An Innovative Roadmap of Establishing Mechanical Definition of Scars from an Engineering Perspective: Impact upon Dermatology, Plastic Surgery, and Forensic Medicine

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Abstract: ***Scars may face many clinicians in different medical specialties. Their managementhad evolved based upon our knowledge. Currently there's no well established definition of the scar and many of the definitions are based upon highly subjective criteria. We are here introducing an introductory model of obtaining objective assessments of scar based upon mechanical assessment. Assessment is important in management in the case of dermatology and plastic surgery as well as for decision machining in forensic medicine.***

Keywords: scar, displacement, stain, skin, animal experiment

1. Introduction

Scar could be defined as abnormal continuity of the tissues preceded by tissue injury or any process that results in similar presentation. Scar had different presentations which could be found in any textbook of plastic surgery or dermatology.

It is caused by disruption of tissues layers arrangements resulting in an abnormality least in one of the features of tissues (shade, volume, and the mechanical properties). We have suggested these three criteria that define scars.

1) Shade of the scar. Skin or any other tissues had a complex tone or color that could be represented in many ways. (1)

There are many color matching tools and systems schemes. Color could be defined in multiple ways.

Figure 1on left Pantone color guide, one of the most famous tools in color matching, on the right digital device for color identification

Many devices have been introduced that are specialized in acquisition of skin color. One of the best dealers with skin tone are maxillofacial prosthodontists. Light reflection from skin will be at different levels, not just from the top layer of surface. Many skin components give an alloying effect. Scars will result in the presence of different components in skin. Even with the coverage of scar tissues with normal layer epithelium and the scar having the same level with surrounding skin, it will remain different from its surroundings due to the partial translucency of the epithelium. The subepithelial tissues, where the scar tissue is present, are different from the surrounding environment, giving an abrupt transition of shade.

The color of the scar is also reflecting the tissue forming it. The effect of the injury is not limited to the site of scar only, but it will extend into the surrounding tissue and until it fades away at a certain distance.

The color of a scar is determined by the chronological stage of the scar. Brisk color has more predominance at the early inflammatory phase. With aging, more dull color will predominate. Imaging scars with advanced technologies, which capture light other than visible light, had a great impact on clinical management, especially in the case of forensic medicine.

1) Volume
Most scars are raised from their surrounding skin level due to their content. (2) Scar content formation has many factors that control it. Both shade and content of scar is beyond the scope of this paper. These 2 criteria are used to judge the scar in its static condition. We have no increase in the volume always as another representation of the scar is by reduction of the volume of the tissues.

2) Mechanical properties
Extension of the scar within its bed. Scars involve disruption of highly organized intricate layered tissue with very complex inter layer movements. Many areas of the body had thin skin with highly mobility. Any tethering of the skin to their deeper tissue or loss of the organization will lead to an abnormal response of scar to movements. Scar in the lip could be extended from outer skin, down or deeply to mucosa representing a highly unsightly appearance. (3)

Our clinical dealing with scar is based upon the fact that we can describe an established situation or wait it until it is established, rather than anticipate the results of a condition from the beginning and know how it will develop or evolve (4). We have no tool to achieve such capability. Our current work is to develop a tool for

- Anticipation of the biological behavior
- Ability to follow up and compare different stages of development.
- Comparison of effect of different treatments modalities
- Getting better Classification of the scars

2. Methods

Human eyes are very clever, and capable of recognizing tiny defects, but they have a deficient ability to quantify and describe many details. Their capability is limited to instant moments and viewing successive closely related samples will fatigue them and dull their sensitivity. There are many advantages of depending upon recording video and analyzing it, because some events could happen once, and careful repetition of the video footage enables us to review it at different speeds and for unlimited times. The viewing of the captured data could make us notice some change by naked eyes, but these changes need engineering analysis to reveal, qualify and quantify them. These analyses exceed the capability of the naked human eye.

We had to depend upon analyzing the videos recorded during performing this experiment by a home written code that gives engineering analysis data that could be processed in MATLAB to yield graphs and charts. The graphs provided here represent a snapshot of each analysis at a certain time. Nevertheless, complete analysis observation in all traction is highly advisable and required to understand the dynamics of skin more thoroughly.

Two mechanical elements we are suggesting have the most visual perceptual judgment by the eyes. They are the elements in Rieth's concept.

- Displacement
- Strain.

Even when naked eyes can see something odd, eventually we can't characterize these changes. In contrast to that, displacement is easily demonstrated and the region which had been expanded to make this displacement.

We had many sets of results.

1) Results derived from the whole sample.
   a) Result at the maximum allowed retraction of each sample
   b) Result up to the maximum displacement of the pre thermal trauma.
2) Results obtained from following the points previously defined.

Additional graphs that are peculiar to the 20-millimeter displacement to show the effect of analysis beside the maximum responses needed due to the original maximum displacement of about 20 mm in the pre-thermal injury.

In order to demonstrate the effect of these elements on recognition of the scar, we had suggested a real model of scar simulation. We had prepared an animal model for the experiment. Our scar model is represented on a wide area of skin then do an exposure for part of it to a trauma that leads to damage and leads to necrosis. Repair will lead to fibrosis which affects the mechanical properties of the skin.

The chosen skin area of the rabbit is the back skin. Skin of the rabbits had an excellent pliability and ability to slide over the deeper tissue for long distances in comparison to limited sliding in humans relatively. A solid metallic rod had been heated on a flame then placed on an area of skin to the back of the animal after anesthetizing it. Pre-injury antibiotics had been administered via IM route. We followed the animal by doing the engineering analysis until complete healing of the scar had been attained. During the healing process, a total loss of the injured skin had been resulted and a window-like defect had been formed. The traction of skin causes this defect to slide over their back muscles. The muscles could be seen through it.

13 successive analyses have been done.

- First analysis prior to the application of the injury
- 2nd immediately after injury
- Third after 10 hours in the first day
- Others had been distributed through the following up period until complete healing had been in the results. The total period of the experiment was 23 days. Rabbits had higher metabolic rate than the humans and it is agreed that rabbit model short term experiments are equivocal to longer one in humans in longer time.

Analysis of all results was done separately and represented in graphs with traction up to when maximum displacement reached 20 millimeters. Although in some models we had gotten higher figures than this.

We had not chosen a wide area on the lateral side (The scar was about in the midline) of the skin to be analyzed because our work is to capture the change in the skin in front of the scar and behind it. We had chosen the lateral side in the experiment of the postmortem analysis. This will also spare the computational resources at the same time.

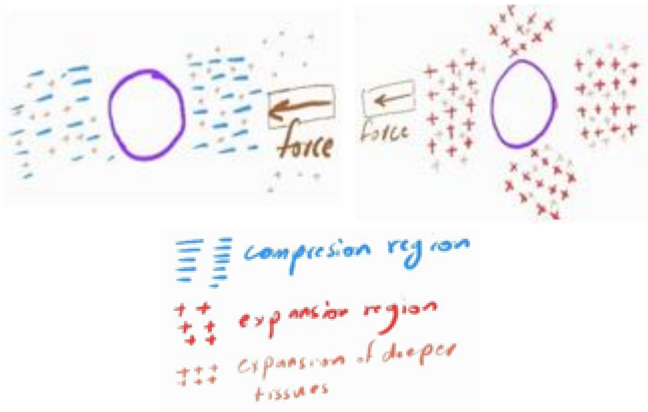
3. Why had we used traction to demonstrate changes instead of pushing or routing?

Pushing a scar will make this car resist displacement due to its highly organized infiltration to its bed and it will cause the skin to crumble between the scar and the pushing site. This infiltration is highly variable due to multiple causes across

- different areas of scar and
- different sites of the body
- chronological stage of the scar

How is the scar affecting its surroundings? Before answering this question, we should know that it is a dynamic status that is best demonstrated by traction. We are applying force to the surface layers, but deeper tissues will behave differently. We think that deeper tissues will assume expansion in all situations, whether we push or pull the external surface, while more superficial tissue will have different responses according to the relation of the force application site. In case of traction all regions of the skin will behave in a similar fashion rendering the final results easier to be interpreted and analyzed.

In our model of skin, either previously discussed postmortem analysis or in the current work about the scar, we have many outputs that could be seen in addition to very little knowledge about the inputs. These are overlapping, making conclusions a process that needs something like Fourier transform. Let's suggest a graph that will demonstrate this area.



Application of rotation instead of traction or compression will produce asymmetrical deformation resulting from combination of different patterns at the same time. This work was the same procedure as our work about post-mortem skin changes. Experimental environment and procedural steps were the same as the previous experiment in the post-mortem skin analysis.

We had chosen the maximum strain of 30% as a cut level to the changes and when we assign different values, we denote it. The range of tested strain ranged from 0 to 30%. The traction was done using a flexible scale used. It was fixed to the rabbit skin using a medical grade adhesive.

4. Results and Discussions

The conditions of skin will be affected by the general health status of the living individual and all analysis should be reviewed in the context of these global events. During the healing processes, the inflammatory markers and mediators will be much higher in circulation resulting in affecting the skin and more elastic changes. This is well known in systemic sclerosis in its early inflammatory stage.

Our analysis clearly showed the development of skin response to mechanical demand. Our developed ulcer is an unpreceded model because it is an in vivo model. It had been done on living skin with respect to the scar's tissues' environment. The harvesting of the living tissues and testing them in vitro will.

- Affect the same amoles due to processing and preservation processes.
- Depriving the sample from its environment where major mechanical properties of determinants are derived from this environment.

We had done another set of graphics up to half of the maximum displacement we reached in the previous analysis. Our models show significant changes on the same sample.

Post-mortem analysis should be correlated with the current analysis. All our current analysis showed clearly changes that could be characterized in both patterns and numbers based on mechanical descriptions.

Speed is one of the greatest analysis criteria that we had not checked due to the manual traction, sadly have been done also in the postmortem analysis. The automated linear stage was not implemented in the analysis of the postmortem linear stage. Speed as well as acceleration analysis is an advanced step that needs better setting and sounder basis, we build the more advanced conclusion upon.

Nevertheless, we had done analysis of the speed and acceleration up to the displacement of 8 millimeters. We could retrieve speed graphs where the budding of the scar is evident. Due to the non-consistent traction speed the results could not be analyzed. These analyses (about speed and acceleration) had not been included in this paper and we will include them in the next research.

The speed field in the x direction clearly shows the budding of the scar's region due to the presence of this highly stiff knot. Comparison of cases where skin had been lost and final stage revealed that distribution of the strain. Area adjacent to this defect had been spared from strain, but in the final stage where the scar had been completely healed and we were able to analyze even the scar region itself.

Digital models should be considered with any engineering analysis. We had demonstrated in previous work our digital model on homogeneous normal skin without local damage. That model needs further modification to establish a scar model. Scar models are more complex to be simulated than normal skin. It has even more than post-mortem analysis due to overlapping of different outputs and inputs, most of them are localized in contrast to more generalized changes in conditions such as postmortem or systemic sclerosis.

Figure 2: immediately post injury shrinkage of this skin toward the center of the applied rod. We had not done an analysis of this shrinkage.

