122 control points are defined on the reference model body. 51 control points describe the surface shape on each side of the symmetry plane, while 20 control points describe the symmetry plane. The control points are divided into sets depending on the anatomical feature they are attached to: head (20 points), torso (26 points), arms (38 points), upper leg (10 points) and lower leg (28 points). Each control point is coincident with a node in the finite element surface mesh.

The surface mesh with overlaid control points is shown in Figure 1.

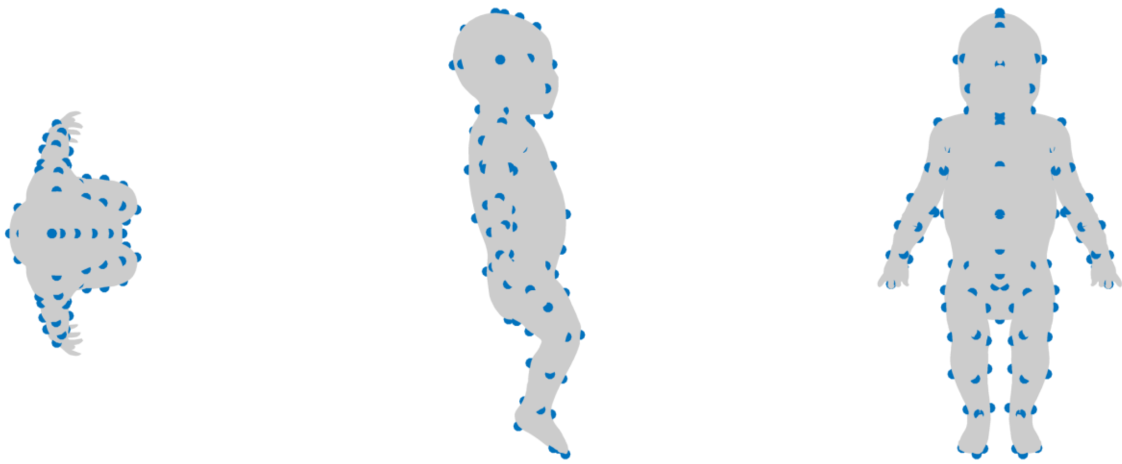

Figure 1

Four measurements are taken on the preemies, $[w_{\text{measured}}, T_{\text{measured}}, L_{\text{measured}}, H_{\text{measured}}]$. These measurements coincide with vectors between control points on the surface of the model, Figure 2.

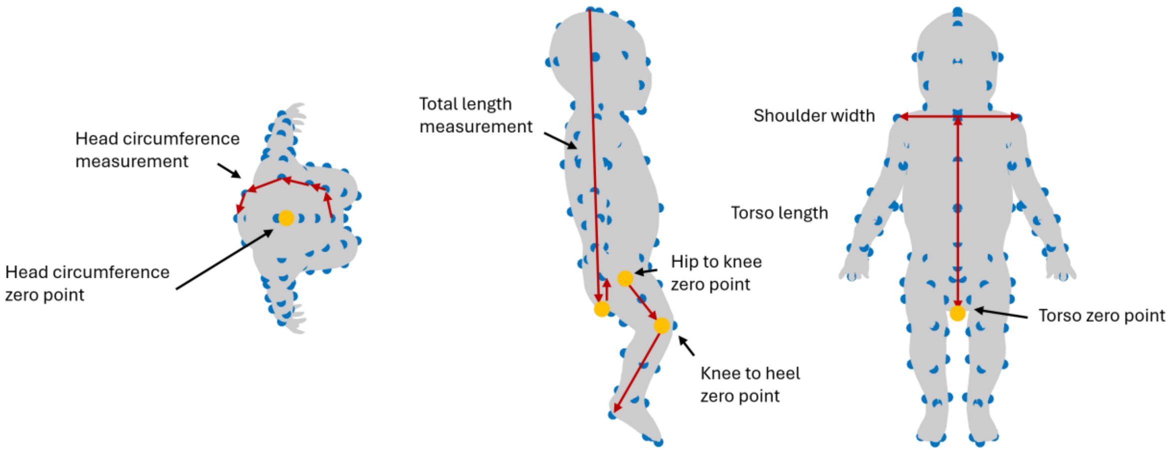

Figure 2

The measurements are calculated for the reference model, $[w_{\text{model}}, T_{\text{model}}, L_{\text{model}}, H_{\text{model}}]$. The necessary scaling factors are

$$f_i = \frac{i_{measured}}{i_{model}}, i \in \{w, T, L, H\}$$

The measurement is matched by linearly scaling the control points belonging to that part of the body. The linear scaling is performed relative to a fix point. For the torso, the fix point is the control point in the groin, SCP_{Groin}. The vectors from the fix point to each control point in the body part are calculated on the reference model,

$$\boldsymbol{v} = \mathbf{SCP} - SCP_{\mathrm{Groin}}$$

The new positions of each control point in the body part are calculated using the scaling factor,

$$\mathbf{TCP} = \boldsymbol{v} \cdot f_i + SCP_{\mathrm{Groin}}$$

Scaling one body part may require translating other parts. For example, if the torso length is scaled by scaling the vector from the groin to each control point in the torso, the head will be in the incorrect position. To compensate for this, the control points belonging to the head are (rigidly) translated the same amount as the top of the torso. Similarly, the arms need to be rigidly translated so that the shoulder joints match.

The total length is affected by the scaling of the torso and the scaling of the head in the Z direction. To match the total length the legs are scaled last. Instead of scaling the legs based on the reference model total length, the legs are scaled based on the updated model total length, so that the scaling factor f_{legs} is found by solving

$$L_{\mathrm{measured}} = L_{\mathrm{head}} + L_{\mathrm{torso}} - L_{\mathrm{groin-to-hip}} + f_{\mathrm{legs}}\left(L_{\mathrm{hip-to-knee}} + L_{\mathrm{knee-to-heel}}\right)$$

$$f_{\mathrm{legs}} = \frac{L_{\mathrm{measured}} - \left(L_{\mathrm{head}} + L_{\mathrm{torso}} - L_{\mathrm{groin-to-hip}}\right)}{L_{\mathrm{hip-to-knee}} + L_{\mathrm{knee-to-heel}}}$$

The zero points and the scaling factor are summarized in Table 1.

Table 1

Body part	Zero point for scaling	Scaled by factor
Torso X	**Groin**	No scaling
Torso Y	**Groin**	$w_{\mathrm{measured}}/w_{\mathrm{model}}$
Torso Z	**Groin**	$T_{\mathrm{measured}}/T_{\mathrm{model}}$
Head X	**Centre of head**	$H_{measured}/H_{model}$
Head Y	**Centre of head**	$H_{measured}/H_{model}$
Head Z	**Centre of head**	No scaling
Hip to knee, XZ plane	**Centre of hip**	f_{legs}
Hip to knee Y	**Centre of hip**	No scaling
Knee to heel, XZ plane	**Centre of knee**	f_{legs}
Knee to heel Y	**Centre of knee**	No scaling

Once the control points have been transformed from the source configuration to the target configuration, the nodes of the FE surface are morphed using the PIPER Kriging module.