ISIS2

measures 3D shape of the back for assessing scoliosis

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ISIS2 is based on the old ISIS principles but uses modern digital photography and computing power to give quicker measurements and an easier user interface.

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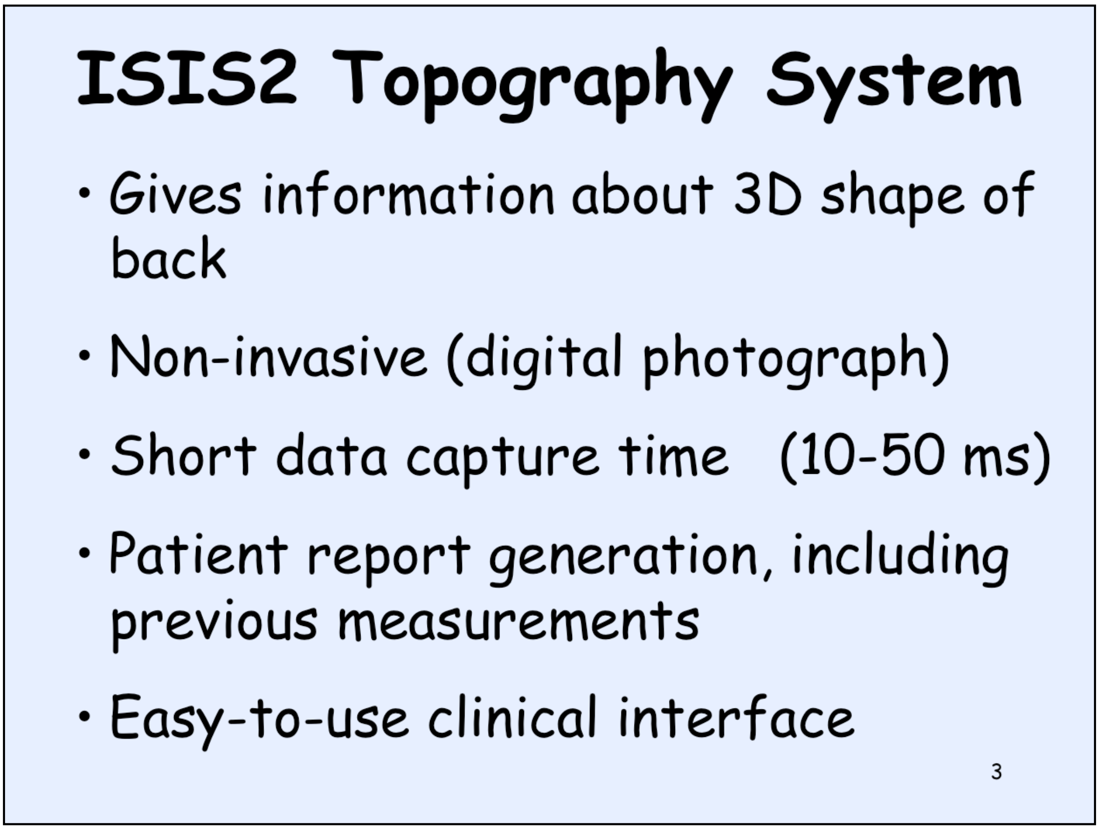


Developed with the Royal Orthopaedic Hospital, Birmingham and the Nuffield Orthopaedic Centre, Oxford.

No radiation, just normal digital photograph and ordinary white light.

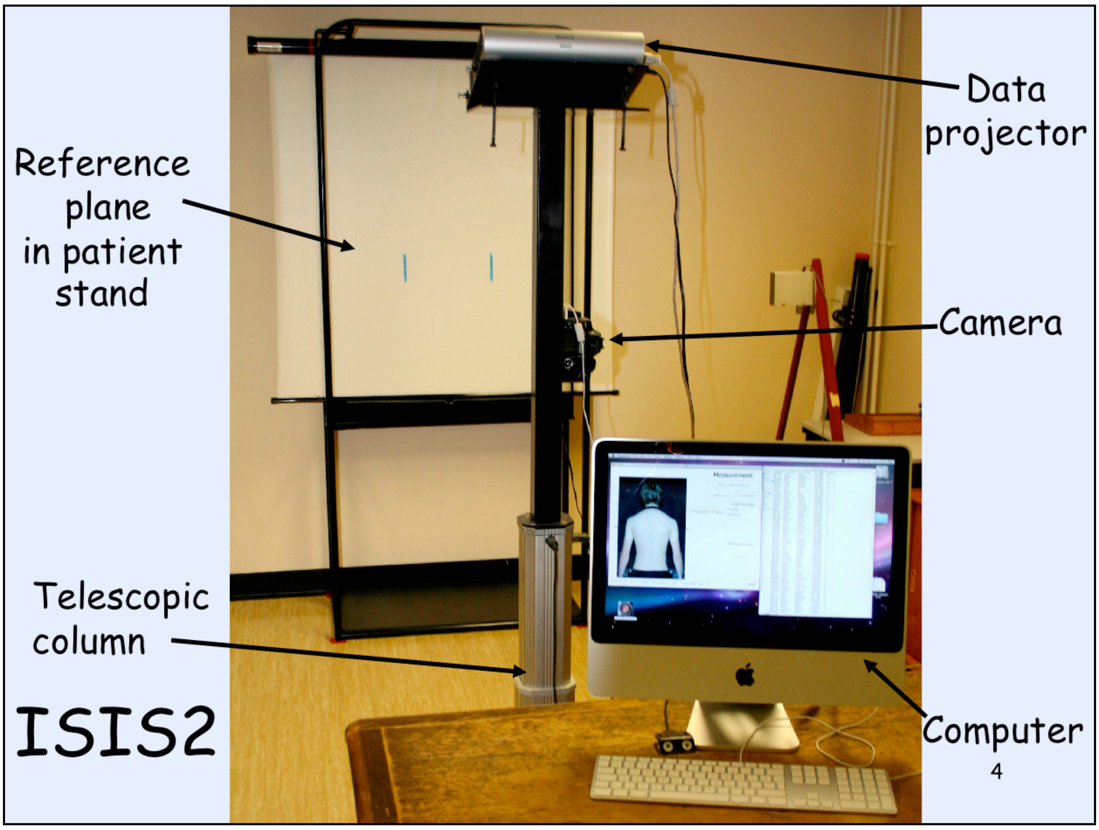
Patient has to stand still for time of photograph, typically 10-50 ms – so very short time.

Previous results are all stored so can plot parameters longitudinally.

Easy to use – you click on buttons on the screen and user interface leads you through it.

Not a substitute for radiography. It provides an estimate of curve of the spine similar to Cobb angle but only an estimate. Where a lot of vertebral rotation occurs it will underestimate the curve. However, the ISIS2 lateral asymmetry parameter (Cobb equivalent) can be used for monitoring - only do another X-ray when ISIS starts indicating a significant increase - and that can reduce the radiation exposure of the patient.

ISIS provides complementary information about the surface of the back that radiography does not. Often the patient is most interested in the surface of their back and what it looks like rather than the underlying bone shape.



Camera is an ordinary consumer camera. Projector is an off-the-shelf data projector (must be LCD type and preferably short throw, un-plug and go).

Whole system costs around £5000-£6000 for all the components.

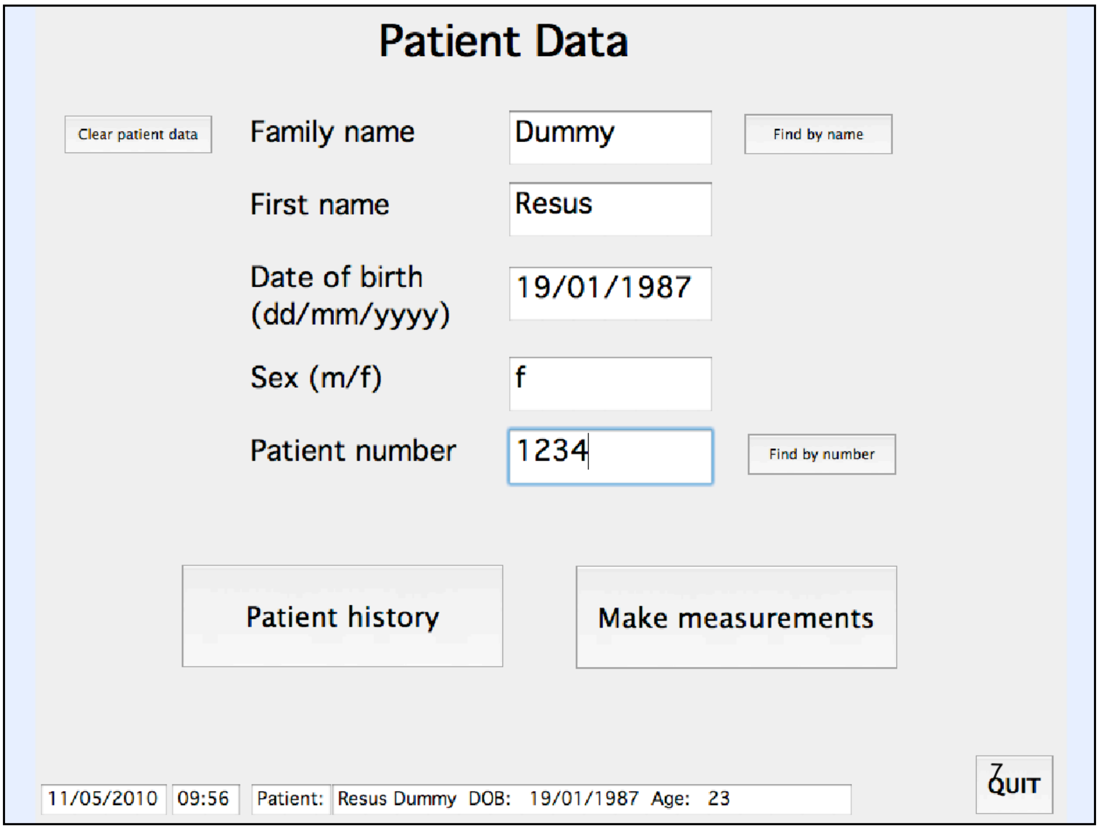
Patient stand

Adjustable abdominal bar – helps patient stay still. Important that the patient shuffles forward to the abdominal bar; they should not lean forward to reach it.

Adjustable arm rests – helps patient relax muscles and yet arms are moved away from back (makes it easier for the computer to detect the sides of the back)

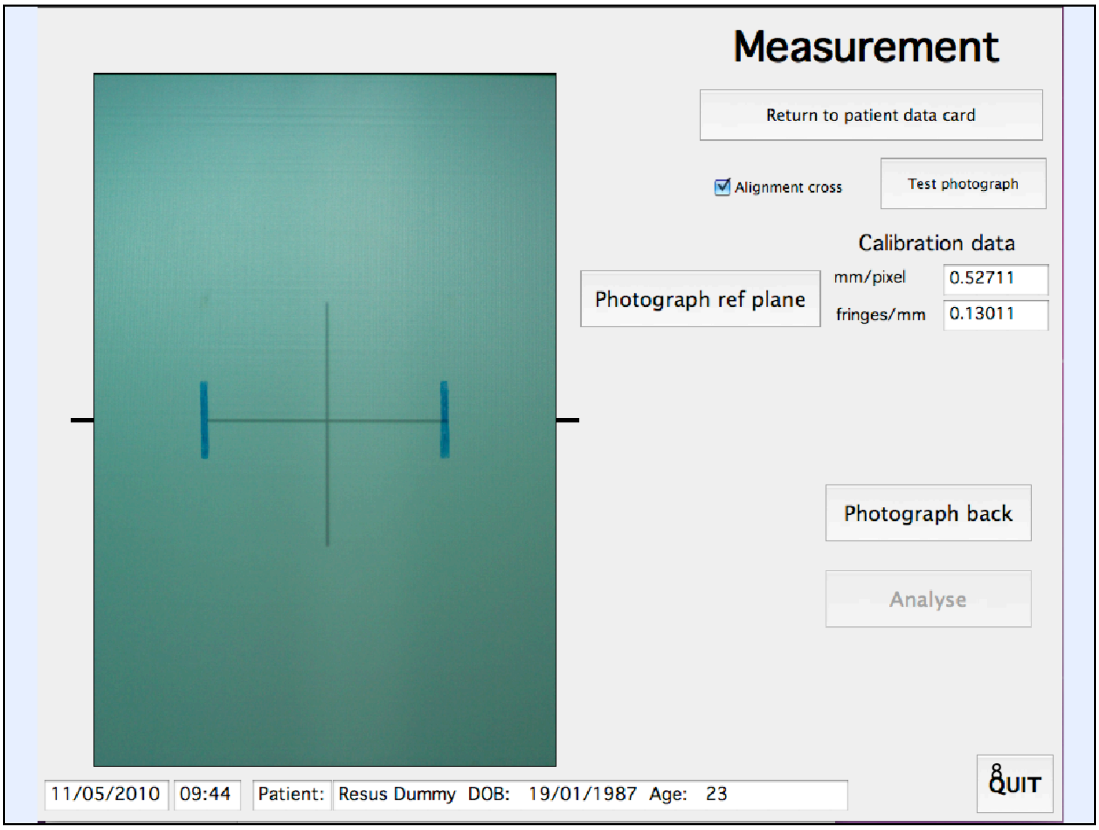
Radiographer should ask the patient to shuffle forward so their tummy touches the abdominal bar. Patient should not lean forward, keep shuffling forward until they reach bar. Then ask the patient to move their feet apart so the feet are directly under the hips (for stability so they are less likely to sway). Often in moving the feet apart the patient moves back away from the bar so check by looking from the side to make sure patient's tummy is up against bar. If not, ask them to shuffle forward again.