An experiment of parametric correlation of skin mechanical properties with the side effects of many drugs (e.g Chemotherapeutic such as Avastin which had cutaneous effects as well as the effect of radiotherapy as it also causes injury to the skin) is highly needed. Although the incision model and suturing it could be regarded as accepted, we think this round model is better than linear incision followed by suturing. It is better to place tissue glue or do superficial incisions without need for suturing because suturing will increase inputs.

Figure 3: Experiment setting.

In order to characterize the peri-scar regions we had suggested the following terms

- Region A is the region of scar that has distinct mechanical properties and retains its own stiffness up to the end. How much this stiffness is? What is this end? These questions should be addressed.
- Region B is the interval between the scar region and traction site, which also needs determination. This is the region that is not involved by the scare but affected mechanically. How could we measure this involvement? a question we will try to answer here in this research.
- Region C is the analogue of region B but at the other side. Application of traction from different axis is highly desirable to investigate the effect of deeper tissues on the more superficial. Cutaneous ligaments had macroscopic orthotropicity that is highly anatomically consistent in the face, and they are one of aging signs determinants. Alterations of force vector by making region B to be region C and vice versa is required for further scar characterization.
- Region D is the region away from region C but is affected by the scar indirectly via region C.
- Region E where the effect of the scar had been faded and it is normal skin.

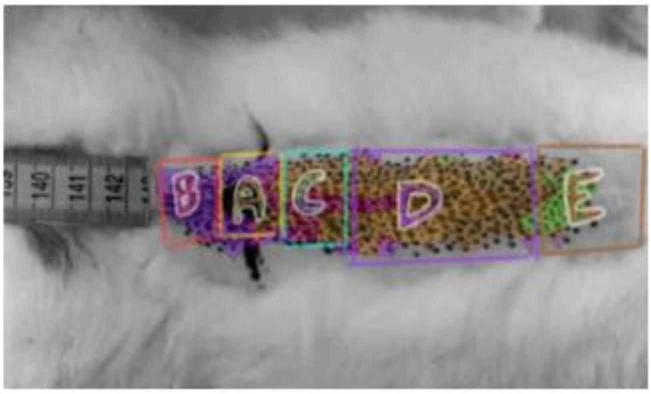


Figure 4: Representing figure for the regions of the scar.

Next figures are for the photos showing displacement associated with traction of the skin for 20 mm.

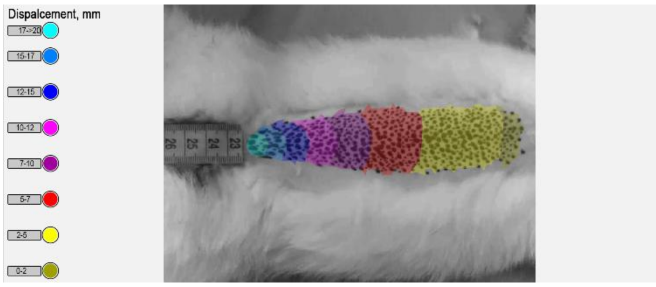


Figure 5: First analysis

Although traction was immediately done using the highest force that led to detachment of the tip from the skin, its highest displacement value was the least across all samples.

Figure 6: The analysis immediately after injury had the least maximum reached displacement

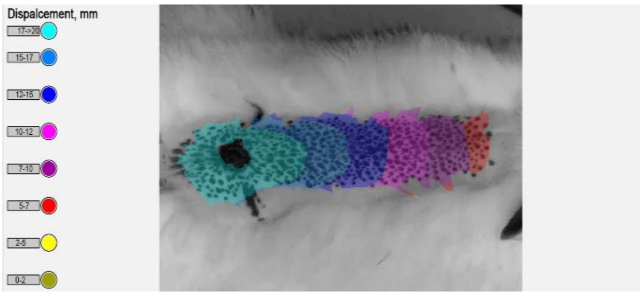


Figure 7: After 10 hours the highest displacement region ( ) had involved the scar.

In all analysis the first, second and third had been done on the first day. The movement is highly shifted from the traction site to involve the injured area and next to it away from. We attribute this to the involvement of the deep region to the injured area.

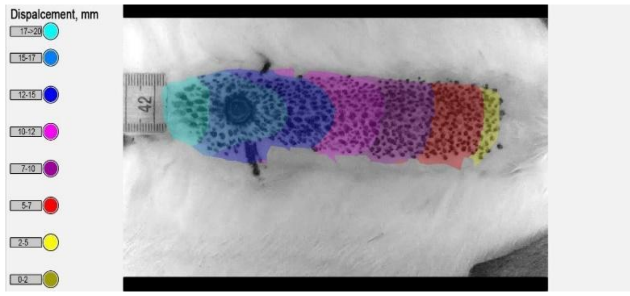
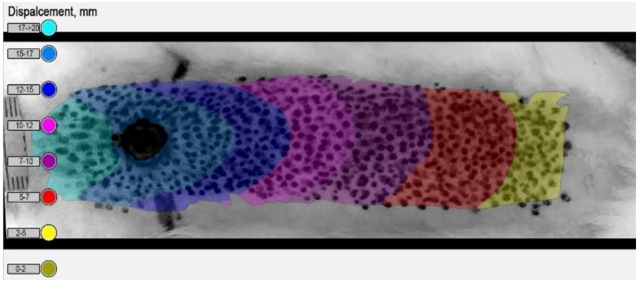


Figure 8: In the fourth analysis, the scar had been excluded from the highest displacement region ( )



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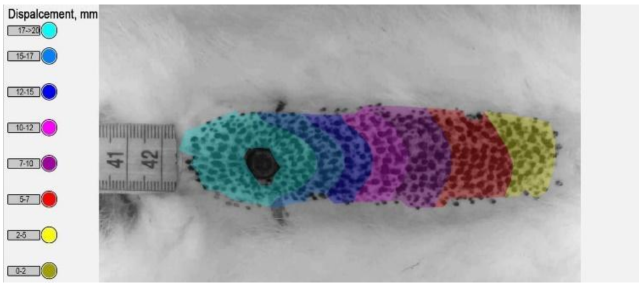


Figure 10: In this analysis, the scar had been included again in the highest displacement region ( )

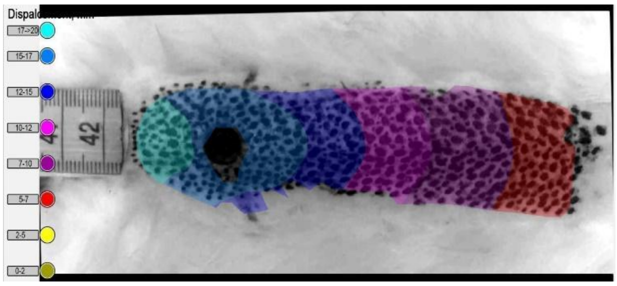


Figure 11: In the fourth analysis, the scar had been excluded again from the highest displacement region ( ) and the yellow region disappeared.

Across all analysis these regions had fixed values as indicated by the color guide (legend).

In many times, the strain could be reduced due to the general inflammatory conditions. In our experiment, this was evident after two days. The strain had been changed dramatically. This could be you to the inflammatory phase after the thermal trauma. Nevertheless, local changes such as shrinkage during injury or defect appearance or clinical healing had more pronounced effects on both strain and displacement as well as other results. In our research, we had not measured the thickness of the skin or other mechanical properties.

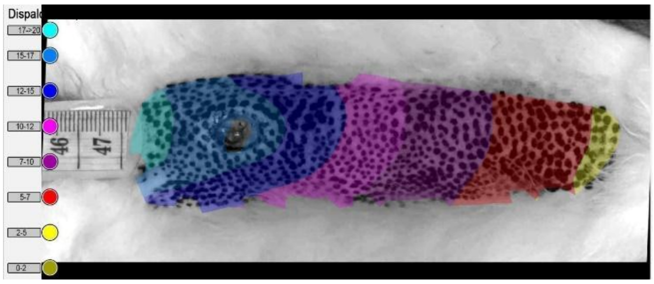


Figure 12: At the middle of experiment, the thermally injured area was destroyed totally exposing the underlying back muscle

This had an effect on the most distant area away from the traction site. Due to their occurrence was coincident with the examination of author to get the fellowship in maxillofacial surgery from KHCMS, more detailed experimentation had not been permissible. Analysis of release of skin after traction had not been done.

We should correlate the appearance of the defect with the change. Change in the defect will be preceded by change in the region as well as after healing, we had not done further analysis for this specific event because its appearance was not a planned. More detailed analysis is needed to further characterize this stage.

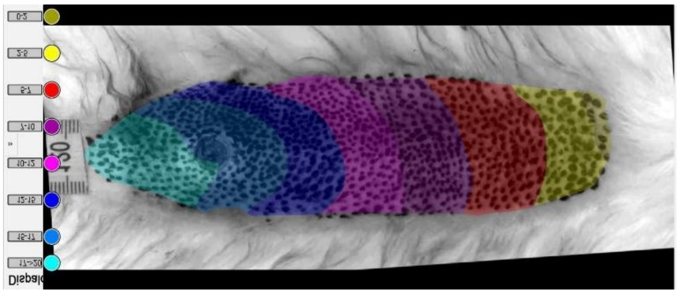
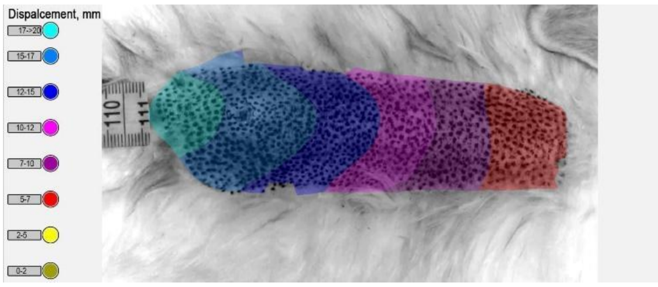


Figure 13: When we had reached what could be regarded as clinical healing, we could analyze the scar region due to the ability to dot the healing region which was damaged previously by the thermal injury



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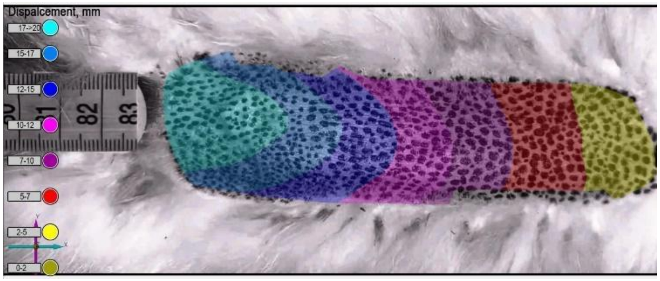


Figure 15: In clinical setting the change in response simply means that in the case of a presence of scar in a mobile area, the eye will percept the abnormal mobility of the skin.

In the case of face, we have extraordinarily complex facial movements that could not be missed easily, and the viewer will compare the normal side to the affected side resulting in more scar showing.

