AN ANATOMICALLY ACCURATE MODEL OF A LAMB CARCASS

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Background

Over recent years there has been a trend towards increased further processing of lamb carcasses to create new value-added products. In 1970, over 90% of New Zealand export lamb was in whole carcass form. Twenty years later, just over half of all lamb exported from New Zealand was further processed into lamb cuts and boneless product, and eight years after that, in 1998, over three-quarters of exported lamb was further processed (New Zealand Meat Producers Board, 1971, 1991; Meat New Zealand, 1998).

Lamb processing, as with most other industries, also has a continual drive for increased efficiency and optimisation of returns. As a natural product, a lamb carcass is inherently variable, making automated processing difficult, yet automation is critical for reducing processing costs, improving product quality, and developing new value-added products. The key to automated processing of natural product is the ability to characterise each item before processing.

The push for increased processing efficiency and novel products requires a greater understanding of the anatomical structure of the lamb carcass, the underlying properties of its various components, and the way in which the components interrelate. The carcass model outlined in this paper provides an excellent visualisation tool for understanding the anatomy of the carcass. This carcass model has wide-ranging applications within the meat industry. For example, the 'generic' carcass model can be customised to represent individual carcasses using data from one or more of a variety of measurement technologies. This customisation allows the components of each carcass to be characterised, providing information for making better grading decisions or for controlling automated disassembly processes.

Objective

To create an anatomically accurate and computationally efficient model of a lamb carcass that can be used to enhance understanding of ovine anatomy and as the basis for more advanced processing systems.

Methods

Using X-ray computed tomography (CT), a lamb carcass was scanned in 3 mm thick slices at 3 mm intervals along the carcass length, to produce over 360 two-dimensional transverse images such as those in Figure 1. Each image shows the bone, fat, and muscle regions at a particular point along the length of the carcass. High-density areas like bone appear white, while muscles and fat deposits appear as light and dark shades of grey respectively.

To create three-dimensional models of the various structures within the lamb carcass, three-dimensional data sets were first built up from the series of the two-dimensional CT images. Several methods were used. The marching cubes technique (Lorensen and Cline, 1987) was used to produce three-dimensional surfaces of the bones and outer surface of the carcass from the CT images. This algorithm uses intensity values within the images to determine a surface. A virtual cube is created from eight pixels, four from each of two adjacent images. The algorithm then determines how the surface intersects the cube. The topology of the surface within the cube is then determined and the cube moves to the next position. The resulting surfaces are made up of thousands of small triangular elements. The vertices of these elements provide an accurate three-dimensional data set to which a more efficient mathematical model with many fewer elements can be fitted.

A manual digitisation process was used to determine the surfaces of individual muscles and muscle groups. This technique was chosen because changes in CT image intensity across muscle boundaries are difficult to detect, so automated edge detection, as used between bone and lean for example, does not work well. For each muscle or muscle group, the two-dimensional X-ray images were analysed sequentially and points defining the outline of a particular muscle were selected as two-dimensional coordinates. The data sets were then combined to produce a three-dimensional data set.

Geometric models were then fitted to the three-dimensional data sets, to fully describe the surfaces of the muscles, bones, and carcass surface. A finite element modelling approach was used, where the surface is divided into a number of smaller regions or elements. The three-dimensional shape of each small surface region can be simply described using relatively low order polynomials (cubic in this case). These bicubic elements provide a powerful means of describing curvilinear surfaces and allow relatively complicated geometries to be modelled with a minimal number of elements (Bradley et al., 1997). A non-linear optimisation process was used to fit a geometric model, made up of a number of bicubic elements, to each of the measured data sets. The fitting procedure minimises the perpendicular distance between the data points and the model surface, to give a better approximation of the true surface shape.

Results and Discussion

Surface models were fitted to all of the major bones and muscle groups (Figures 2 and 3) as well as to the outer surface of the whole carcass. The use of higher order bicubic elements allows the surfaces to be described with relatively few elements and has been found to be more efficient than using linear elements (Nielsen et al., 1991). Almost all of the muscles were modelled using fewer than 36 elements per muscle, although more elements were used for the longer *longissimus dorsi* and *psoas major* muscles. Many of the bones had much more complicated surface geometries, and required more elements to accurately describe them. For example, 48 elements were used to model the scapula (Figure 4), 86 for each thoracic vertebra, and 108 for the sacrum. The model of the outer carcass surface was the largest, with 436 elements. To model the same carcass surface at the same level of accuracy using linear elements required almost 7000 elements.

The accuracy of the fit was measured for each surface model. The error for each data point is defined as the Euclidean distance between the data point and its closest projection onto the given mesh. Summing these individual errors gives an indication of the overall quality of fit. The root mean squared (RMS) error for the various models ranged from 0.7 mm to 2.8 mm with the majority lying between 1 mm and 2 mm. These errors are largely within the measurement error incurred in manual digitisation. However, if greater accuracy is required, the number of elements could be increased and the fitting process repeated.

The carcass model provides an excellent visualisation tool, allowing researchers to easily view the anatomical structure of a carcass. Additional data can also be included in the model, so it can be viewed within the context of the carcass anatomy. For example, muscle parameters such as collagen concentration or normal ultimate pH could be displayed to facilitate new product development. As a computational model it could also be used to simulate the chilling process or the stresses and strains various parts of the ovine anatomy undergo, which has a significant impact on muscle quality.