Slide screen to give reference plane for calculating the 3D shape. A reference plane photograph has to be taken once for every measuring session. Usually it is taken first and the system is automatically calibrated from this photo before the patients arrive. The ref plane photograph and patient photograph have to be taken before the Analyse button is available on the computer screen (it is greyed out if either photo has not been taken.) See slides 8 and 9 for more details on doing the calibration.



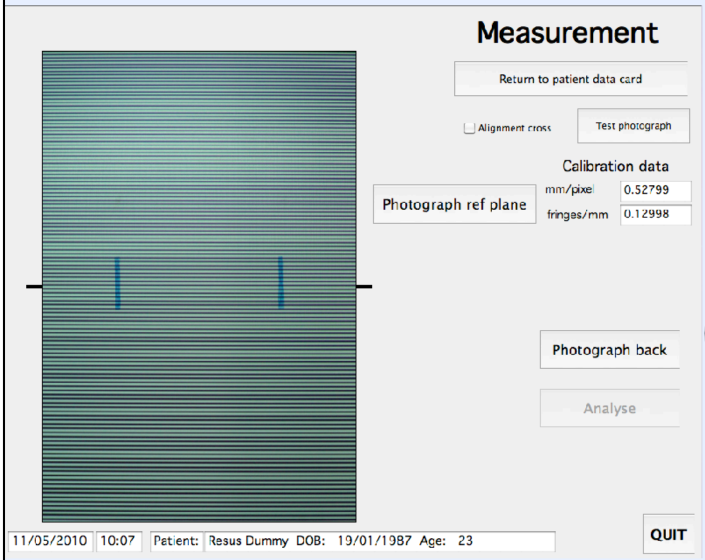
Look at the user interface. First card asks for patient information to be input. Then you can carry out measurements or look at previously measured data on a particular patient. The 'Make measurements' button takes you to the measurement card. The 'Patient history' button skips over the Measurements and Results cards to the Monitoring card.

If you have a new patient you need to type everything in by hand. If the patient has been before you can just type a family name or first name and click the Find by name button or a patient number and click the Find by number button.



First you have to calibrate the system. You have to get the vertical turquoise lines in the centre of the photograph for the calibration procedure to work. There is an easy way to do that. Here is a screenshot of the Measurement card of the app. You click on the 'Alignment cross' selection box and this lets you see on the screen where the centre of the photo will be. You can then move the camera up or down to get the alignment cross in the middle of the vertical lines. Then click on the 'Alignment cross' box again to de-select it and the projected pattern goes back to the horizontal fringes. Can take a test photo to make sure you have it right and then click on the' Photograph ref plane' button.

Reference Plane - calibration



Pixel size
~ 0.5 mm

Fringe frequency
~ 0.13 fringes/mm
(~ 8 mm/fringe)

Height accuracy
~ 1 mm

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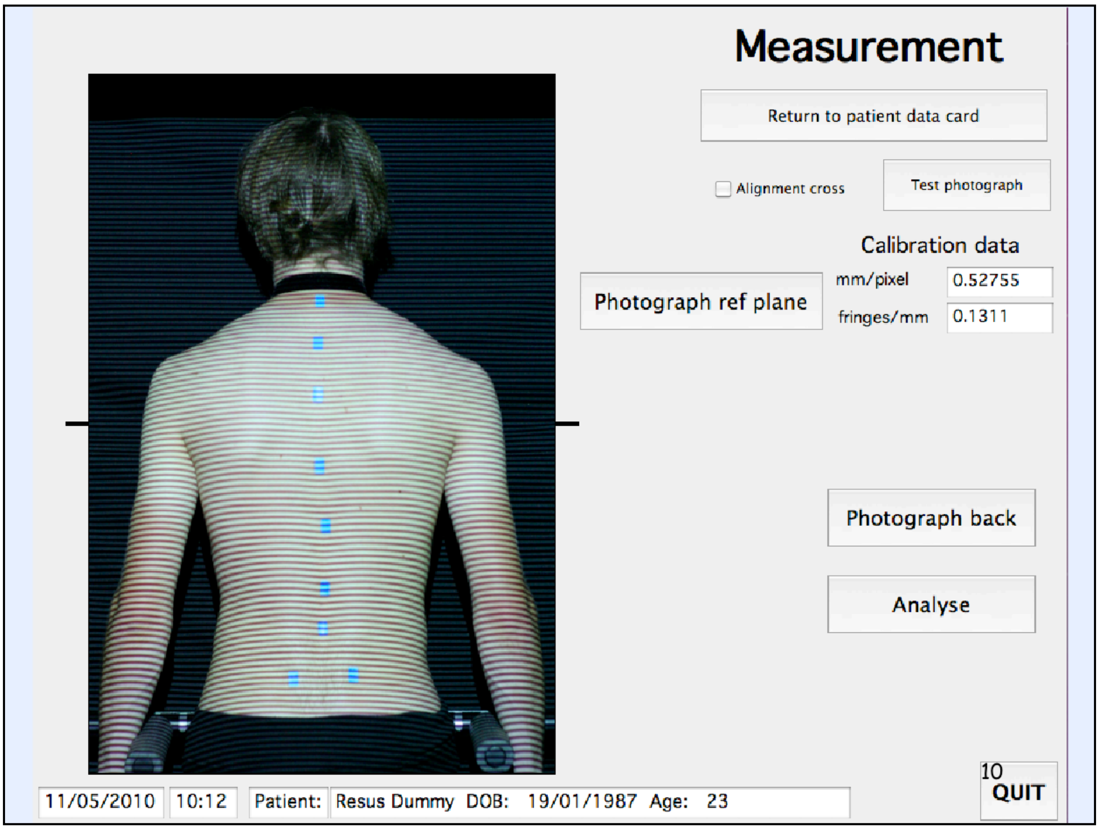
Reference plane has to be measured once at the beginning of each session (not for every patient, just once for the whole session). Pull down the roll-up screen and attach it to the hook. Adjust the height of the telescopic actuator so camera is centred on the turquoise vertical lines using the alignment cross. Take a test photo if you want. Then take the reference plane photo and the system is automatically calibrated.

Should the camera/projector stand be moved relative to the floor then you have to take a new reference plane photo (do a new calibration). Moving the camera/projector up or down using the telescopic actuator does not change the calibration. If you switch the app off (close ISIS2 down) you will need to re-calibrate when you open the app again.

Note the 'Analyse' button is greyed out. This is because a back photo has not yet been taken.



Patient wears a black halter-neck top (or just a neck band for the boys) and a black apron. Hair has to be tied up if it covers the back or neck. This gives a clear black limit at the top and bottom of the back which makes it easy to get the computer to automatically crop to the part of the photo that is of interest (just the back) – saves lots of calculation time if you just analyse the part of interest.

Stickers are placed on the back - one at the vertebra prominens, two on the dimples of Venus (posterior superior iliac spines), some down the spinous processes. The number on the spinous processes should be enough to define the curve, maybe 5-9, more for a more curved spine. The computer counts the number of stickers automatically so it does not need to be a specific number.

Use the long axis of the sticker in a vertical orientation. Do not use too many stickers for very small patients. Make sure the stickers are not so close together that the sticker detection image processing joins them together.

If the patient bends his/her head hard forward, the skin will move over the VP. Try to have the patient looking directly forward for sticker placement. Bending the head forward may help in locating the VP but ask the patient to raise the head again before placing the sticker.

Make sure there is a gap between the top sticker and the black neck band and between the bottom PSIS stickers and the apron.

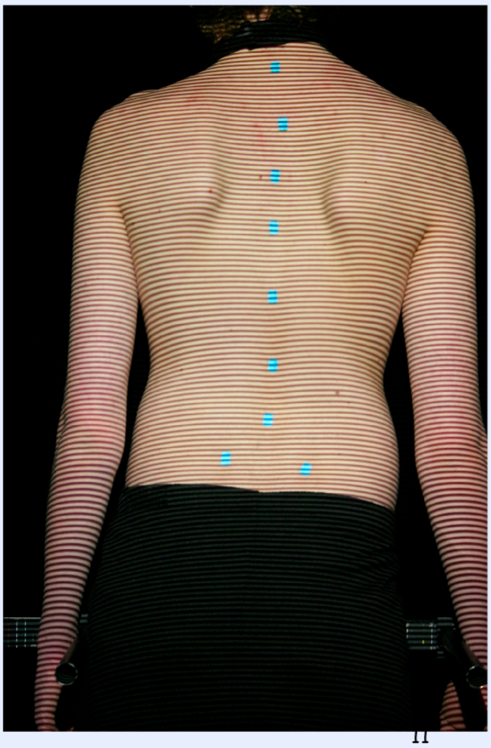
For patients who have had an operation it may be impossible to place many stickers down the spine as the spinous processes may have been removed in the operation. The ISIS2 lateral asymmetry angle (Cobb equivalent) will not be accurate after an op in any case.

Here you can see a photograph of a volunteer. The 'Analyse' button is enabled because both a reference plane and a back photograph have been taken. When you are happy with the quality of the back photograph, you click the 'Analyse' button and the computer starts its calculations to obtain the 3D data surface.

Camera too low

Abdominal bar too low

Armrests positioned too close



Before we go on to the processing just a few slides illustrating poor photographs.

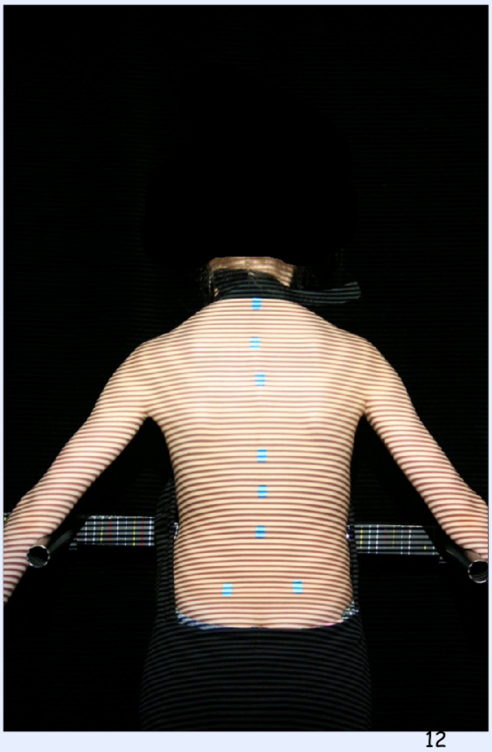
It is important that you get a good photograph. Patient should be roughly central both horizontally and vertically – move the camera/ projector using the telescopic actuator. You will probably get away with a picture like this but the lens is better in the centre so a centrally placed back will give more accurate results.

As far as the abdominal bar goes, slightly too low is better than slightly too high because it keeps it out of the part of the photograph that is analysed. However, if it ends up in the analysed part it is not a disaster – you will just see some extra surfaces sticking out to the side of the back but the main analysis down the central area of the back will still be correct.