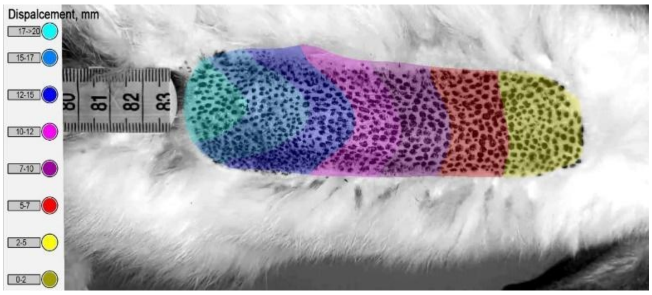


Figure 16: The Yellow region had multiple disappearance and subsequently appearing cycles.

We attribute this fluctuation to the general conditions of the skin and indirect effect from the scar via inflammatory mediators rather than direct mechanical effect. This is an intrinsic change of the skin. In region B and C as well as D had an extrinsic effect from the neighboring of the ulcer or the initial injury.

Examining displacement successive figures showed how the displacement had been restricted in the first day post thermal injury. The pattern in the final stage for distribution of displacement had been returned to its original distribution after passing through different stages. We had these stages that we are correlating to the clinical situation.

- Immediate stage where tissue becomes stiffer.
- Developing of the inflammation
- Development of the defect
- Healing

The area of the scar could assume stiffening while the distant regions had passing through softening and vice versa.

The previous stages could not be enough to draw a clear conclusion. We are speaking about multiple inputs with different outputs that must be reviewed at the same time.

Previous figures are for the photos showing displacement associated with traction of the skin for 20 mm.

Next figures are for the photos showing strain associated with traction of the skin for 20 mm.

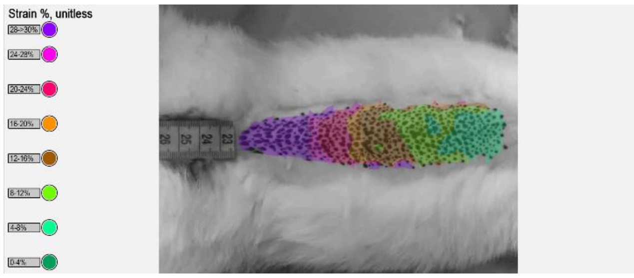


Figure 17: The strain in the pre-injury analysis shows clearly parallel region to each other, in contrast to the case of post thermal trauma where the scar location is surrounded from upper and lower region by more strained regions in all analysis.

Comparison between first and final analysis is very clear in showing differences but doing longer experiments could reveal even better results and complete return could be achieved. High strain simply means more expansion.

Figure 18: All the region C and D behave same strain in the region C as well as displacement had been depressed.

Our 2 sets of analysis had been related to the displacement (up to 20mm and the maximum allowed traction). Another analysis determined by the traction force should be attempted which could give more fidelity about the mechanical properties of the skin.

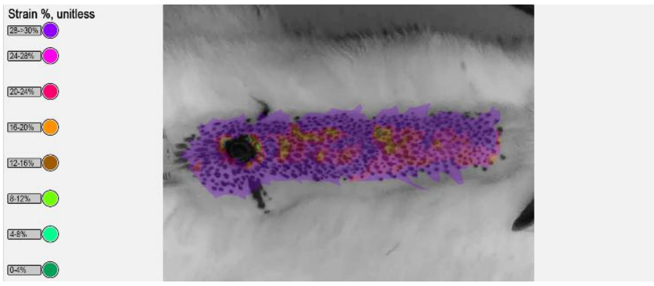
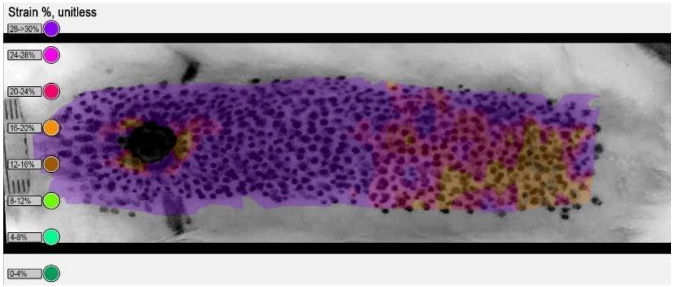


Figure 19: Strain starts to raise in region B and C. many regions share the same expansion.

Figure 20: Strain return and decreased in the region B and C

The negative values had not been reached due to the setting of the experiments. We could arrange another setting, where compression will be investigated. This will introduce more complicated results that is better delayed until we make the basic rule to that govern skin response and we had found in current traction model.



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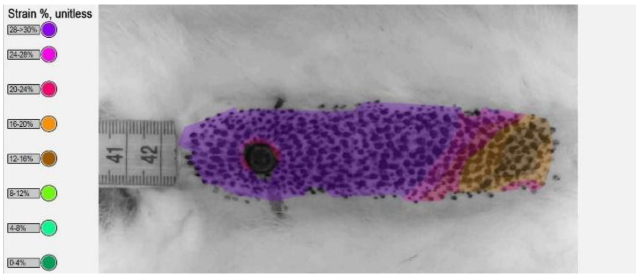


Figure 22: The strain of the post scar region had been raised again before beginning to decline in the subsequent analysis.

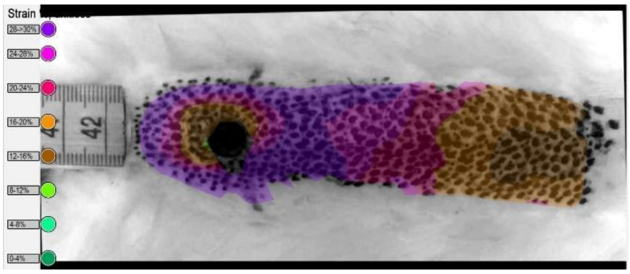


Figure 23: Close to the previous figure

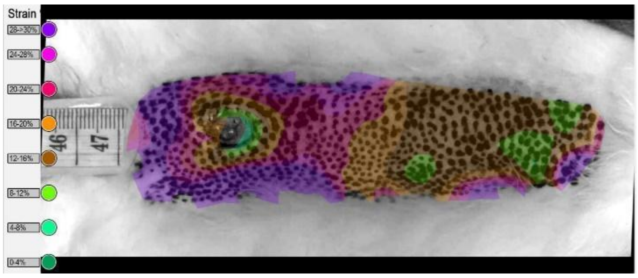


Figure 24: Strain reduced in region A and D.

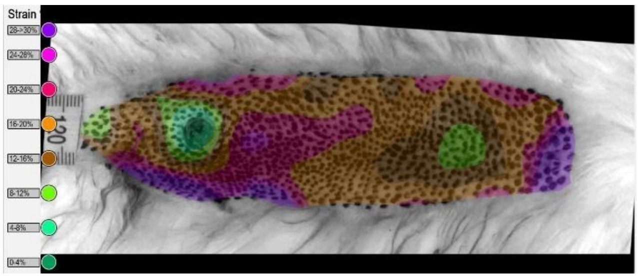


Figure 25Region D had well established island of possible stiffness

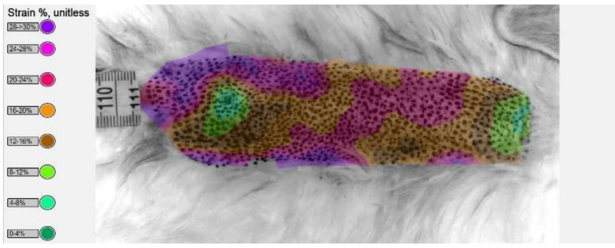
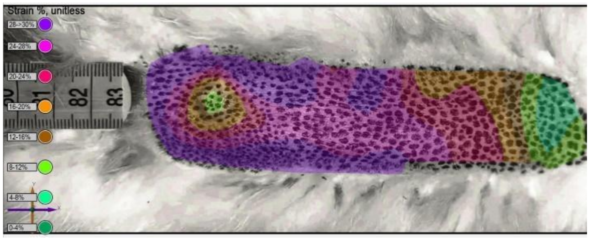


Figure 26: Starting of strain increase in the region D and E



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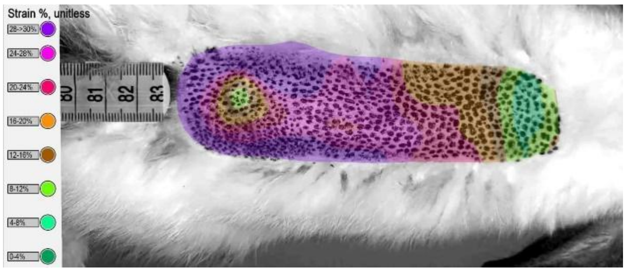

Figure 28: Original pattern of the strain in the pre-injury analyses seems to return.

The gaining of the original pattern could be regarded as a good sign. The upper border of the region C and D begin to change.

The strain showed clearly which region is responsible for expansion or stretching of skin. The growing region of less strain in the distant side from the scar reveals a relief in that distant region. The healed site of the scar from what we could be regarded as knot of increased stiffness due to reduced strain.

The pattern of strain distribution had been transitioned from highly arranged to segregate after injury immediately that changed into chaos then begin to be reorganized again. The back skin of the rabbit fits with the lifestyle of this animal. We anticipate human skin to have much less ROM than this animal.

Previous figures are for the photos showing strain associated with traction of the skin for 20 mm.

The next figures of the strain and displacement after maximum traction had been applied.

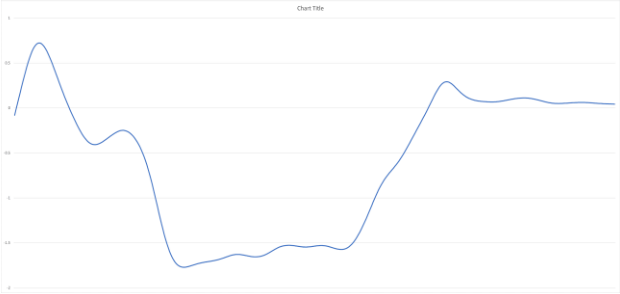

Figure 29: Angle of the traction ruler in the 1st (preinjury analysis)

Although it was manual nut it appears highly steady. Effect of this rotation on the results should be investigated. We need sophisticated equipment to do such a job for rotation and traction at the same time.

We should deeply investigate a plastic property in different ways such as:

- Effect of the force magnitude.
- Needed time to complete the return. In some tests return was manually controlled, and in others, it had left to return on its behalf. This inconsistency is highly discouraged.
- Many surgical operations could provide samples for research. On table scalp expansion is highly related to our research.
- Tattooing is very important, as it will provide a reference to return to it each time.

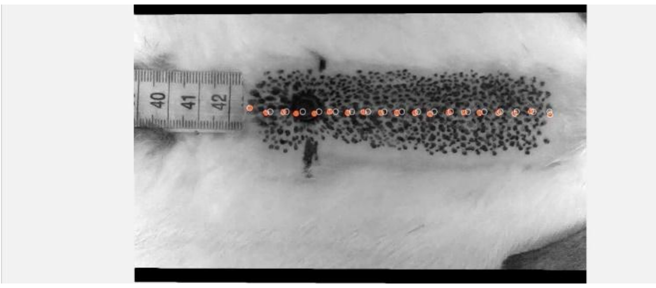

Figure 30: Some points had not been returned to their original positions. It could indicate and give a clue about plasticity of the skin

That we had told previously in the paper of the post-mortem analysis. This plasticity should be investigated deeply. To show the effect of the plasticity we had checked the final position of the most stage that had greatest plasticity as think, which is immediately post thermal injury.

