]. Again, in reality, there are large variations in Young's Modulus and ultimate compressive strength [8] between different bones hence this is another area for future investigation. To represent the ligaments stabilising the metacarpal bones in the palm of the hand, the proximal and distal heads of the bones were connected using stiff (E=200GPa) beam elements. Bone and ligament materials were defined using *MAT_ELASTIC.

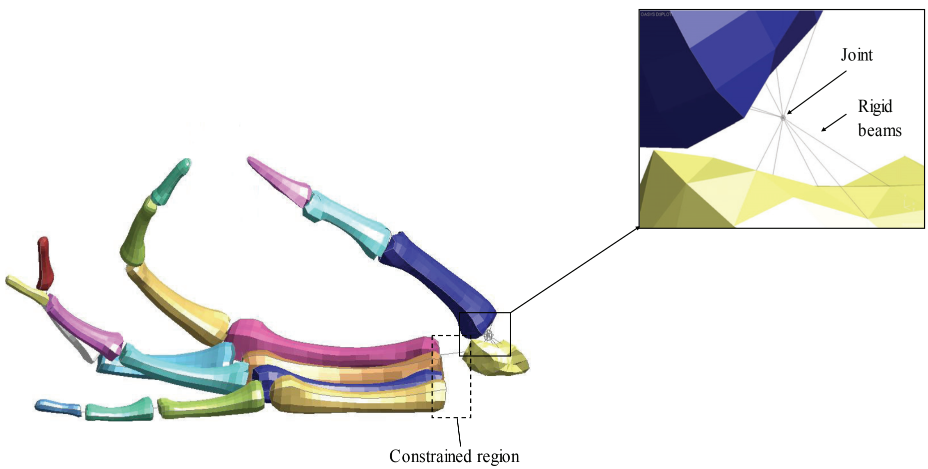

Figure 1: Bone geometry showing example joint and constrained region.

The CRC geometry was created by a 3D laser-scan (Konica-Minolta Vi-9i, Simpact Engineering Ltd., Coventry) of a typical bleach bottle closure. This closure features two opposing corrugated areas that indicate where the "squeeze" should be applied. A force-deflection test was carried out across these opposing areas, from which the closure stiffness was determined. The closure was also meshed using hexahedral brick elements and its material was defined using *MAT_ELASTIC.

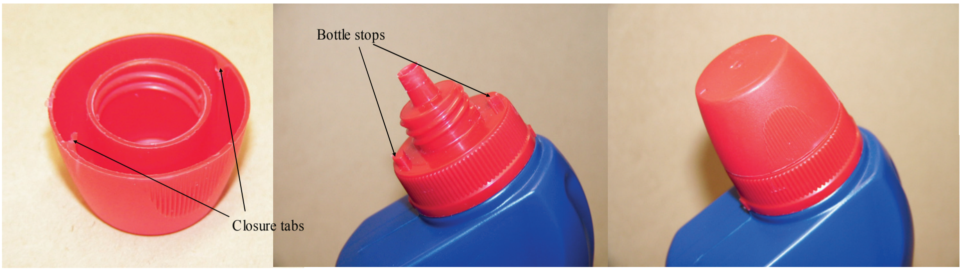

Figure 2: CRC used in the study.

A rigid beam was attached to the closure at its centre of rotation. This in turn was connected to another rigid beam, that was constrained for all degrees of freedom, via a revolute joint (*CONSTRAINED_JOINT_REVOLUTE). This provided a stable axis about which the closure could rotate freely, as it could on the screw thread on the real bottle. The stops on the bottle which prevent the closure from being rotated until it has been squeezed sufficiently were represented by rigid solid elements constrained for all degrees of freedom.

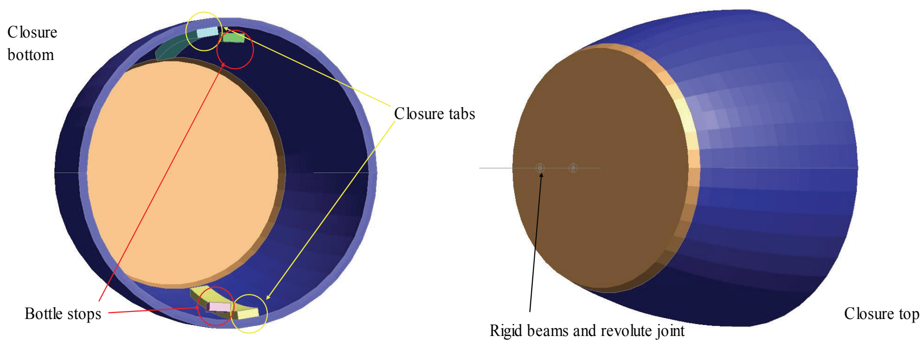

Figure 3: CRC model.