Abdominal bar far too high

Arms too wide

Neckband too close to VP



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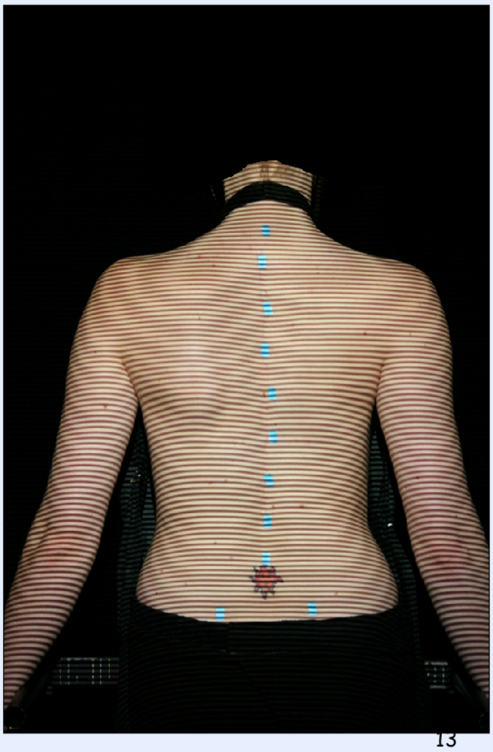
Black apron very close to PSIS stickers

(tattoo)



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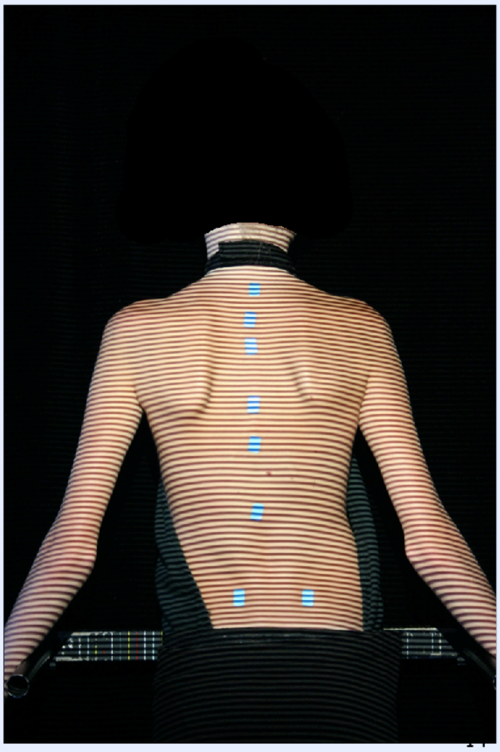
Tatoo can better be covered with micropore tape. Also larger moles need covering. Otherwise the computer thinks that dark parts of the tattoo or the mole are dark parts of the fringe and you can get odd results.

Here apron is very close to one of the dimple of Venus stcikers. It is better to have a gap between the stickers and the neck band or the apron so the mask does not cut out part of the back that really is of interest.

Halterneck gown wrapped round, covering part of back



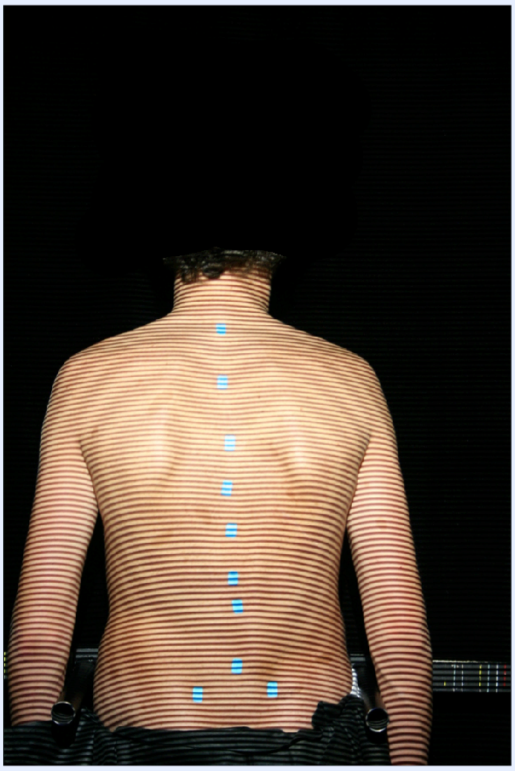
So you are losing part of the surface of the back because it is removed by the mask.

No neck band

Patient off-centre

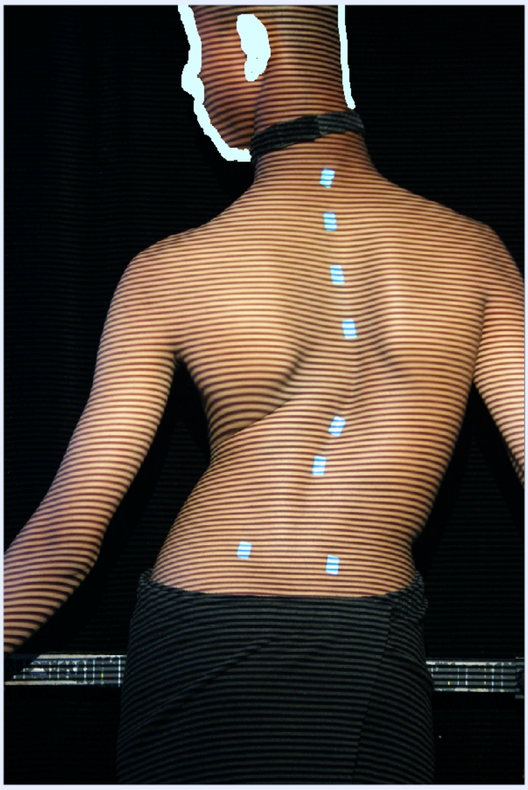
Abdominal bar too high

Armrests positioned too close

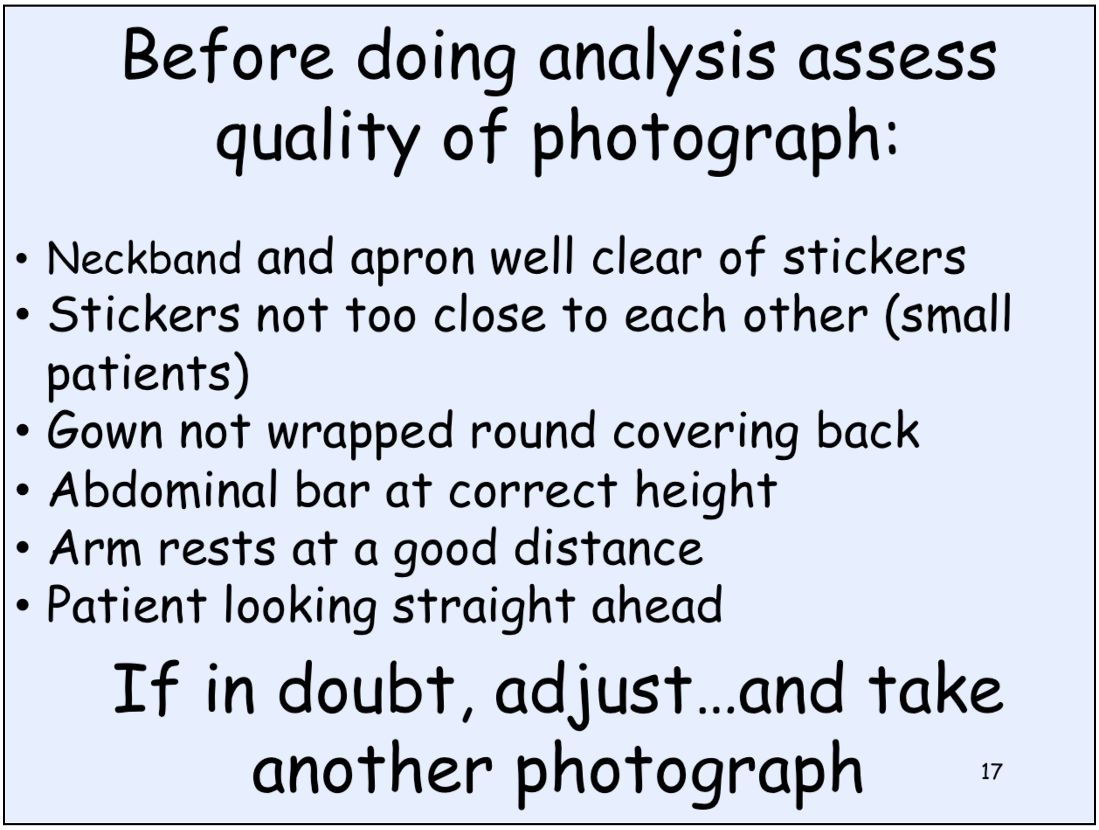


Here is one with no neck band. His hair is dark so it will act as the upper limit but better to use the neckband. If the patient had blond hair the picture would not be cropped correctly.

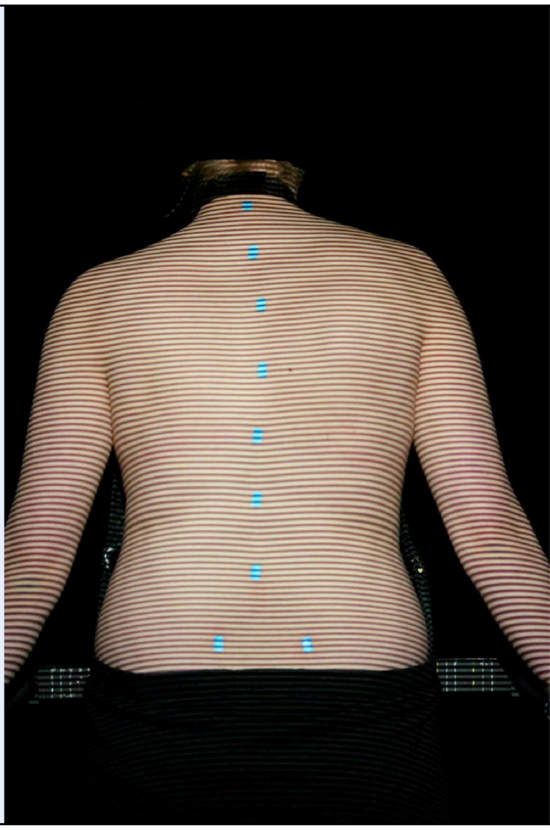
Patient looking left, back probably twisted



This photograph should have been discarded and a new one taken. Turning of the head as above is very likely to have involved some rotation in the shoulders. Arm rests are also too far from the body.



Check list for a ‘good’ photograph.