We compared strain and displacement after traction 1mm with the strain and stiffness after full traction and return to the same position. This had been compared to the initial analysis pre-application of the thermal injury.

We should emphasize the need for making traction on the same axis of these points. A special jig with adhesive could be produced to fulfill this need.

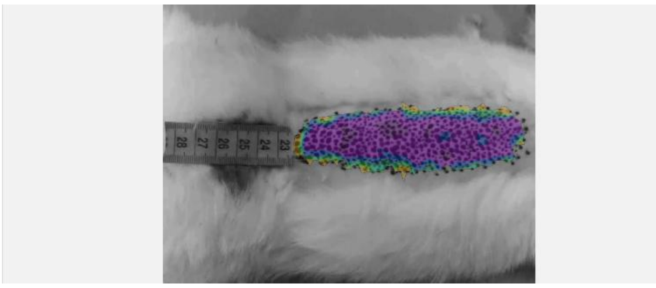

Figure 31: Ruminant strain in pre-injury

Remnants at the periphery could be a result of the data artifacts that could be considered as zero.

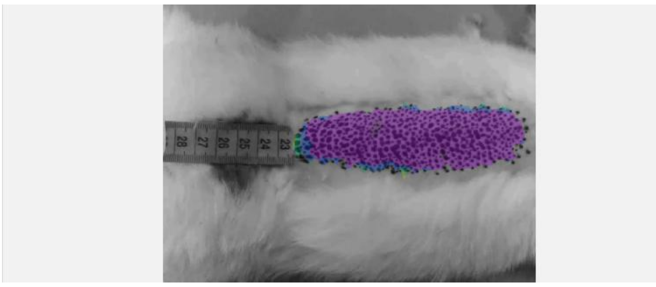

Figure 32: Ruminant displacement in pre-injury

Figure 33: Ruminant strain in post-injury

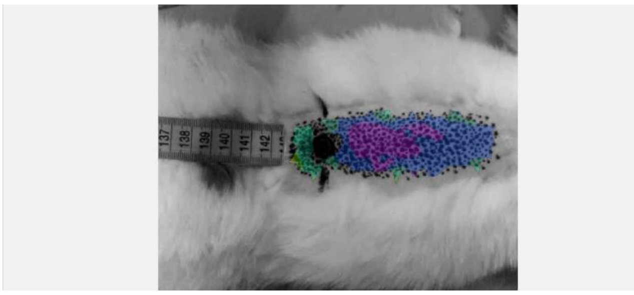

Figure 34: Ruminant displacement in post-injury

Because of many difficulties in performing the analysis, we had sufficed the analysis of strain and displacement. The X and Y fields for strain and displacement had just been done in selected stages.

Comparing the next analysis of Y strain will reveal important aspects, these stages should be scrutinized well.

1) Pre-trauma
2) Defective skin by necrosis. We had regarded this as the middle stage.
3) Final staging

Next figures of the start X and Y fields

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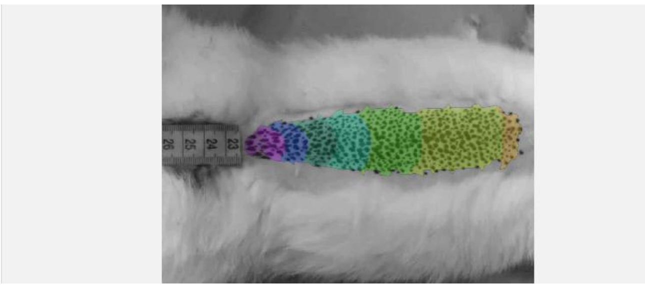

Figure 35: Displacement in the field X

Displacement in the field X of pre-trauma showed clearly that the side closer to the traction force application will have a small region of displacement in comparison to the remaining regions. In another word, this means that region is less stretched and other regions distant from traction side need less force to tract them. Although we had not used a force scale to link the exerted force to the displacement of skin or strain results. The use of such a tool could have final say in many conclusions.

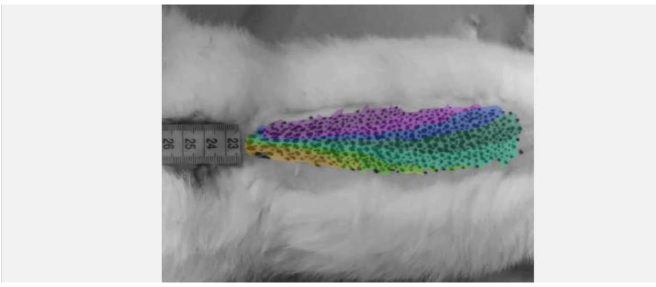

Figure 36: Displacement in the field Y

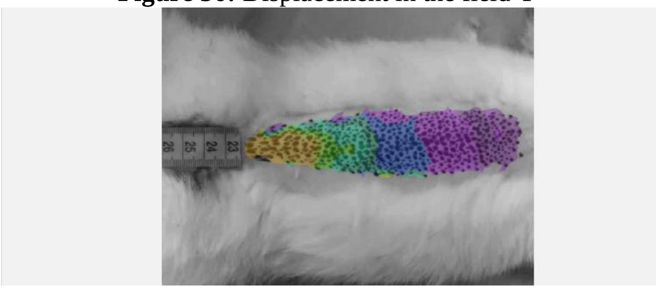

Figure 37: Strain the field X.

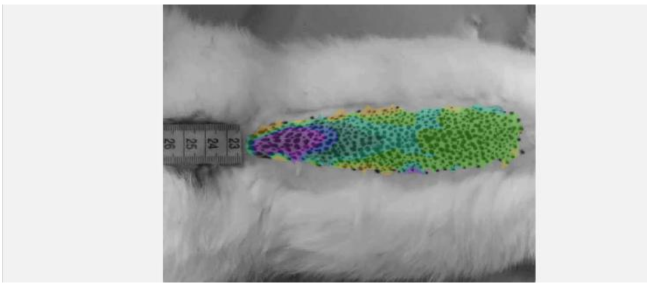

Figure 38: Strain the field Y

Analysis of the Y field strain clearly shows significant changes in the upper and lower regions to the scar in the first, middle and final analysis. Indicating what we had called (calling expansion from adjacent tissue). This especially shows the amount of the spread of tissue contracture and the resultant stiffening.

In the pre-injury analysis, the negative value of the strain is higher, but in the case of defective skin and final stage analysis Y field strain the positive values had much higher distribution. In addition to this. Y field displacements reveal part of the hidden facts.

Previous figures of the start X and Y fields

Next figures of the middle X and Y fields

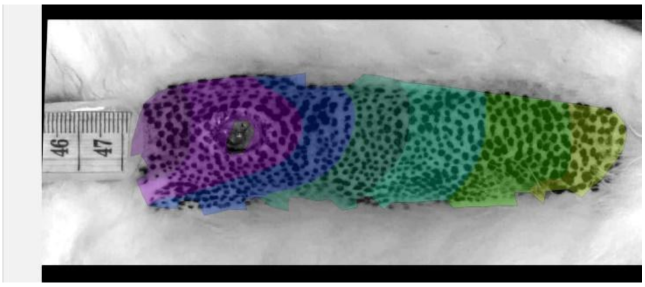

Figure 39: Displacement in the field X

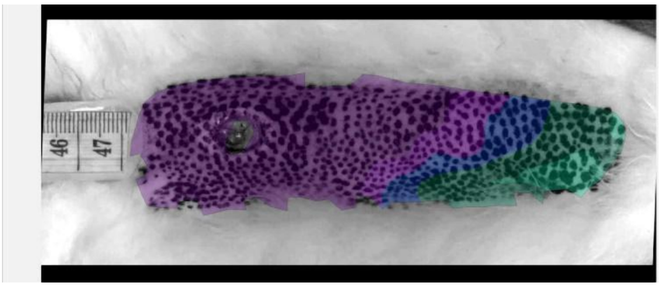

Figure 40: Displacement in the field X

Calling from the adjacent regions was dependent upon the traction vector. Tissue calling from the lateral region plays a significant role related to many aspects in different medical desciplnes.one of theses aspect is the design of flaps in plastic surgery.

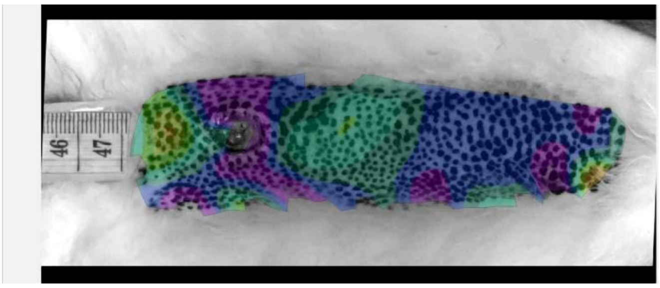

Figure 41: Strain the field X.

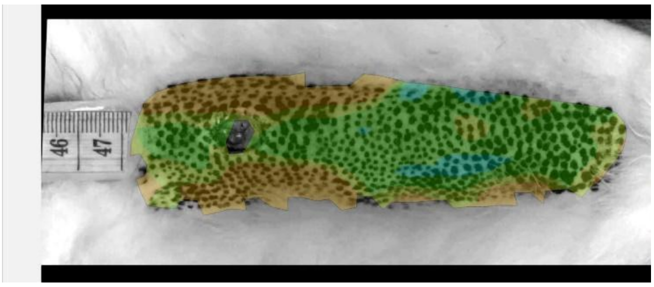

Figure 42: Strain the field Y

Previous figures of the middle X and Y fields

Next figures of the final X and Y fields

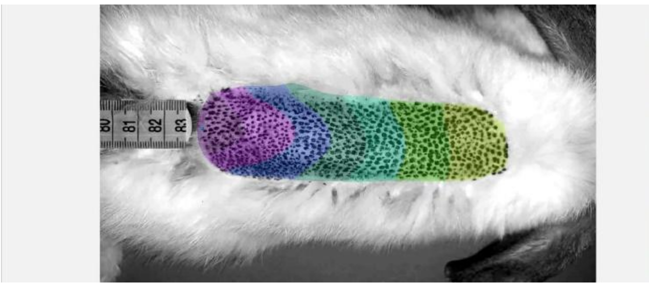

Figure 43: Displacement in the field X

As the axis of traction is parallel with X in the coordination system, no significant difference is seen between the total displacement and displacement in the field X especially in the regions close the central axis of the traction.

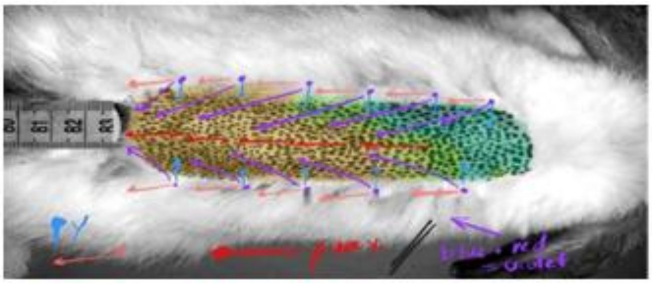

Figure 44: Represent tissue calling vs pure X displacement.