The hand was arranged in a "pulp" grip configuration on the closure. Forces were applied to the model in two phases. Firstly, two opposing forces were applied to each fingertip, creating the "squeeze" motion on the closure. The forces were ramped up linearly from zero until the closure had deformed sufficiently that the closure tabs cleared the stops on the bottle allowing rotation of the closure to occur. At this point, the forces stopped increasing and were kept at a constant value (6N). At the same time, two further forces were applied to the finger tips in opposite directions tangential to the closure surface creating the "turn" motion on the closure. The motion was allowed to continue until the closure had rotated far enough for the tabs to fully clear the stops on the bottle, when the analysis was stopped. The "turn" force at this point was 2N.

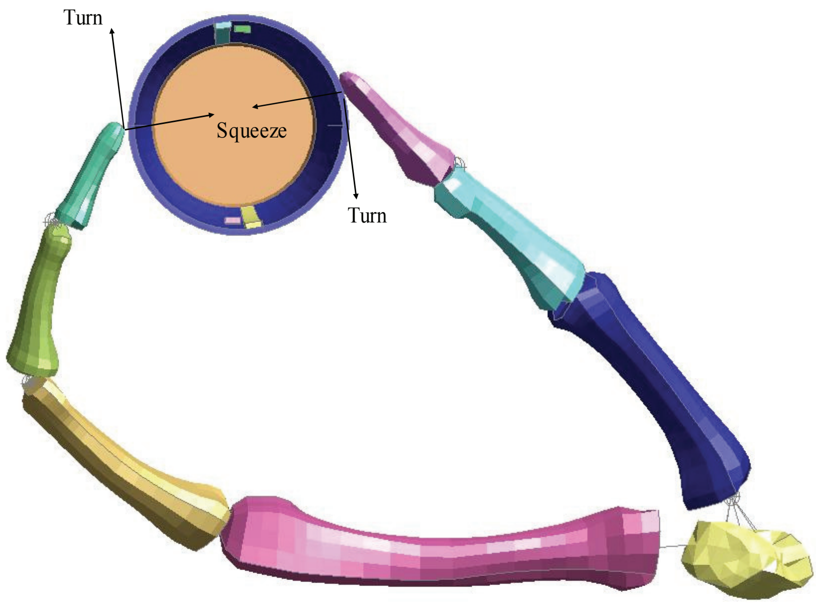

Figure 4: Complete model geometry showing applied forces.

Although the amount of closure rotation is not enough to fully unscrew it from the bottle, it was felt to be representative of real use. This is because video ethnography of consumers opening the closure showed that they tend to perform the squeeze and initial turn in one motion, before moving their hand to a different posture in order to unscrew the closure fully. It was also clear that it was this initial part of the motion that consumers had difficulty with, hence the model was representative of the key issue; the combined "squeeze and turn" motion.

RESULTS

After solving the LS-Dyna model, plots of minimum principal stress (i.e. maximum compressive stress) and maximum shear stress were created and compared, for the timesteps at the ends of the "squeeze" and "turn" parts of the motion. Example plots of stress contours are shown in Figure 5.