Good photo

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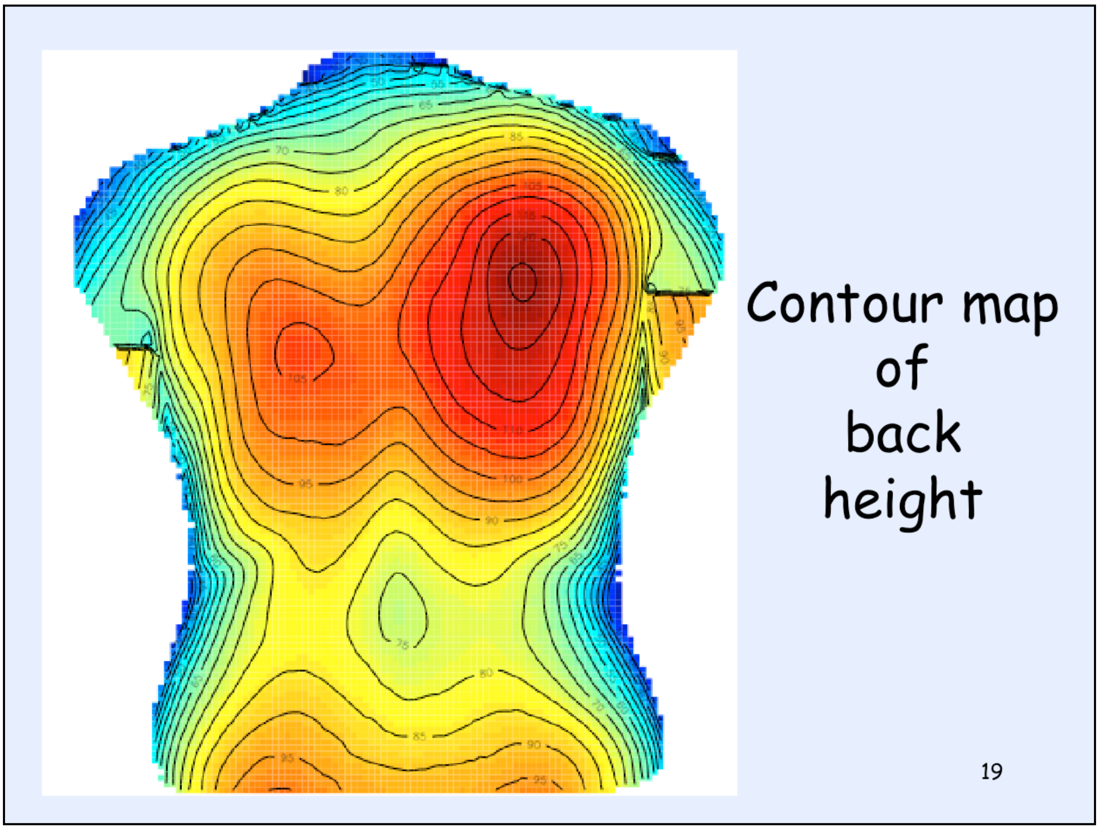
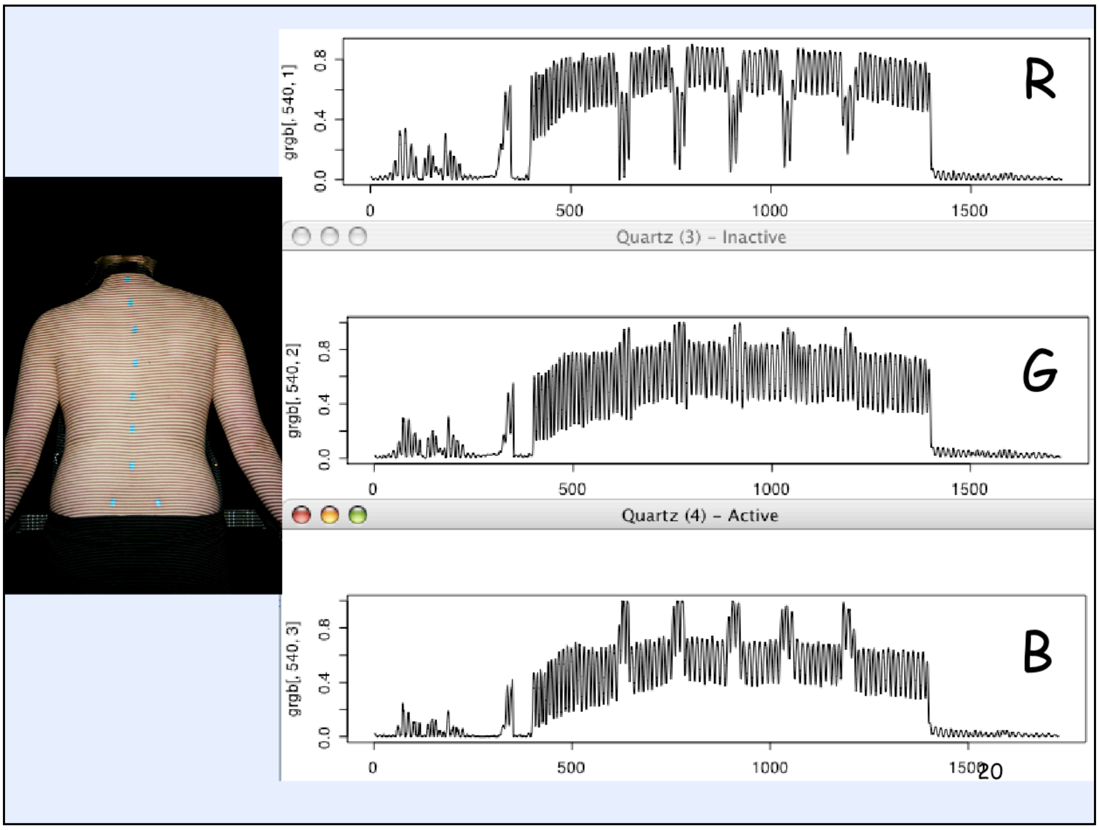
Here is a ‘good’ back photograph



Like a geographical contour map, this shows the height of the surface using colour and lines (contours).

The lines are all at the same height above the ref plane in mm – if you look closely you can see 125 mm is the max contour line on the right shoulder blade area and there is a line every 5 mm. Red shows the highest areas and blue the lowest.

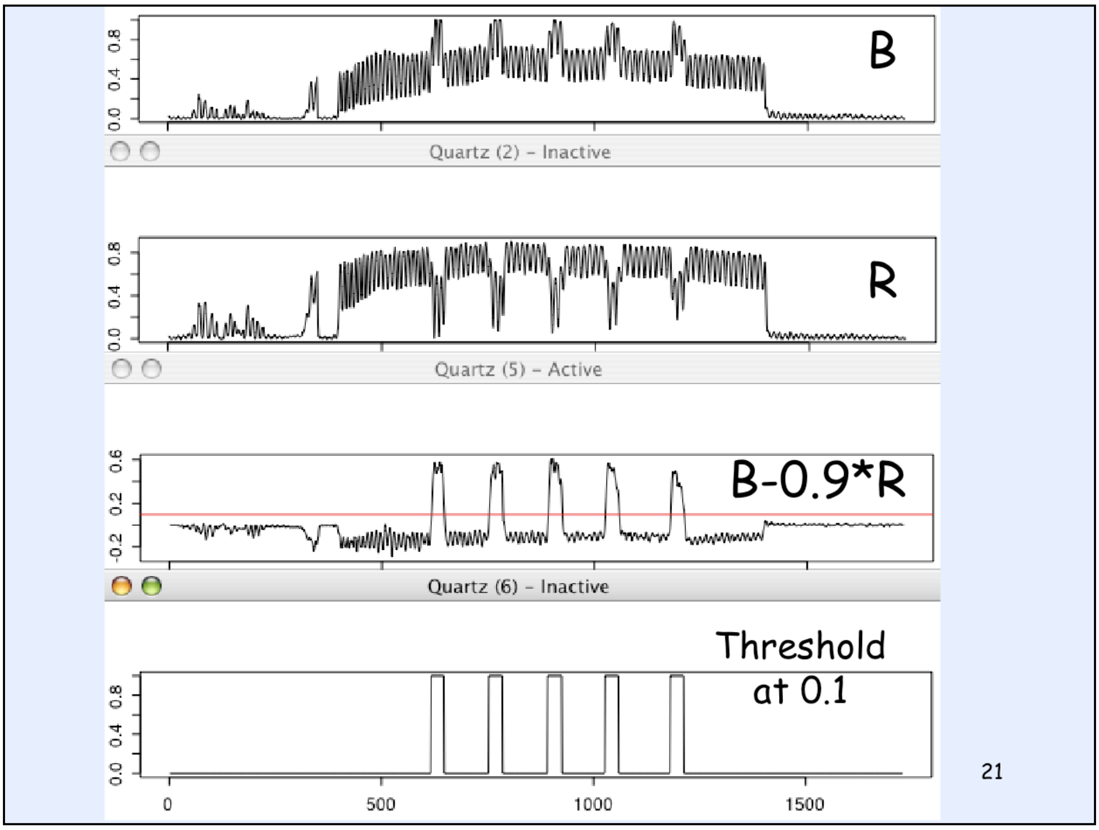
Now at this point the heights are all relative to the reference plane and do not take into account whether the patient is standing straight. So if someone was standing a bit squint it could look as if one shoulder blade was much more pronounced than the other simply because of the stance. The stickers are used to change to body axes. We use the top sticker on the vertebra prominens and the bottom two on the dimples of Venus for this. So now we have to detect the locations of the stickers.



Here we are showing you a bit about the processing of the stickers so you will understand better what is needed if the automatic sticker detection algorithm is not good enough.

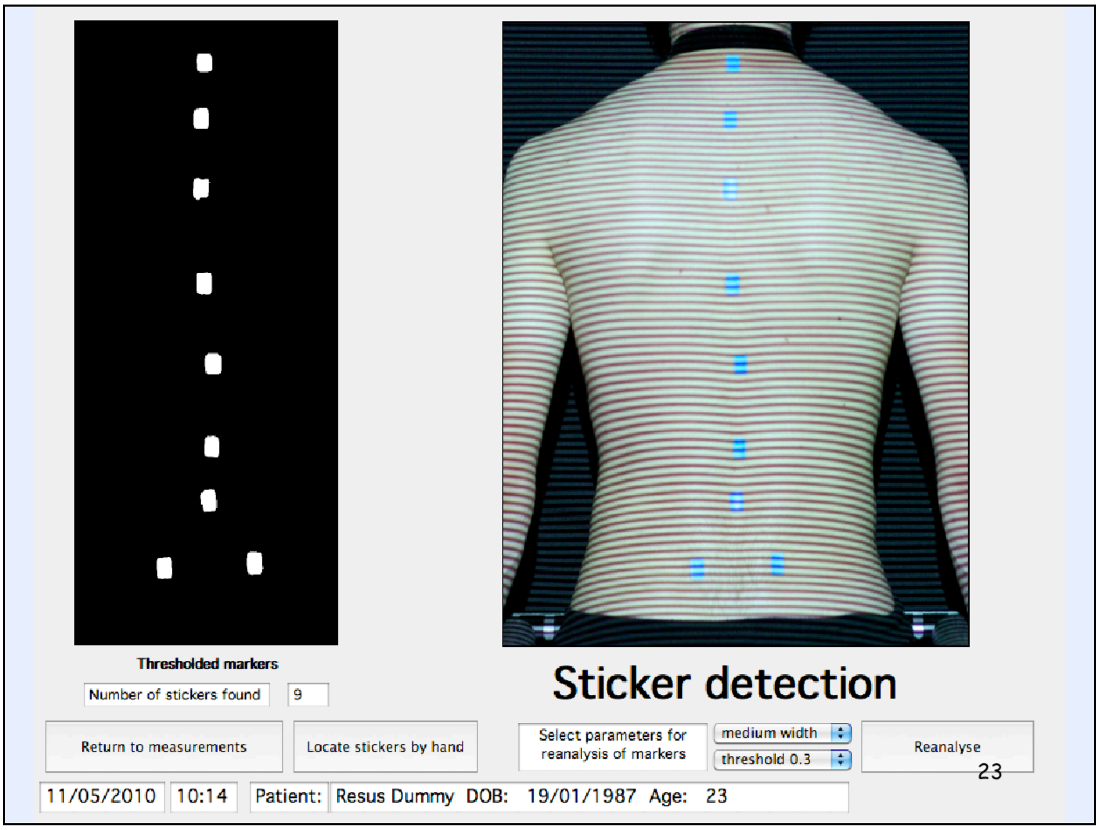
There are three channels of data in a colour photo, red, green and blue (RGB data). Each channel is analysed separately.

Above you can see the data from one column down the centre of the photograph which runs over the stickers for all three channels. They start off close to zero initially in the black background and the dark hair. Then shows higher values over the skin areas (up to a maximum of 1). The variation in the signal between roughly 400 and 1400 along the x-axis is because of the fringe pattern of light and dark stripes on the skin. The lower values are the dark part of the fringe and the higher values are the light part of the fringe. Finally the signal gets back to almost zero over the black apron at the bottom of the photograph. The turquoise stickers give high readings in the green and blue channels but low in the red channel.



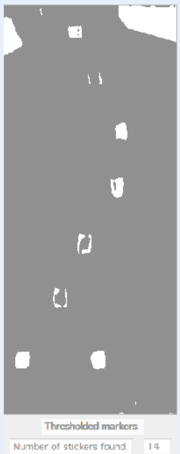
The fringes appear in all channels at much the same levels (white light being a combination of R, G and B) but the stickers do not. So by combining the channels, subtracting a portion of the red from the blue I can make the sticker pixels much more prominent. The parts that are just fringes almost cancel each other out but subtracting the R from the B emphasises the stickers. Then I set a threshold and all values above that are set to 1 while all values below are set to zero. The computer sets that threshold automatically but it does not always get it right. It depends on skin colour – very small pale patients and very dark patients are the ones that sometimes give incorrect results. However, the detected stickers are presented to the user so you can check this.

Here you should be checking that the number of stickers detected by the computer is equal to the number that are actually present. However, you should also be making sure that each sticker is well represented. Here we have the correct number of stickers but several are really incomplete. So you would answer 'No' to the pop-up question about whether you were happy with the detection or not.



If you say No then extra controls pop up on the screen so you can adjust the threshold level or the width or choose to locate the stickers by hand.