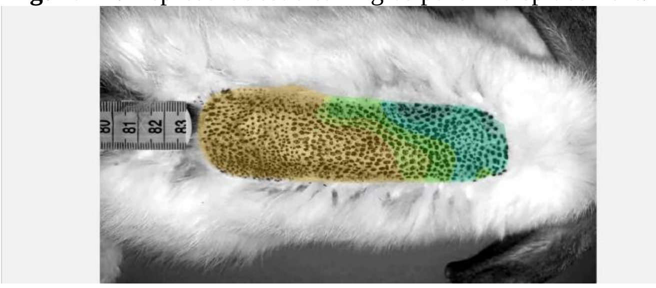

Figure 45: Displacement in the field Y

In the final stage the pattern of calling had been reversed. This could be affected by the setting of the experiments. One of explanation is that the traction angle had not been fixed. Another explanation is that the fibrosis causes more tethering to a side and less to another side leaving it less restrained and higher range of movement which could be correlated with a local activity.

Figure 46: Strain the field X.

X field strain showed clearly, in the case of established healed scar, that we have a central change of stretching and the scar region is the same as the region furthest away from the traction site.

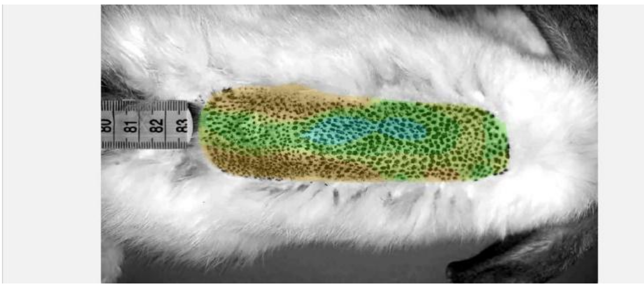

Figure 47: Strain the field X.

Due to the setting of the experiment, the chart of the speed and displacement is of no great impact upon the analysis. One of these criteria is that the traction time is not consistent across all analysis although we had manually made them equal.

Next figures had been exposed to the maximum possible traction.

1st analysis displacement

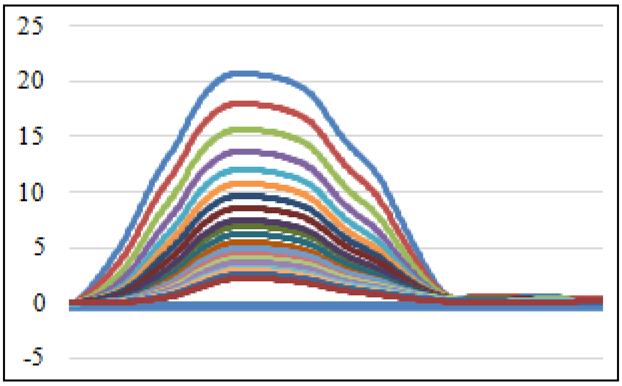

Figure 48: Displacement of the chosen points. Space between each is 5mm

The maximum displacement to minimum is about 10.5, which could be compared to the final stage. This ratio is one of the golden ratios in different sciences that gives an idea about relative displacement b3tween different regions. We admit that the size of the examined is not the same across all analysis. This is one of the causes why we need tattooing.
Due to the manual traction, we did not get consistent results. We need.

- automated return and traction
- Or leave the skin to get in autonomic return by the potential stored energy. This necessitates high frame data acquisition equipment to capture the high response of the skin autonomic return.

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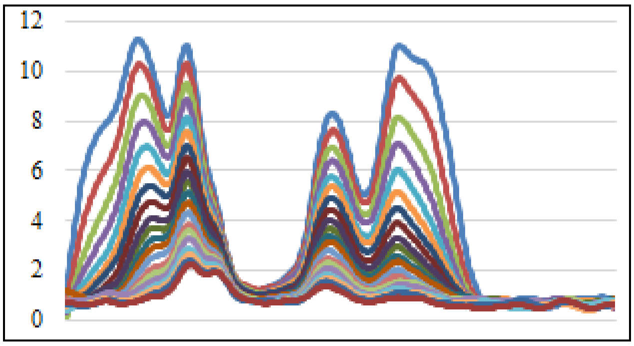

Figure 49: Speed chart of the selected points

In the first speed ratio the difference is also significant from other stages. The ratio of the first and last stage indicates that the distant points away from the traction site had been strained to the least level and had lease required energy.

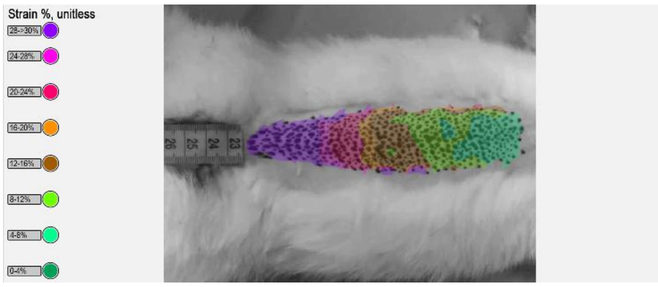

Figure 50: strain

All next figures are for the highest possible tractions. At low strain magnitude, we could examine responses of the area of interesting, namely scar region, and its adjacent periphery and at highest strains, the attraction had effect distant regions. In another word how the scar region had been affected and how it affects the distant region. So that we do maximum traction analysis and 20mm traction analysis to investigate both situations

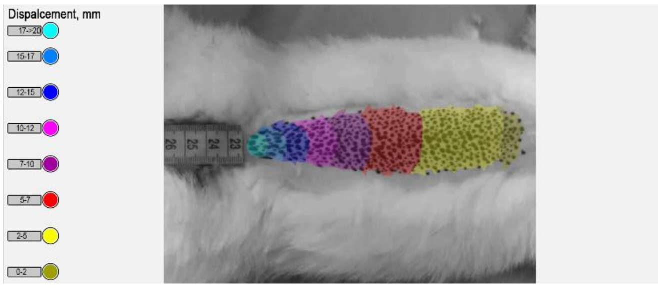

Figure 51: 1st analysis displacement

The first analysis had already reached 20mm as maximum displacement. This value could be due to the setting of the experiment. Multiple analysis is needed to establish whether this is normal or fluctuation. Many mechanical features had circadian changing pattern and this possibly involving the skin.

2nd analysis displacement

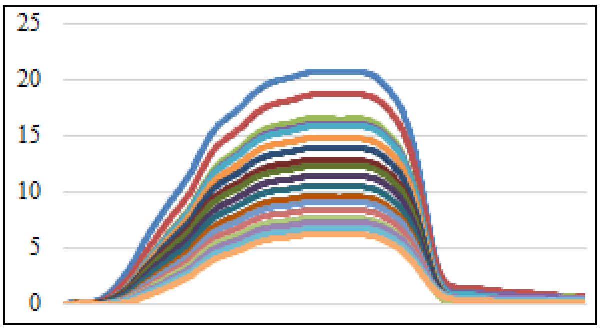

Figure 52: Displacement ratio 3.5

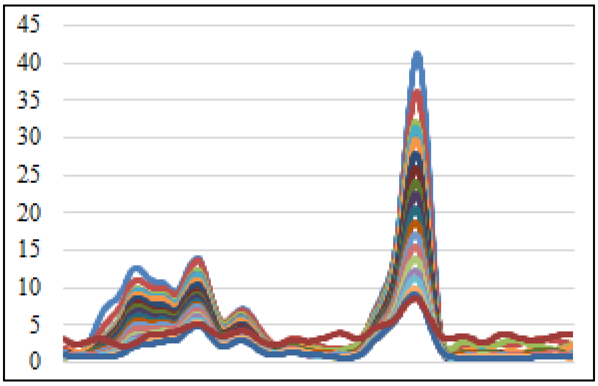

Figure 53: Speed ratio 5

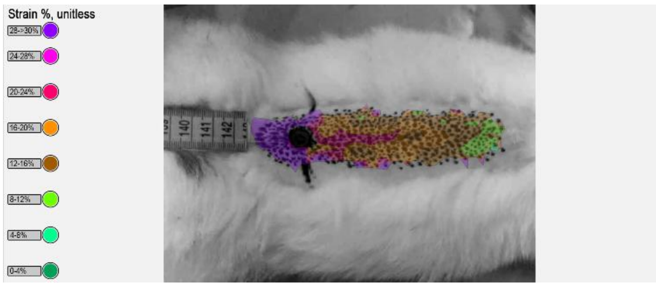

Figure 54: Strin

Figure 55: Displacement

The maximum displacement, after about 12 hours, had become higher. A possible cause is the edema and initiation of the inflammatory response that not just resulted in expanded of tissues, but as well as increased their ability to be stretched.

One of their important points to be considered when testing the mechanical properties of the skin is to relate its proximity to different anatomical structures. Skin will be affected by different ligaments, which tether it to the deeper tissues, and they are age related.