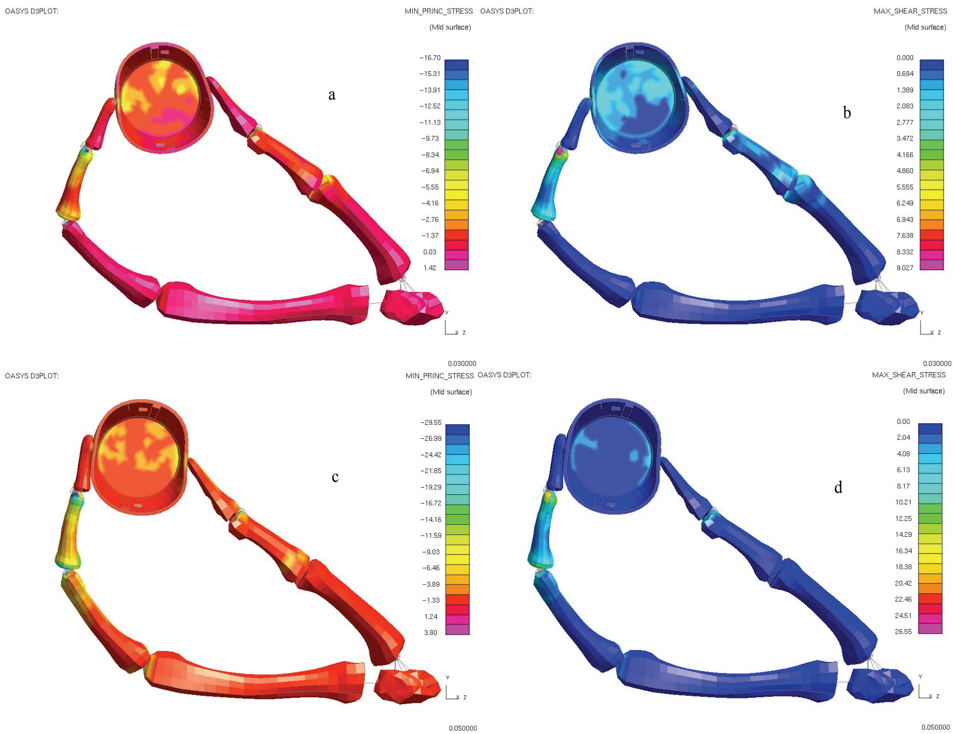

Figure 5: Maximum compressive stress (a) and maximum shear stress (b) at the end of the "squeeze" motion; maximum compressive stress (c) and maximum shear stress (d) at the end of the "turn" motion.

The maximum compressive stress and maximum shear stress at each joint interface are presented in Table 1, normalised against the minimum value of joint interface stress in each case.

	Normalised maximum joint stress			
	End of "squeeze"		End of "turn"	
	Max. compressive	Max. shear	Max. compressive	Max. shear
Thumb CMC	1.0	1.0	0.9	2.9
Thumb MCP	3.0	4.0	2.8	2.9
Thumb IP	3.0	12.9	6.4	14.6
Index MCP	1.0	1.0	15.6	38.0
Index PIP	4.9	7.0	15.6	20.4
Index DIP	11.9	12.9	21.1	29.1
Average	4.1	6.5	10.4	18.0

Table 1: Normalised maximum joint interface stresses. CMC = Carpometacarpal joint; MCP = Metacarpophalangeal joint; IP = Interphalangeal joint; PIP = Proximal Interphalangeal joint; DIP = Distal Interphalangeal joint.

DISCUSSION

It can be seen from Table 1 that there is a significant increase in average maximum joint interface stress when the "turn" force is applied to the closure. The joints in the index finger experience the largest increases in interface stresses. The force input does of course increase between the two timesteps of interest, however the total applied force magnitude on each finger increases by around 30% only, whereas the average maximum joint stress magnitudes increase much more significantly than this. While applying the "squeeze" alone, the thumb and index finger are very stable. However, the application of the "turn" force causes the thumb and finger to accelerate rapidly meaning there is no longer a stable structure to support the "squeeze" force; the index finger quickly tends towards hyperextension at its joints, the thumb towards flexion.

In terms of the implications of the model for consumers, this can help explain why people find the combined "squeeze and turn" action difficult; a small increase in required force at the finger tips to produce the "turn" motion results in a large increase in joint interface stresses and hence a likely increase in pain and/or discomfort.

The obvious conclusion that can be taken from this in terms of product improvement, is to isolate the "squeeze" and "turn" motions from one another. Ethnographic studies show that once the cap is unlocked and able to rotate freely, users have few or no difficulties. If the initial movement could be altered to "squeeze" only rather than the current "squeeze and turn", weaker users would be able to concentrate their efforts more effectively. Obviously, any design changes such as this would need to be assessed to ensure that the level of child-resistance was maintained.

CONCLUSIONS AND FURTHER WORK

A simple LS-Dyna model of a human hand has been successfully applied to the assessment of a "squeeze and turn" child resistant closure operation, identifying that it leads to high levels of joint stress in users and a possible design improvement that could reduce this. There is now the possibility of applying the model to the assessment of more complex manual tasks.

There are several areas of the model that should be improved to make them more representative of the real situation, in particular the joint model, material properties of constituent tissues and representation of the skin and fleshy parts of the fingers. Work is currently ongoing to improve these aspects.

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