Adjusting the threshold



Stickers split up
or eaten away:
DECREASE THRESHOLD

Areas away from stickers
also detected:
LOCATE BY HAND

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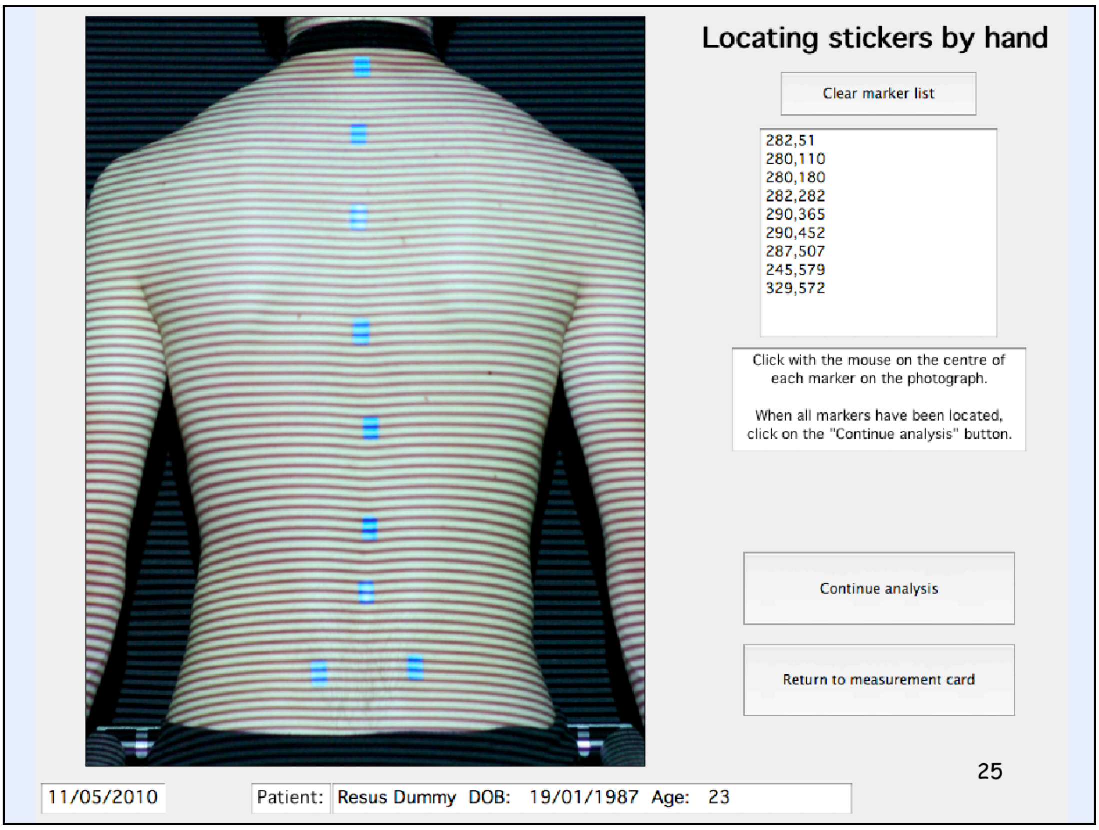
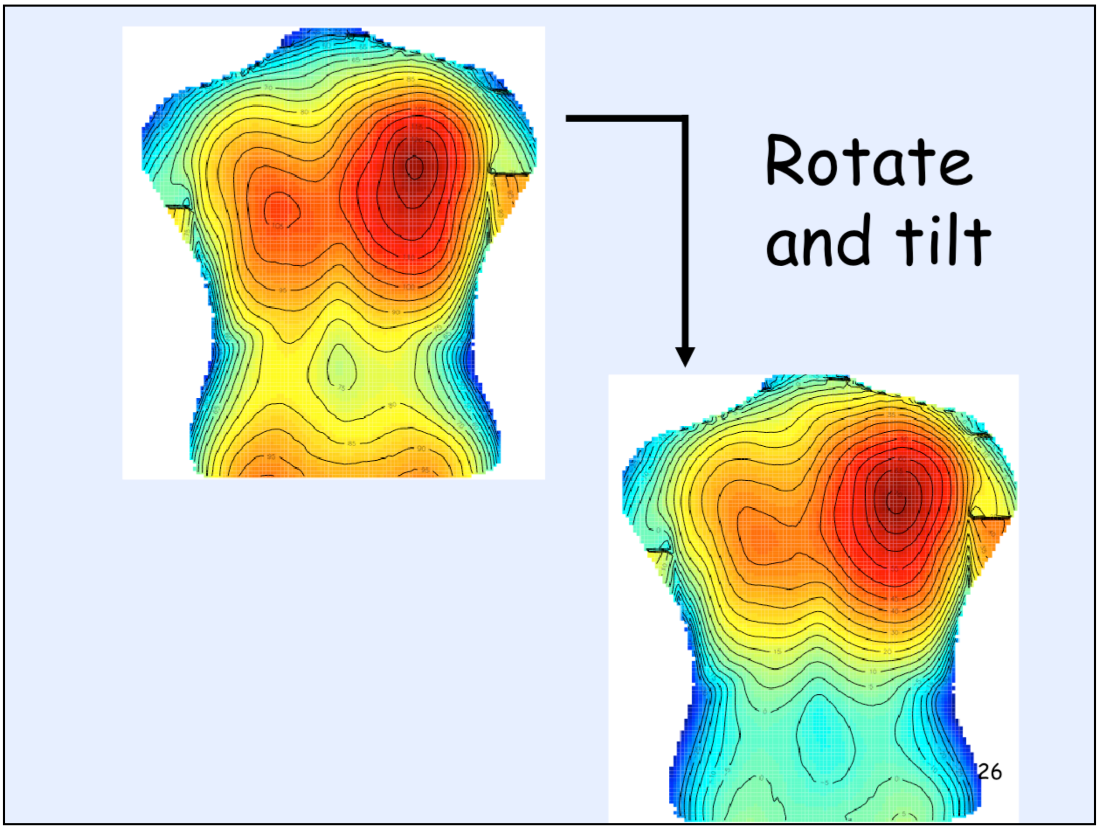
The left one was the original result. The stcikers are incomplete so the threshold needs to be reduced. But when the threshold is reduced in this case the result was the right one where areas off the back at the top on either side of the neck are now being detected as well. So in this case you need to locate the stickers by hand (click with the mouse on each sticker, see next slide).



You click with the mouse on the centre of each sticker and its pixel location is added to the marker list box at top right. It is best to click in a logical way, perhaps starting at the top and moving down or else at the bottom and moving up the stickers. If you make a mistake, click on the clear marker list and start again with clicking on the stickers.

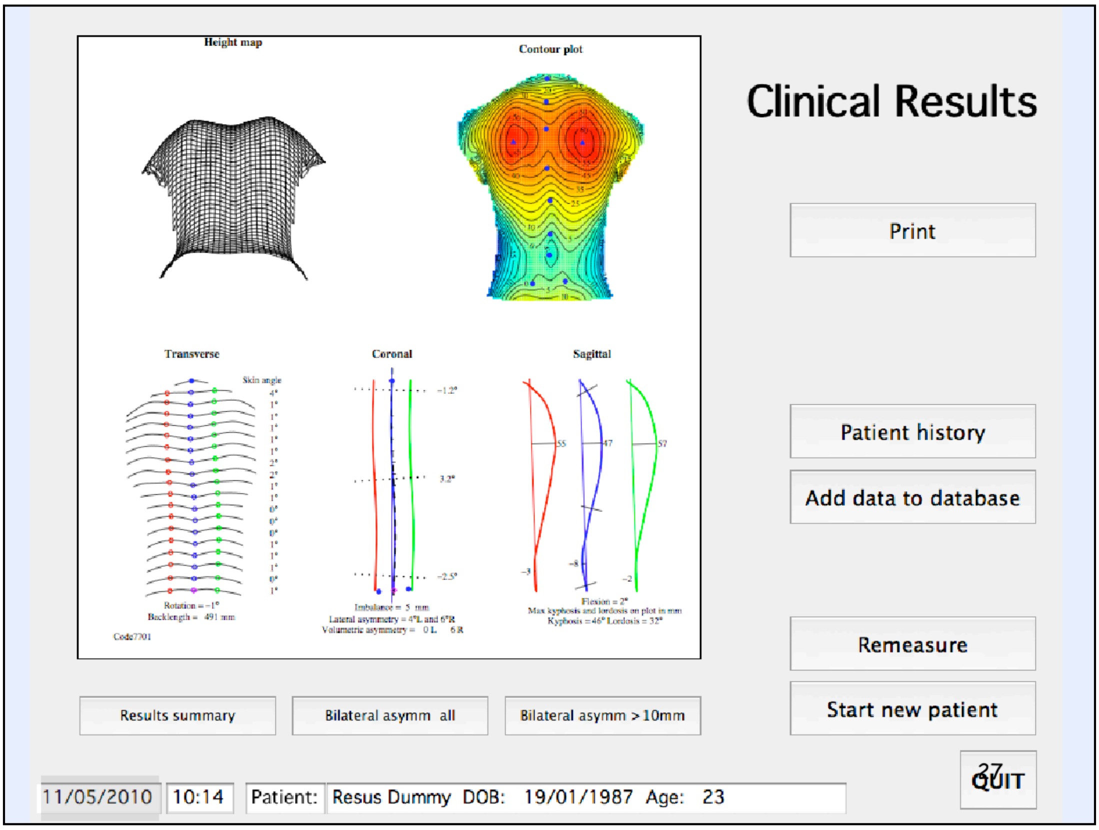
Finally, you end up with good sticker data and then the computer tilts and rotates the surface so it is height measured relative to body axes.



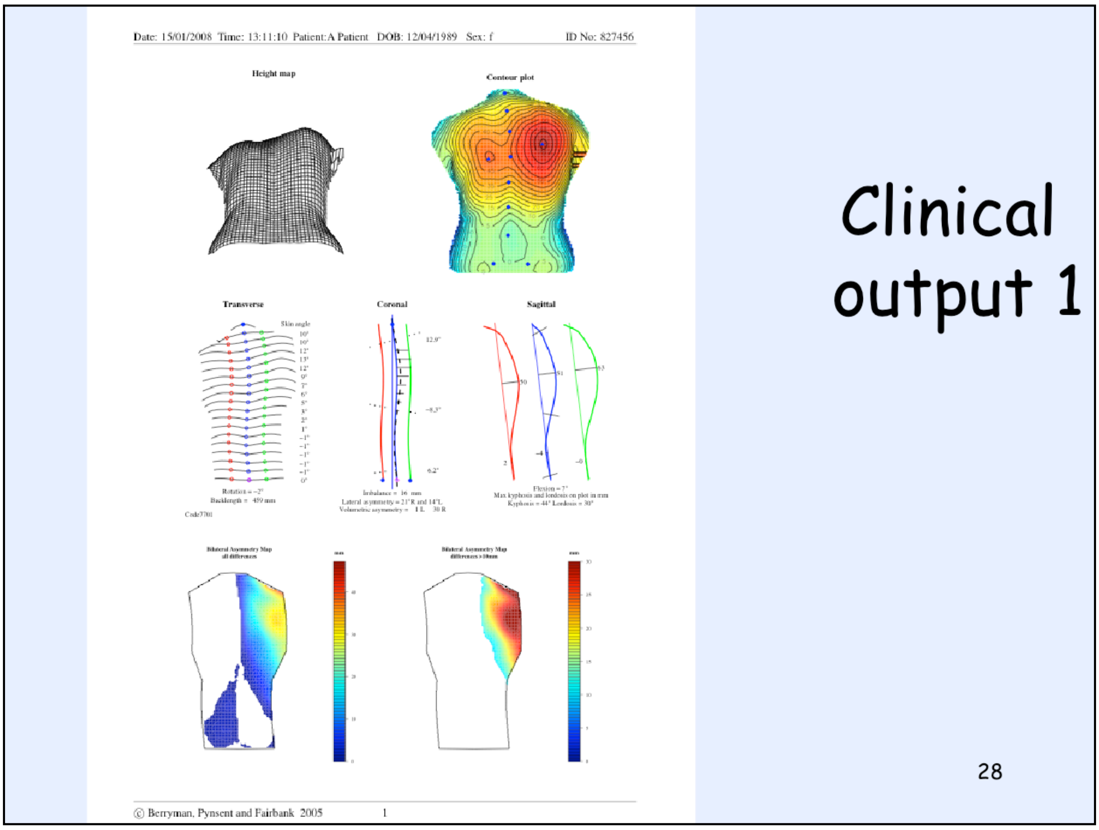
Then we tilt and rotate the surface so it becomes relative to body planes. First we rotate the surface so the two dimples of Venus markers are equidistant from the ref plane (pelvic rotation). Then we tilt the surface so the vertebra prominens is directly over a line through the sacrum parallel to the line through the two dimples of Venus markers. The result is a surface related to the body axes of the patient.