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3rd analysis displacement

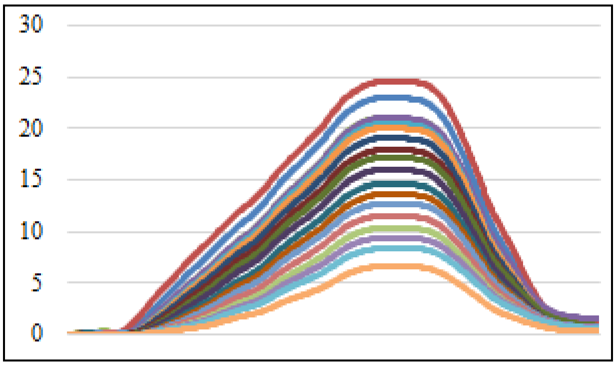

Figure 56: Displacement ratio 3.5

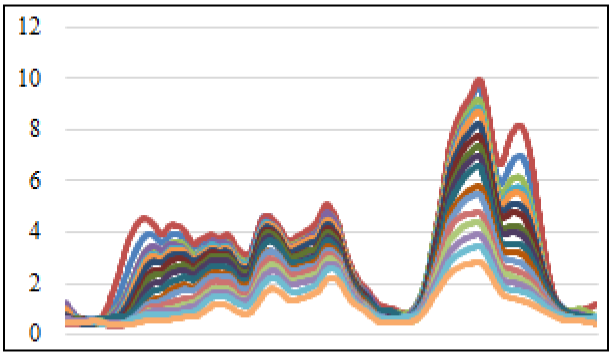

Figure 57: Speed graph

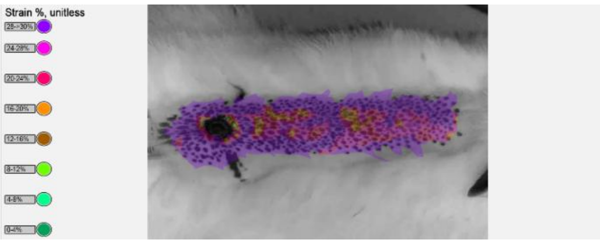

Figure 58: Strain

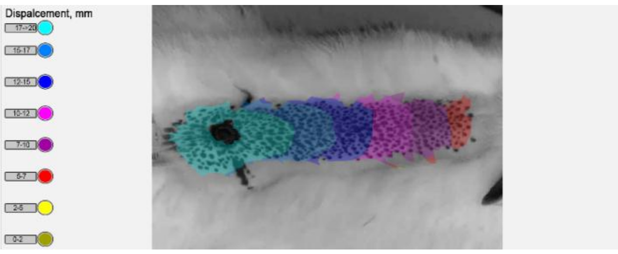

Figure 59: Displacement

4th analysis displacement

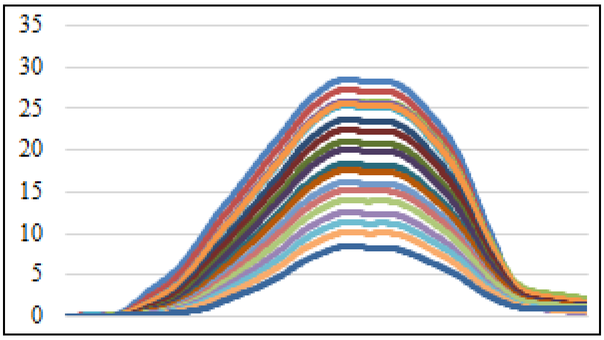

Figure 60: Points displacement ratio 3.5

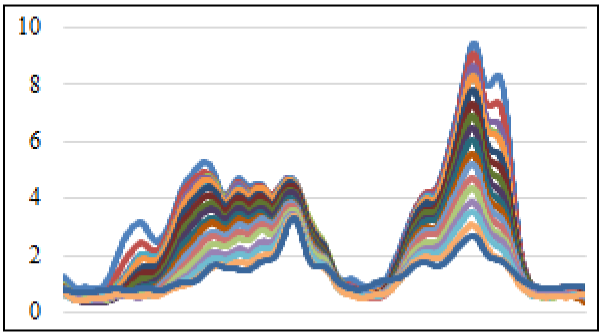

Figure 61: Points speed

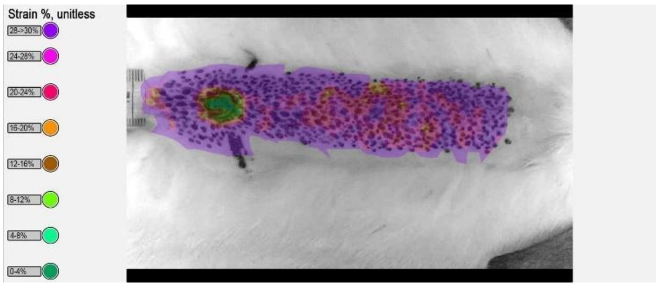

Figure 62: Strain

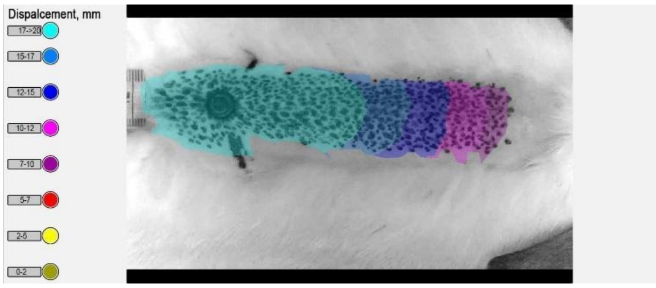

Figure 63: Displacement

5th analysis displacement

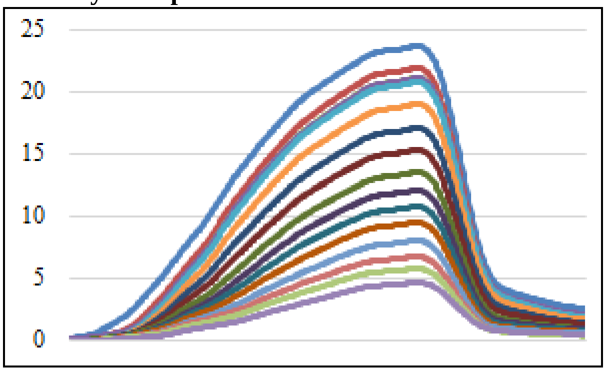

Figure 64: Points displacement ratio 5

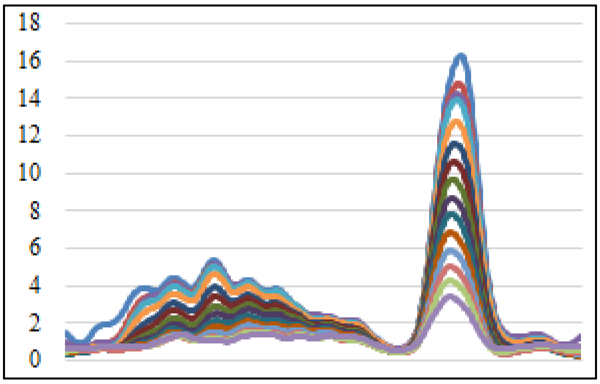

Figure 65: Points speed

International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

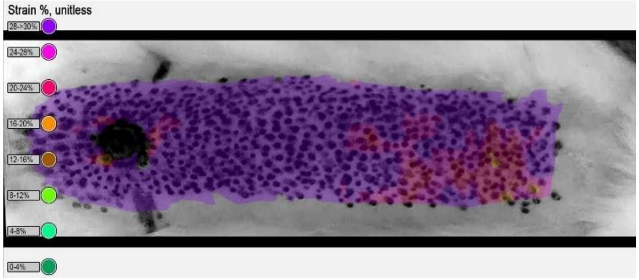

Figure 66: Strain

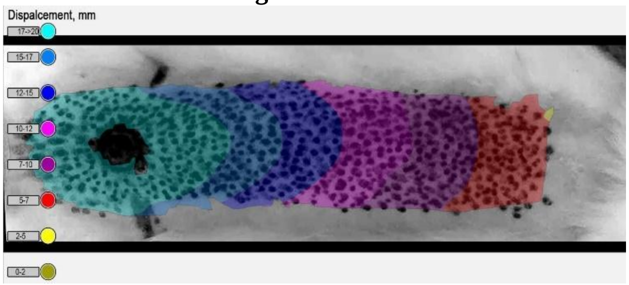

Figure 67: Displacement

6th analysis displacement

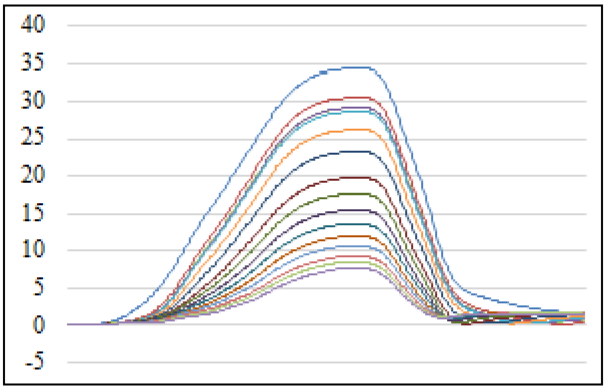

Figure 68: Points displacement

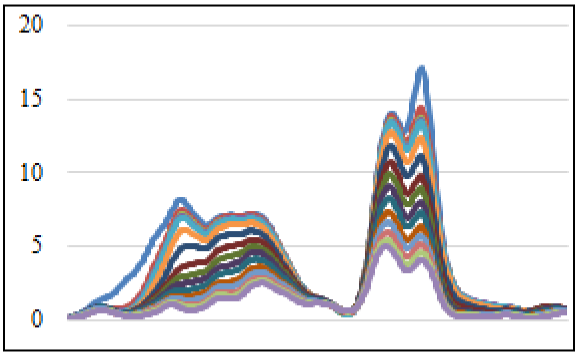

Figure 69: Point speed

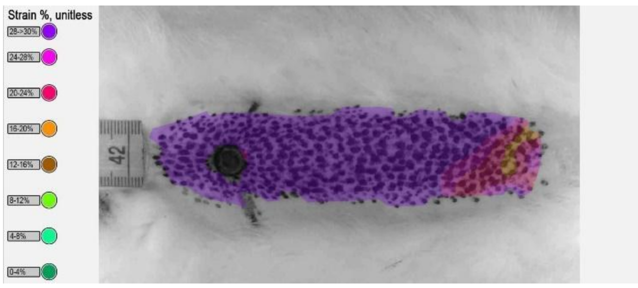

Figure 70: Strain

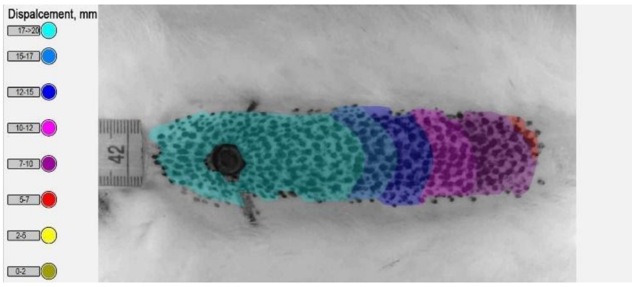

Figure 71: Displacement

7th analysis displacement

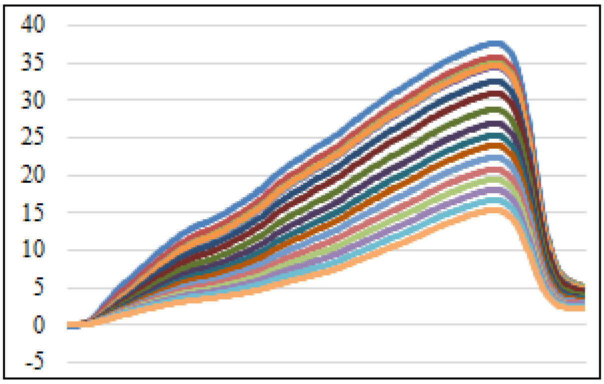

Figure 72: Displacement of the selected points ratio 2.4

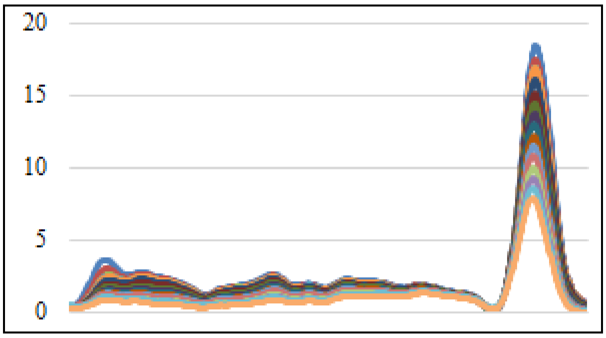

Figure 73: Speed of the points

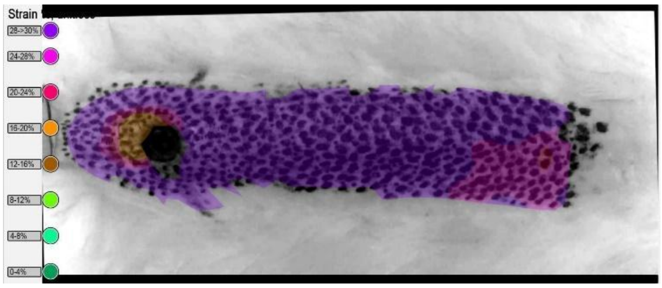

Figure 74: Strain

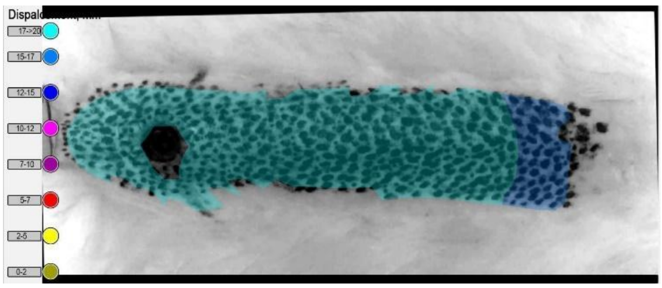

Figure 75: This pattern had closer locking to the final analysis pattern.