The model can be used as the basis for modelling other carcasses, perhaps even those of different species, without going through the laborious process of a full CT scan, digitisation, and model fitting. It is possible to use a much smaller, more critical set of measurements from any carcass and adjust or customise the original model to the new shape in question. Clearly, though, there are limitations to extensions of model use: as the gap between the objects (animal, breed, species) increases, the adjustment problems become more difficult. The various measurement technologies and customisation routines that will produce the best results are a part of the current research focus.

Conclusions

The anatomically accurate carcass model will enable improved visualisation and understanding of ovine anatomy and will be of significant benefit to the meat industry. Combining the carcass model with on-line measurement techniques to customise the model to an individual carcass will allow more accurate prediction of yield and improved carcass breakdown, to get maximal returns for each carcass. Increased automation of the carcass grading and carcass disassembly processes will be possible, giving a more consistent product with reduced processing costs. The model could also be used for training and marketing purposes, using virtual butchery to demonstrate exactly where and how the carcass should be cut to produce the desired set of meat cuts. The applications for this type of modelling approach are therefore wide ranging.

Pertinent Literature

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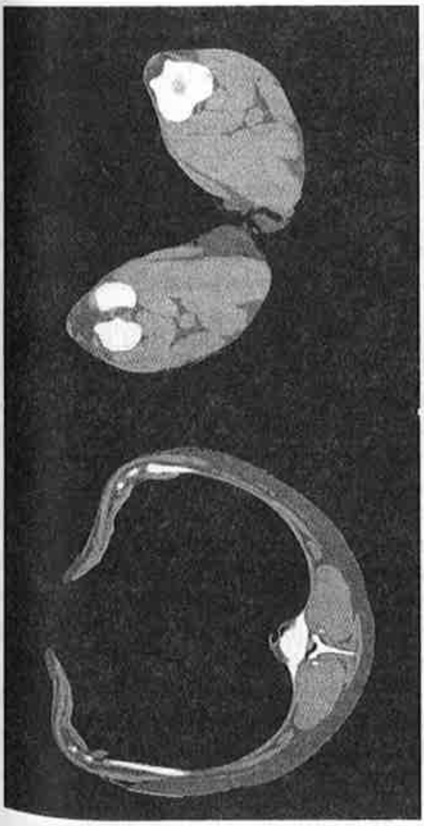

Figure 1. Example CT images showing bone, muscle and fat regions in two 3 mm slices.

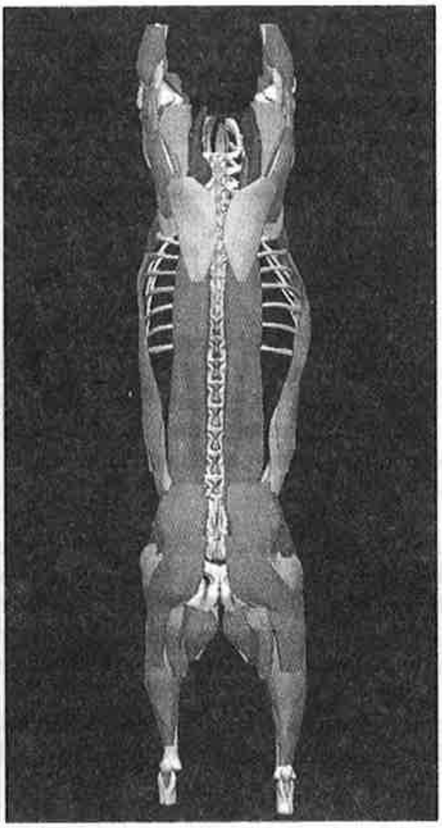

Figure 2. A generic model of the bones and major muscle groups of a lamb carcass.

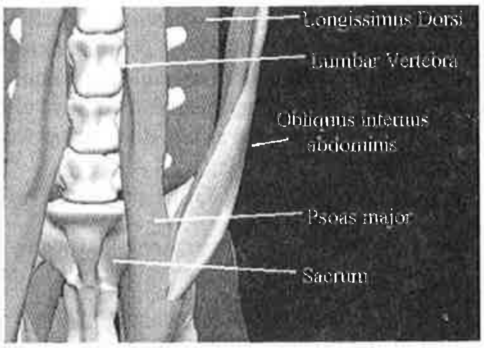

Figure 3. Close up view of the lumbar region of the carcass model.

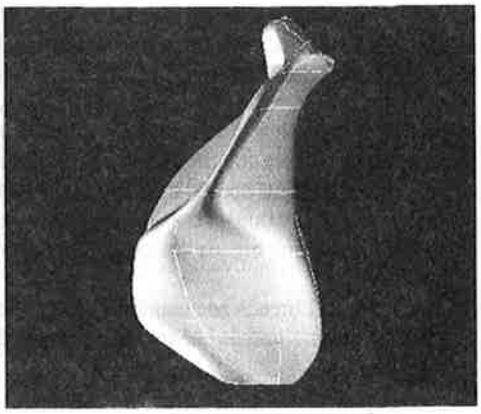

Figure 4. Three-dimensional model of the ovine scapula.