Look at the lumbar region in the contour maps of this slide. Before the rotate and tilt the left hip area is higher than the right. After rotate and tilt they are much more even.

The body axes are as follows: the x-axis is horizontal, goes through the sacrum and lies parallel to the line between the dimples of Venus, positive to the right. The y-axis runs vertically in the coronal plane, positive upwards. In the sagittal plane the y-axis may be at a slight angle to the vertical if flexion or extension is present. The z-axis is normal to the x-y plane, positive outwards (towards the camera). The z = 0 plane includes both the vertebra prominens and the sacrum.



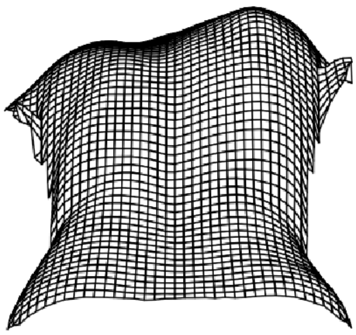
When the calculations are complete the results are presented on screen. Clicking the Print button gives a paper output of these results plus the photograph of the patient.



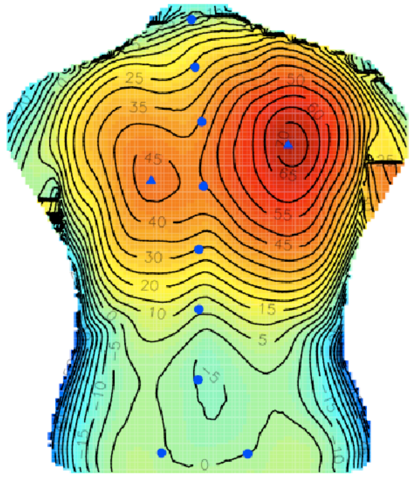
We then calculate various parameters from the surface. This is a results printout, also stored as a pdf file by the database.

Clinical results upper

Height map



Contour plot



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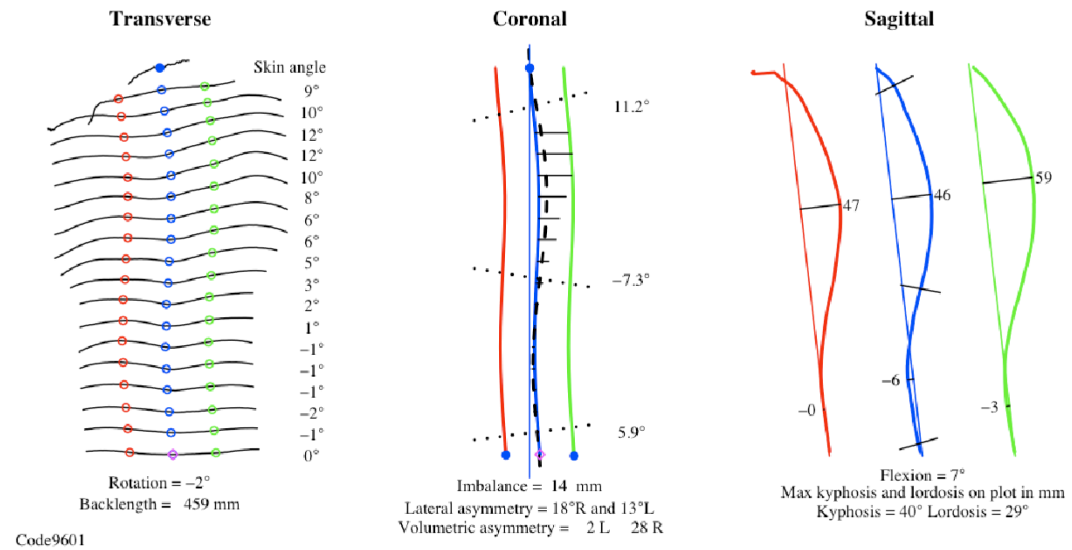
These are new plots compared to old ISIS. The left hand one is a wireframe plot that is a 3D surface viewed up the back from about hip level. It is meant to give a subjective impression of the back similar to a forward bend test. The right hand one is a contour plot - similar to a geographic map with colour indicating height, blue is lowest, red highest. The contour lines link points of equal height and the height is given in mm on every contour (at 5 mm intervals). The blue circles are the positions of the markers and the blue diamonds indicate the highest points on each side of the back. The colours on this plot always indicate the same height, so the more red is seen the bigger the hump on the back. The fact that the colours mean the same in each plot means that it is possible to compare plots from one visit with the next.

Clinical results middle



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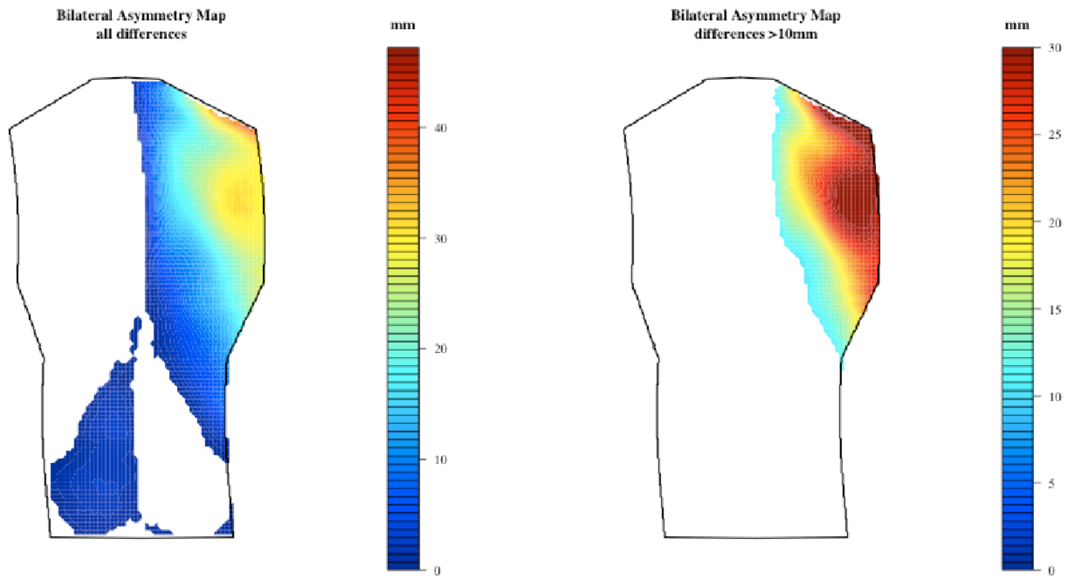
These plots are very similar to the old ISIS plots, just giving a bit more detail.

The transverse plot shows transverse sections at 19 levels between VP and sacrum. Old ISIS did calculate 19 levels but only plotted 10. The blue circles show the position of the estimated line through the spinous processes at each level. The red and green circles indicate the paramedian lines at 10% of the back length on either side of the spine line. The angle of pelvic rotation that was needed to align the two iliac dimples is given below the plot and the back length also in mm.

The coronal plot is in the centre. The blue line is a curve fitted through the markers on the spinous processes. An estimate of the centre of the vertebrae at each level is made by combining the position of the spine line with the skin angle at each level. It is shown by the dashed black line. The points of inflection on that line are then located and the Cobb angle equivalent, lateral asymmetry, is measured. Sometimes it gives a two angles, sometimes one and even occasionally none in a very straight spine. The angles (lateral asymmetry) are shown below the plot, as is imbalance the distance in mm between a gravity line dropped from the VP and the sacrum (which is assumed to be midway between the iliac dimples). The last numerical parameters reported on this plot are Volumetric asymmetry - giving a measure of the difference in volume between the sides of the back to try to give a measure of volumetric deformity. The difference in area between the sides of the back at each level are calculated and normalised and these are plotted as horizontal lines at each level. If these horizontal lines reach the paramedian lines then the volumetric deformity is fairly significant. The horizontal lines show the volumetric differences at each level and these are summed to get overall volumetric asymmetry parameters for the left and right sides and these are printed below the plot.

Clinical results lower



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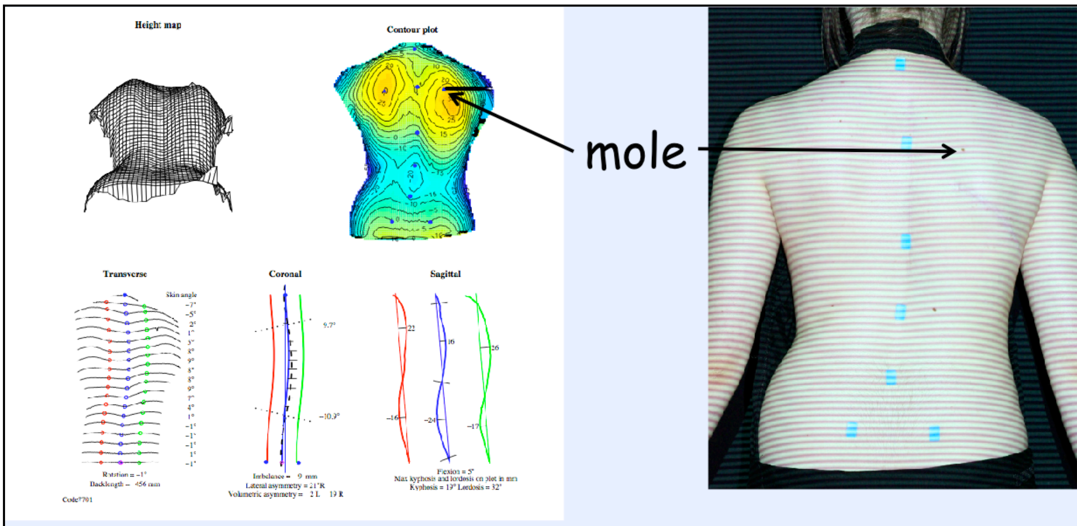
The plots at the bottom are new compared to old ISIS. We have not used these much yet, just getting a feel for what they mean. Whereas the horizontal lines of the coronal plot indicate the differences at each level (for about 12 levels), we can actually calculate the difference between each pair of pixels distributed symmetrically (horizontally) about the symmetry line (the curve through the markers). We don't cover the whole back because the differences at the edges can get extreme and do not really signify anything. We stick to the central portion. The left hand plot shows all differences between the two sides. The plot is white on one side where it is the lower side and coloured on the opposite side where it is higher. The colour indicates the difference, blue being lower difference ranging through green, yellow, orange to red at the highest differences. The maximum scale will vary from plot to plot and patient to patient but there is a colourbar and scale on the right so you can read off the maximum value. Here it is around 40 mm. The figure on the right shows only the differences greater than 10 mm. The colours here are fixed to set heights and so mean the same from plot to plot and patient to patient. If heights greater than the maximum 30 mm occur they are coloured the same as 30 mm - so strictly the darkest red indicates heights of 30 mm and greater. You can see from the LH plot if the max difference is greater than 30 mm (here there is an area on the shoulder where that is the case. Generally the more red in this right hand plot, the more volumetric asymmetry there is between the two sides of the back. The choice of 30 mm for then fullscale is a bit arbitrary at the moment and could be reviewed if you think you want to be able to distinguish between 30 mm and 40 mm differences say. Even a good straight back will have small differences between one side of the back and the other so some colour should show on the LH plot. But where all differences are less than 10 mm, there will be no colour on the RH plot. For someone with kyphosis, there may also be little colour on the right hand plot. These plots are principally to visualise transverse volumetric asymmetry for scoliosis patients. This patient, for example, has quite a substantial hump on the right side even though she only has a 20 degree curve in the spine.