The development of window like defect absolutely had an impact on the underlying area of the skin and we think that this effect is of greater influencing on the mechanical response than the effect from adjacent regions although both regions should be deeply investigated.

8th analysis displacement

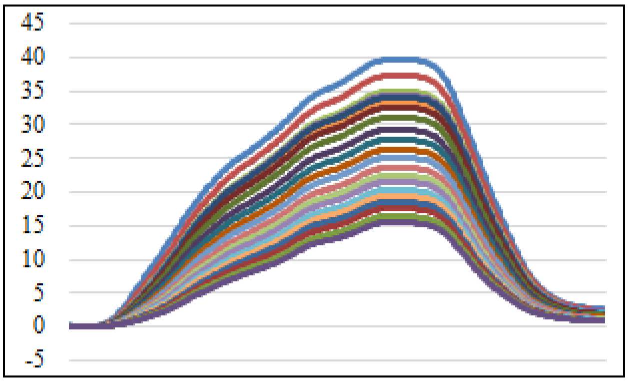

Figure 76: Displacement of the selected points ratio 2.8

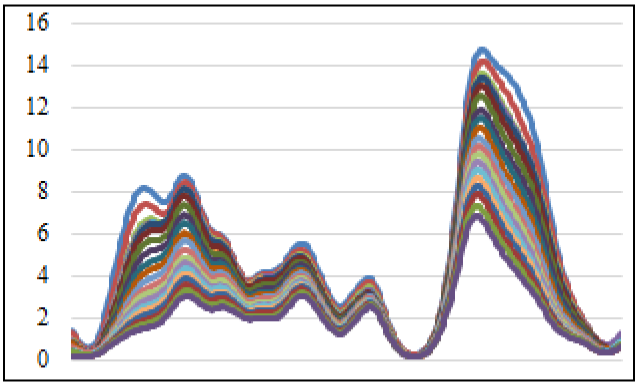

Figure 77: Speed golden ratio2.14

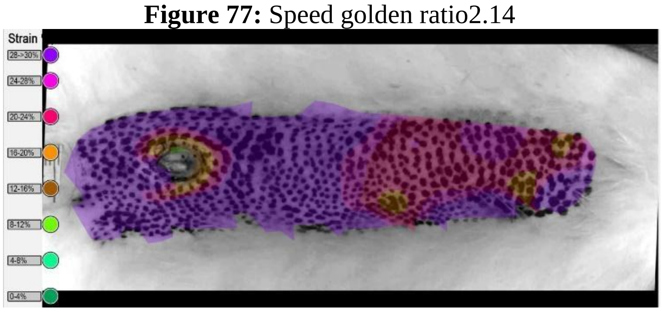

Figure 78: Strain

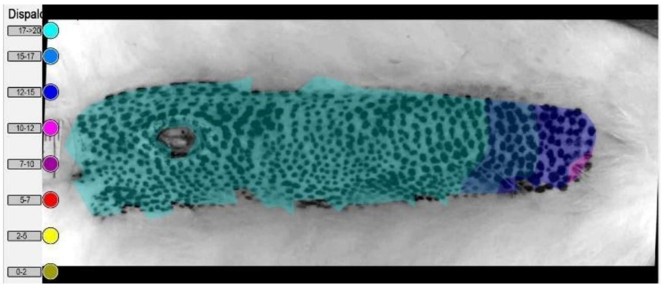

Figure 79: Displamcemt. In this stage a window like defect had been developed

9th analysis displacement

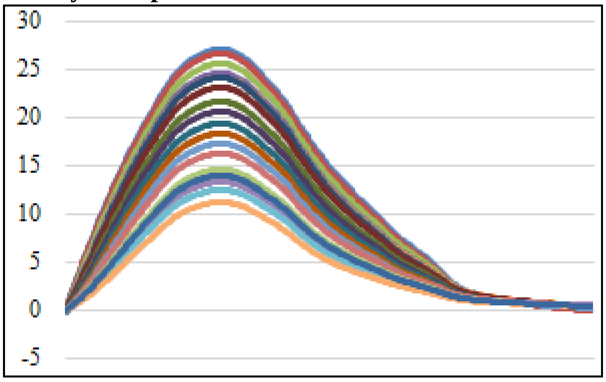

Figure 80: Displacement ratio 2.25

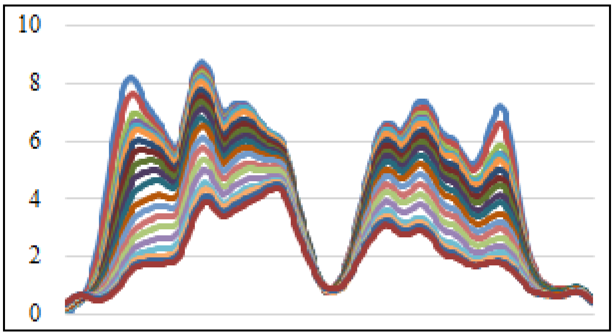

Figure 81: Speed

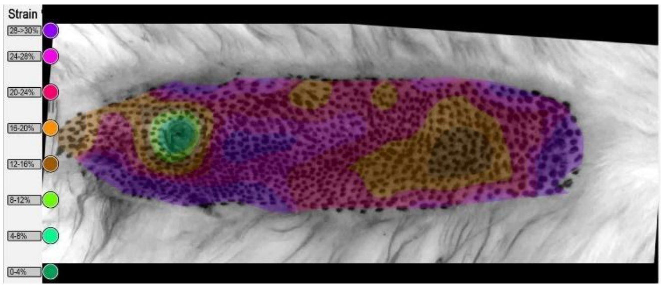

Figure 82: Strain. Stiffening of the scar location is also affecting the away region

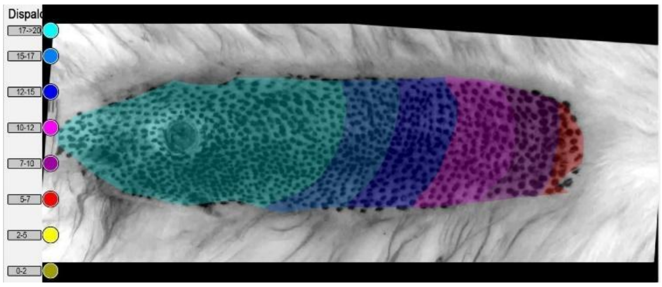

Figure 83: Displacemnt. This stage location is between the defect appearance what could be regarded as the clinical healing. There could be stiffening.