Mole causes discontinuity in back surface; clinical results probably not affected but better to cover mole with micropore tape

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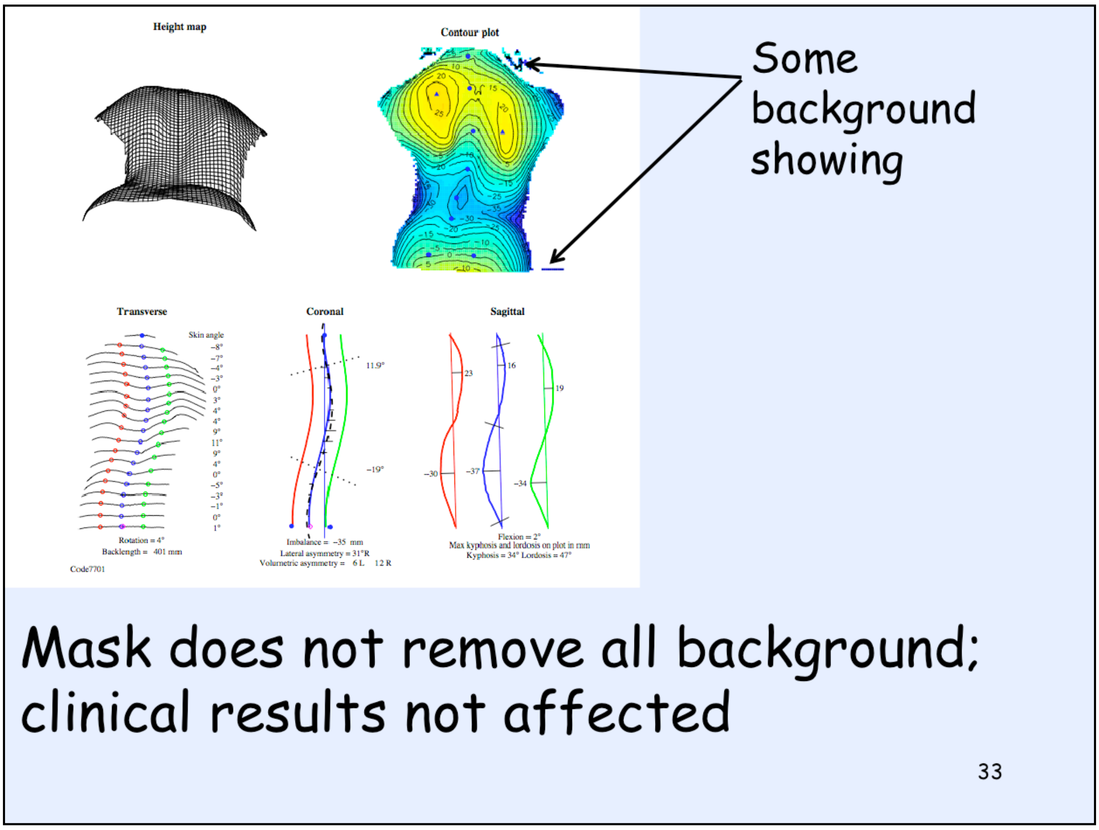
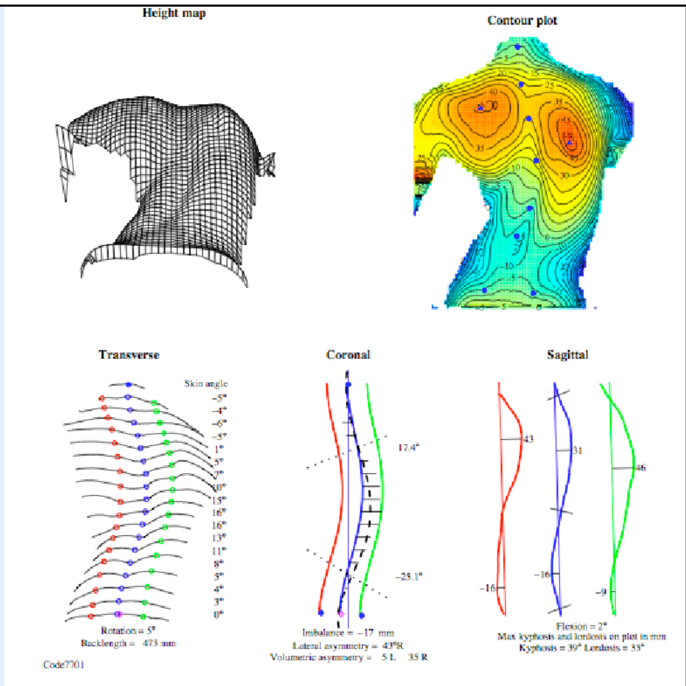
Mole on shoulder has caused the phase unwrapping to break down and we get discontinuities on back (heavy black lines over right scapular area). Mole should be covered with micropore tape and photograph repeated. However, so long as the discontinuities occur away from the central section of the back, the clinical parameters will mainly be correct.Volumetric asymmetry is the parameter that is likely to be wrong. The volumetric asymmetry parameter might be wrong if the discontinuity comes far enough onto the back. The contour map does not look nice but the data stored is fine.



The mask that removes the background (parts of photograph not on the back) has not removed all the background. This may not look as good as when the background is fully removed but it does not affect the clinical parameters. So nothing needs to be done. The extra surface at the shoulders is most likely to occur with a very dark coloured back. A horizontal bar at the bottom can occur if the abdominal bar was higher than the hips and therefore in the part of the photograph that was analysed. Neither causes any problems with the clinical parameters.



Arm not fully removed;
clinical results not affected

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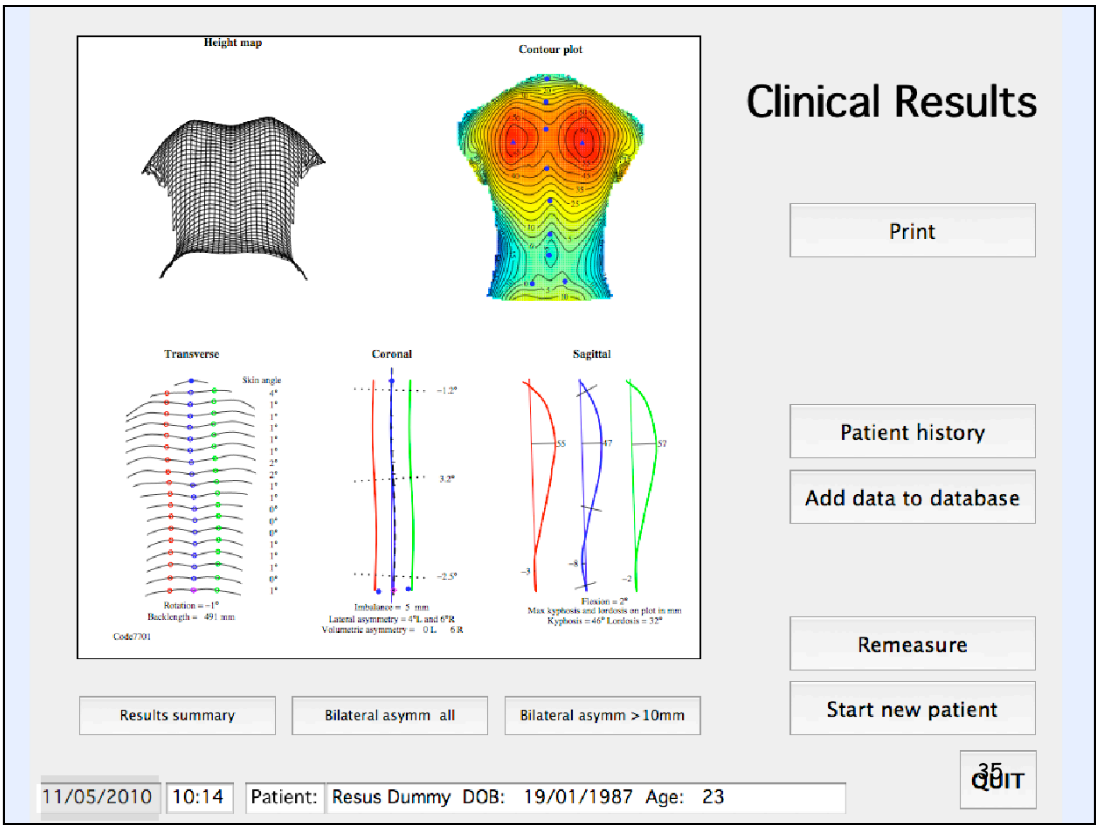
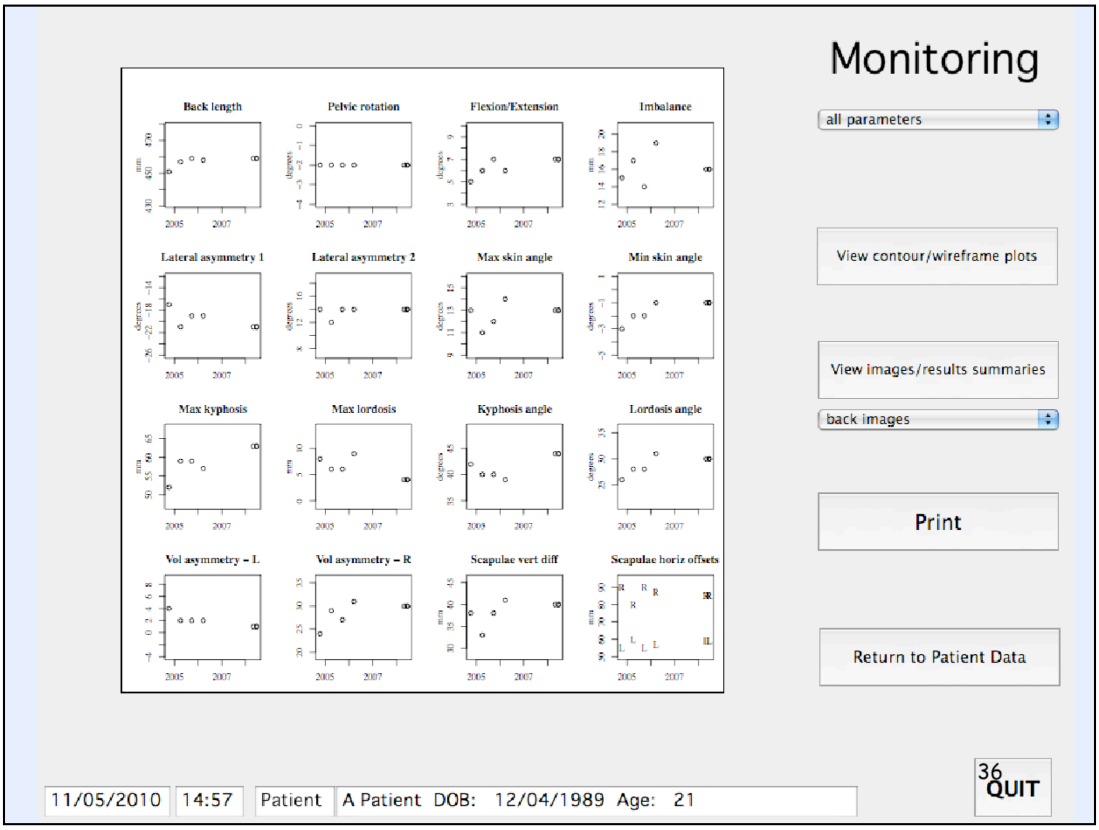
This occurs when the armpit has not been correctly detected. This is most likely to occur when the patient has a very dark skin colour or when the arm is too close to the body. It does not affect the clinical results and so nothing needs to be done.

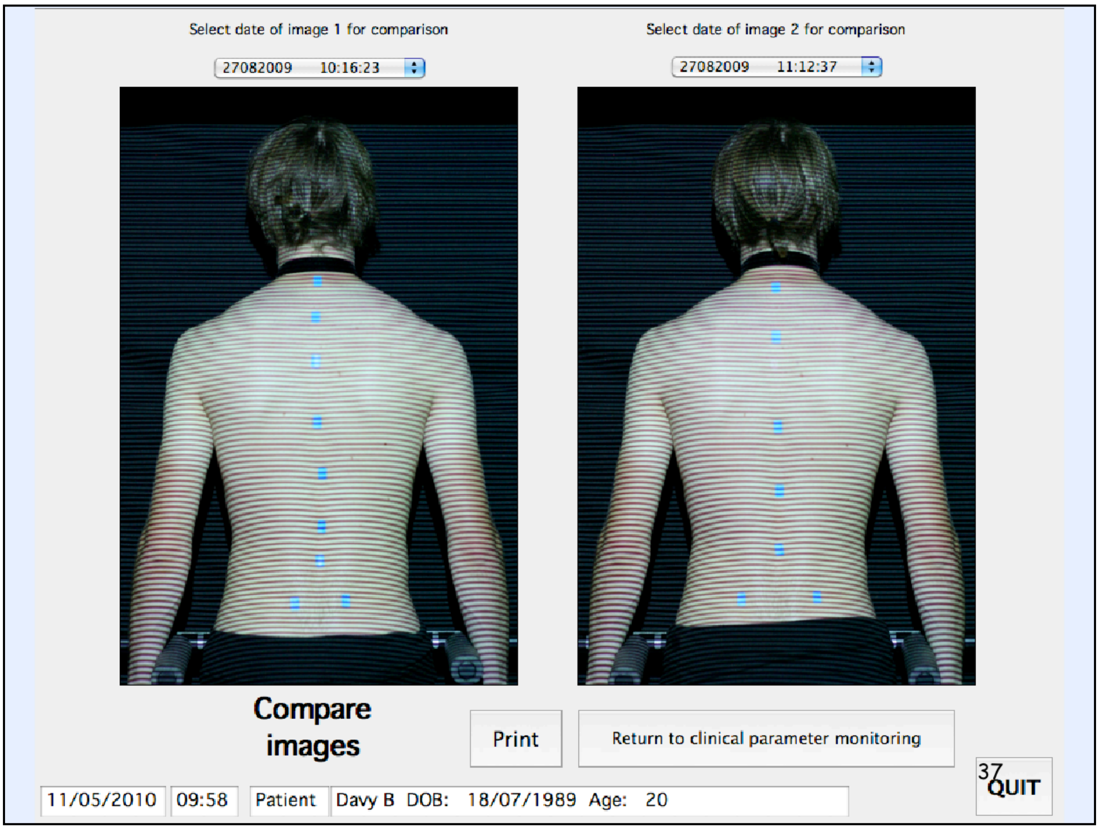


When the calculations are complete the results are presented on screen and you can check to make sure the results look fine. If all is well, then clicking the Print button gives a paper output of these results plus the photograph of the patient. Clicking on the 'Add data to database' button will store all the data for this measurement. You cannot leave this card without storing the data or at least being prompted to store it (you may then choose not to store if something was wrong).