10th analysis displacement

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SJIF (2022): 7.942

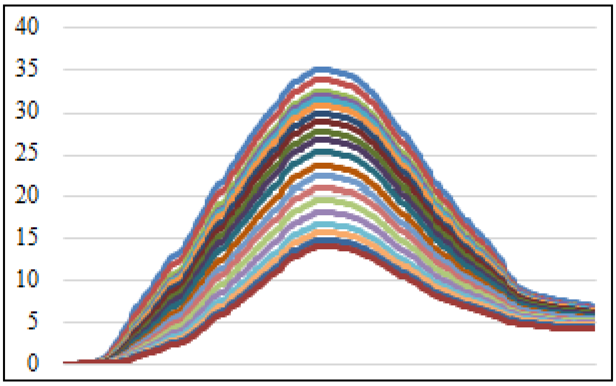

Figure 84: Displacement ratio 2.6

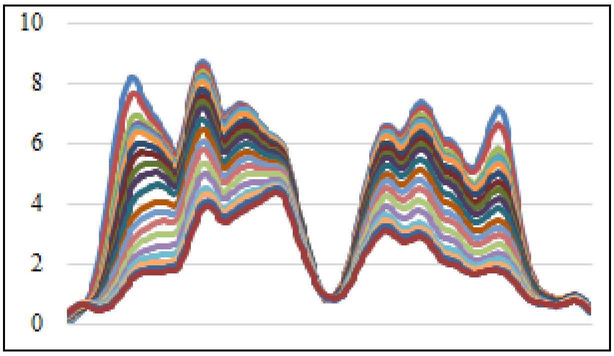

Figure 85: Speed

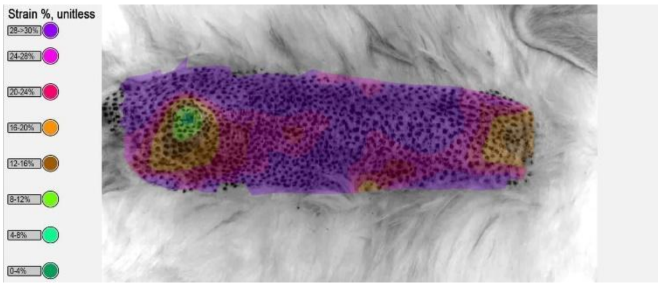

Figure 86: Strain

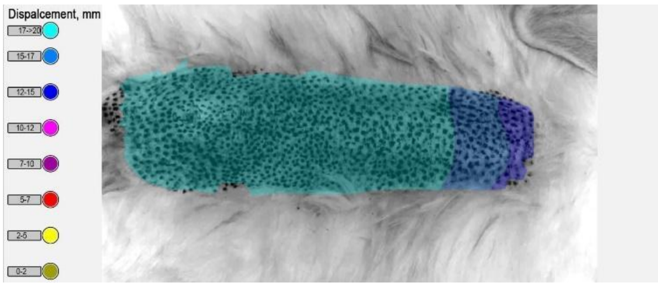

Figure 87: Displacement

11th analysis displacement

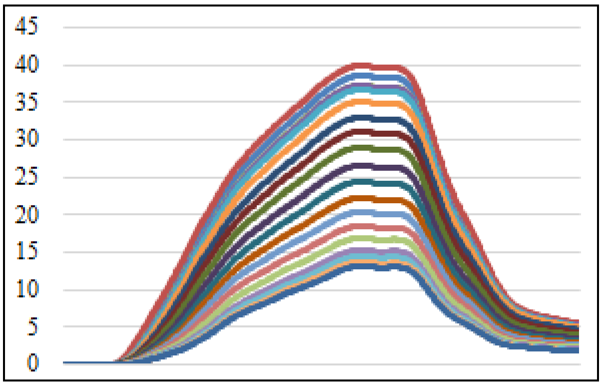

Figure 88: Displacement ratio 3.07

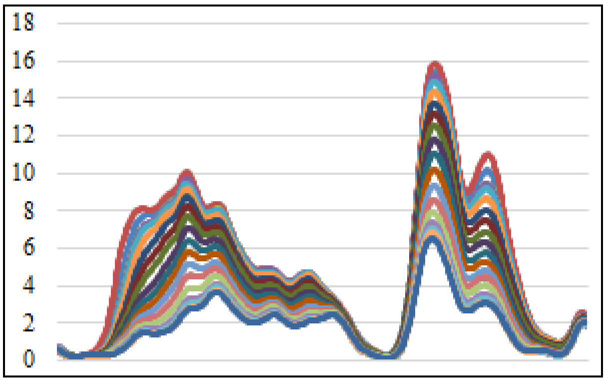

Figure 89: Speed

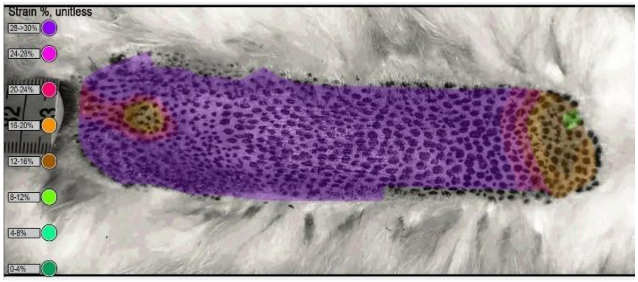

Figure 90: Strain

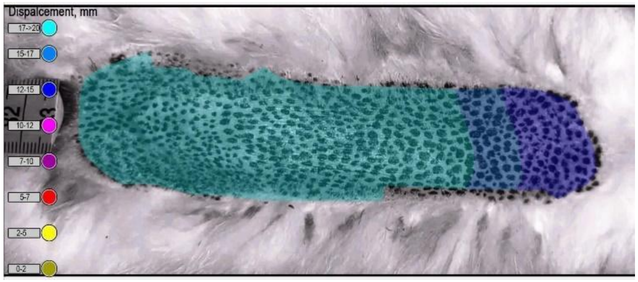

Figure 91: Displacement

12th analysis displacement

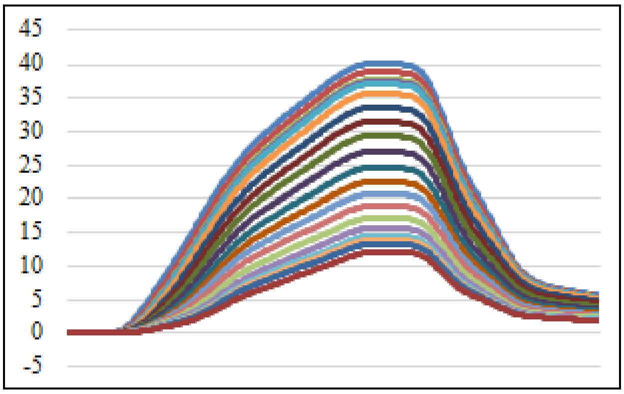

Figure 92: Displacement ratio 3.3

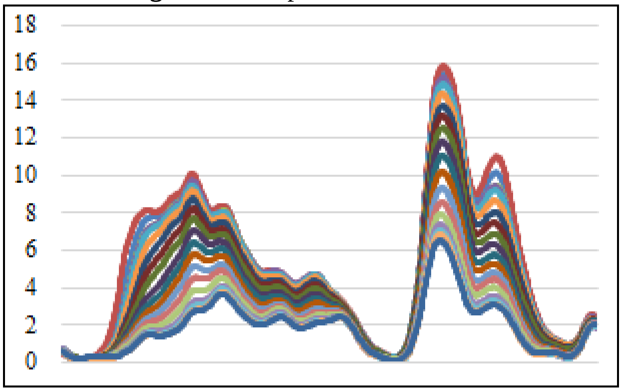

Figure 93: Speed ratio 2.61

Figure 94: Strain

At the end of the experiment, the mature scar and the skin immediately surrounding it, both had what we called (island of stiffness). It's representing region A in the case of a traction experiment. Our model involves round region as a scar not a linear type of scar, which could yield more parametric results.

When we pull the skin, each area will pull the next one. Any area that has a different configuration will behave differently in response to the first one. It will affect the adjacent regions subsequently. The advancement of regions of displacement when they reach the scar area will advance at its periphery. But with more traction, the whole region will be advanced at a single entity presenting a bud-like advancement. In another word, when we had pulled the skin and the traction began to reach the skin it had delayed or lacked response, but the region laterals to it had more response. Continuing the traction force the scar to move forward as the whole region. The first condition could be called engulfment stage, and the second stage is called budding stage.

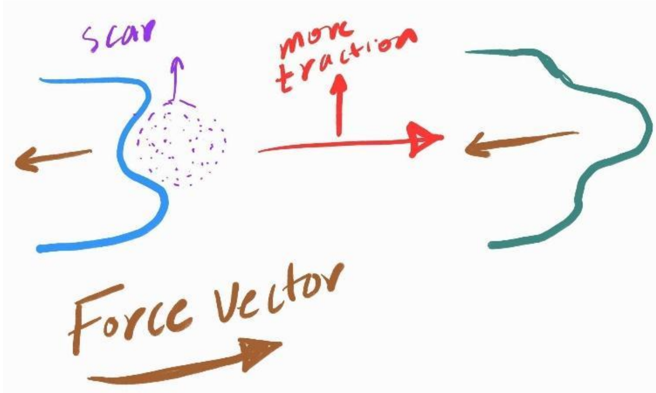

Figure 95: This graph is best seen in running video.

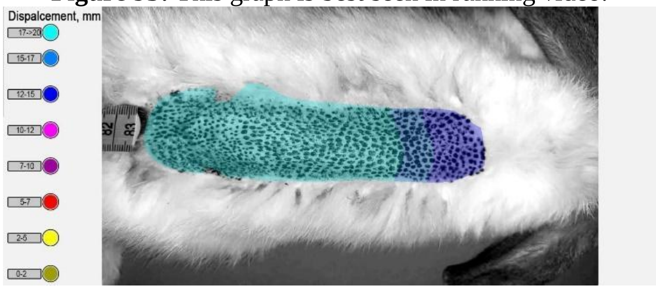

Figure 96: Displacement

The maximum displacement should be linked to the pattern of displacement distribution.

The previous figures of the displacement after maximum traction had been applied.

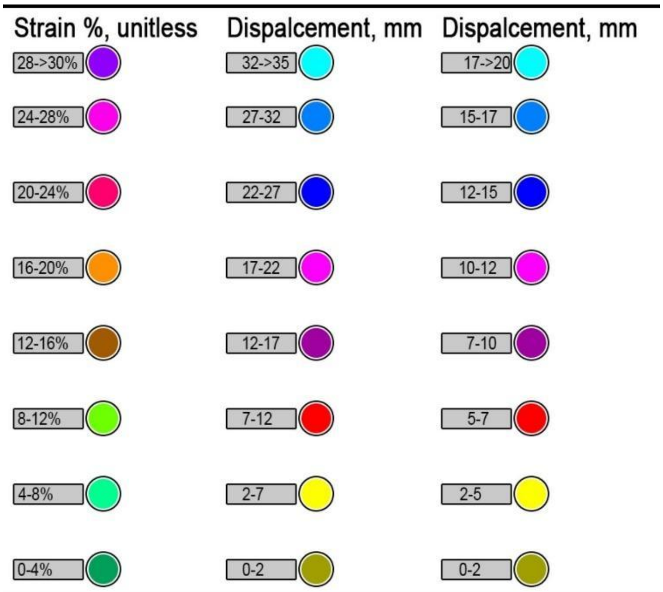

Figure 97: In all of our analysis the legend's (that is the key for understanding values through colors map) maximum and minimum values should be finely adjusted to get the best reveal of the results and the maximum benefits.

5. Conclusions

- No need for statistics to be done in such research. One of the statistics important things is to yield figures from data enabling us to understand the pattern of changes. Engineering analysis is evident in their significancy as they give clear patterns that could be compared in-between easily.

- In our research, we had many factors that had been suggested to influence the results.
- Characterization of the scar in accurate mechanical terms with capability of giving data with numbers is needed and possible.
- We had described different definitions represented by graphs and charts that need to be considered in any mature research.
- Dynamic evaluation of scar should be done to explore. Its mechanical properties.
- Establishment of a model is of paramount importance to get a parametric approach.

6. Needed improvements

1) Traction force was neither automatic nor motorized on a straight rail. It was manual which could have some sort of deviation.

Different speeds in case of automated traction are needed. We agree that automated on rail traction is highly advisable, but as we apply the traction on single point manual traction has been accepted. In case of return high frame, data acquisition is highly required to acquire fast return. Return is happening because of the potential energy of the strained skin due to the traction. We might apply traction on multiple points and at different locations, but this need more deeper analysis based on clear basis that could be retrieved from simple research, such as this research.

One of the main advantages of the automated traction stage is the ability to determine how much we should withdraw their skin. Testing the effect of different traction speeds is very important. Nevertheless, our experiment in its current setting is a good simulation to a clinical situation and an example of a scar follow up.

2) In many analyses, the data acquisition was suboptimal, necessitating further processing of the data.
3) We need to do analysis of the thermal shrinkage.
4) No tattooing had been done.

Tattooing will make dotting consistent. The use of skin printer will give more consistent results. Our dotting was using black ink, while the usage of white ink could enable us to analyze even the black crusted injury area.

5) It is highly advisable for tattooing the region to better track the changes in the skin more accurately.
6) Ultrasound evaluation of the scar is highly advisable to get a better understanding of how scar is developing and mature.

And how the scar is behaving under mechanical loads. In our experiment the appearance of the defect in the skin absolutely had been preceded by signs that could be shown by ultrasound. High frequency probe is needed to examine the condition of the skin (edema, thickening, thinning…. etc.)

7) As we had not implemented a force scale in our experiment, an important piece of information had been missed.
8) One of the least investigated phases in our research is the return.

We hadn't done a reverse analysis approach. Accordingly, many of the outputs about mechanical behavior of the skin hadn't been gotten. Such as the general health condition of these samples. Results should be correlated with the feeding.

9) Inconsistencies in choosing data acquisition position with different focal lengths and magnification across different analysis.
10) In the acute phase, where tissue has been injured, we anticipate a rapid increase of many inflammatory mediators in the circulation.

We hadn't followed any of them. In the next experiments, we suggest investigating blood levels of
a) ESR
b) CRP
c) Leukocytes account

The blood analysis could be correlated to the engineering results. Another suggestion is to introduce a model of general inflammation without skin injury to reveal the effect of these mediators on the skin.

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Author Profile

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