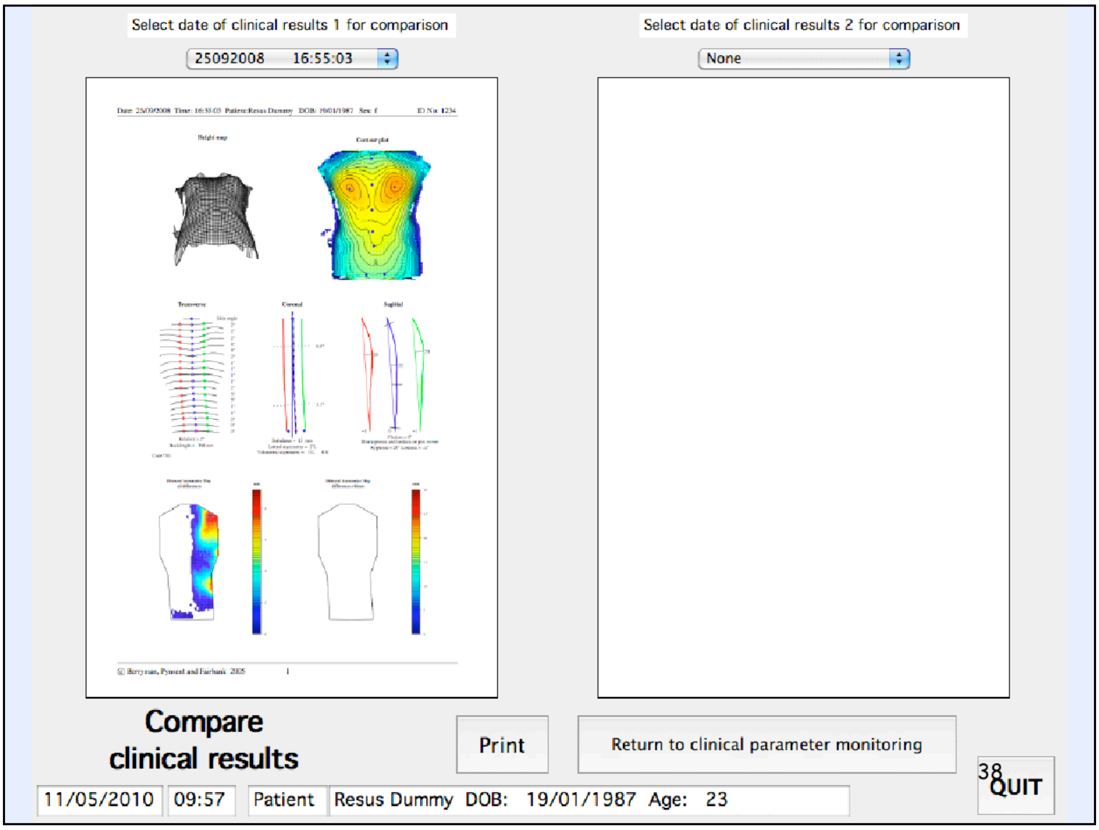


Can reach this card either from the results card when a patient has just been measured or from the opening Patient data card if you are wanting to look at old results for a patient who is not going to be measured.

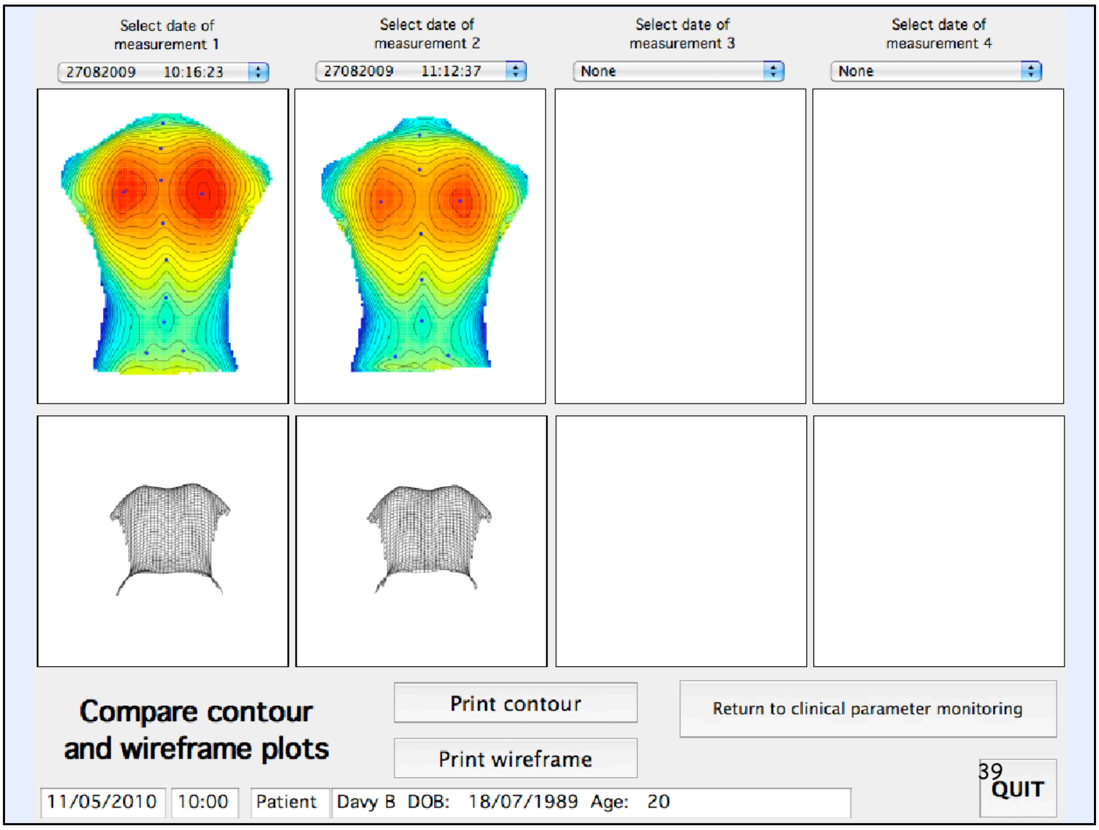
Monitoring - when a patient has been measured at several visits. This type of plot shows the variation in the different numerical parameters with time. I have established the variability in each of these parameters by repeat photographs and carried out Bland Altman analysis on them and I intend to add the 95% confidence limits to each point on the plots. I think we may need to improve the scaling too. At the moment it is autoscaled but then very small differences can sometimes look large if the scale only covers a very small range. For lateral asymmetry (Cobb angle equivalent), it might be better to scale from 0 up to 40 say always unless LA was greater than 40 in which case it would automatically increase to cover the measurements. I need to build in a lot more intelligence to the scaling here but so far have not had the time for this.



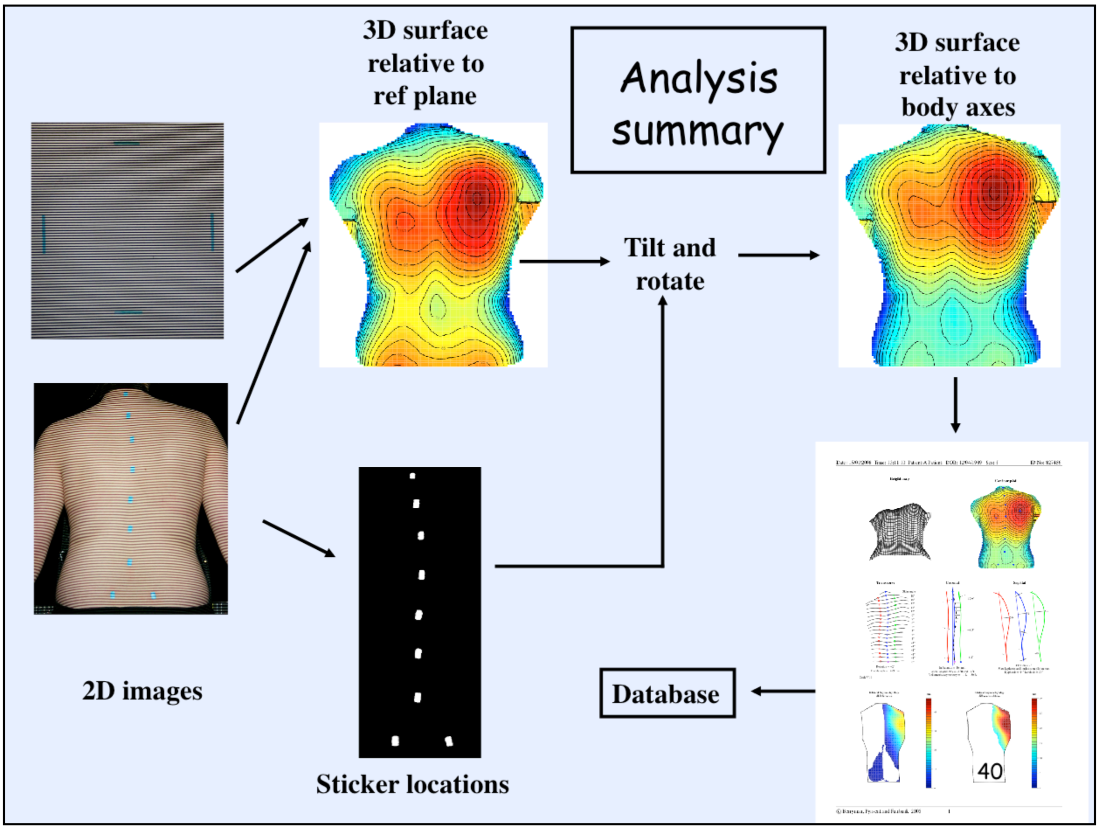
Here you have selected 'back images' from under the 'View images/ results summaries' button. At top of each column there is a pulldown menu that gives a list of all the dates and times when this patient has been measured. You select the one you want. You can thus look at the photo from all the measurements that have already been stored for this patient and print the photos if required.



Here you have selected 'clinical results summaries' from under the 'View images/ results summaries' button. At top of each column there is a pulldown menu that gives a list of all the dates and times when this patient has been measured. You select the one you want. This gives an easy way to get printouts of patient data after the measurement date. The database is interrrogated to get the list of dates and times and then you select what you want.



Here you have chosen to 'View contour/wireframe plots'. This is new since April 2010. As well as plotting the clinical parameters longitudinally you can also look at up to 4 contour plots and wireframe plots but only for patients measured from April 2010 onwards. Might be useful for comparing before and after operations or looking to see how the shape has changed rather than just the numerical parameters.



So summing up what the system does, one ref plane for a whole session, one back photograph for each patient. First calculates surface relative to ref plane and camera axes. Then detects stickers. Then rotates and tilts surface so it is measured relative to body axes. Only then does the system calculate clinical parameters. These are presented on screen and on paper and all are stored in the database/data directory. The database can then be interrogated at a later measurement so the new results can be compared with the old.