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Morphology of a human finger pad during sliding against a grooved plate (pilot study?)

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Abstract

This pilot study shows that Optical Coherence Tomography can be used to capture the morphology of the finger pad during sliding interaction with a grooved plate. The videos show how the finger pad ridges deform to slide or compress closer to the edge of the grooves. This study has demonstrated the future possibilities of investigating and visualising the interaction of a finger pad with a plate specimen of controlled roughness to improve and optimise surface characteristics of consumer products.

1 Introduction

In recent years, considerable work has been done to study the interaction between human skin and counter-face materials with different roughness. Tomlinson et al. [1][2] measured the forces produced when a finger pad interacts with triangular and rectangular ridged counter-face materials respectively. In the study of finger pad interaction with a triangular ridged counter-face material, Tomlinson et al. [1] have shown that adhesion was the predominant friction mechanism for shallow triangular ridges while interlocking with finger pad ridges was more influential for higher triangular ridges. Also, Tomlinson et al. [2] found that the sliding of a finger pad across a rectangular ridged counter-face could be classified into 4 stages of friction evolution. The main friction mechanisms were adhesion, ploughing friction and/or the reformation (hysteresis) of the finger pad depending on which sliding stage.

Derler et al. [3] found that the frictional behaviour of human skin (hand and finger) varied in response to the glass specimens with different surface roughness and contact conditions (dry/wet). In addition, Derler and Gerhardt [4] also reviewed various parameters influencing the friction coefficient of human skin, which includes the surface roughness of contacting materials. Other studies such as Delhaye et al. [5] studied the surface strain of finger pad in sliding contact and Liu et al. [6] studied the apparent and real contact of finger pad using Optical Coherence Tomography.

These studies have established the potential friction mechanisms during the finger pad and ridged material interaction using experimental and modelling. However, there is still a lack of clarity in the extent of which individual friction mechanisms are at play because there is little visualisation of the interaction. Visualisation is helpful in identifying the friction mechanisms between finger pad and a transparent counter-face material. Visualisation is especially suitable for the friction mechanisms that involve with the deformation of human skin because these mechanisms are dictated by the surface roughness and the surface geometry of the counter-face material. In addition, adhesion friction mechanism is visualised easily during the state transition of human skin from static to dynamic. For example, the contacting surface of human skin remains in contact with a smooth counter-face material without breaking off and sliding while the sub-surface of human skin has moved. Therefore, a method for visualising the edge interaction between a finger pad and a counter-face material is needed.

Optical Coherence Tomography (OCT) has recently been used to study finger-pad skin surface and sub-surface strain during sliding [7], sub-clinical assessment using angiography to assess severity of skin suffering with atopic dermatitis [8], changes on eye/eye-lid surface during contact lens interaction [9] and morphological parameters changes of forearm skin during natural stretching [10]. As such, the aim of this study was to investigate the feasibility of using an OCT system to capture the morphological changes of finger pad ridges across a counter-face material with an uneven surface. The required quality of the captured images was deemed to be the level that would show how the skin deforms around the grooves from the static state to the dynamic state.

2 Materials and Methods

2.1 Test subject and plate specimens

The test subject was a male, aged 26 years old. The experiment was done on the subject's left index finger in a natural state without any pre-treatment. The environmental conditions during the test were around 20°C and 45-50 % relative humidity. The protocol of the study was approved by The University of Sheffield (Ethics Number 002074).

Transparent contact plate specimens were manufactured from polypropylene with an average thickness of 455µm. Grooves were made by sliding a knife across the plastic plate. The specimens are summarised in Figure 1. Videos showing the sliding interaction between the finger pad and various grooved plates are made available on Biotribology Journal (Elsevier) labelled as: Figure 1(a) - Small triangular groove, Figure 1(b) - Big triangular groove, Figure 1(c)

- Small rectangular grooves, Figure 1(d) - Big rectangular groove, Figure 1(e) - Big curved groove.

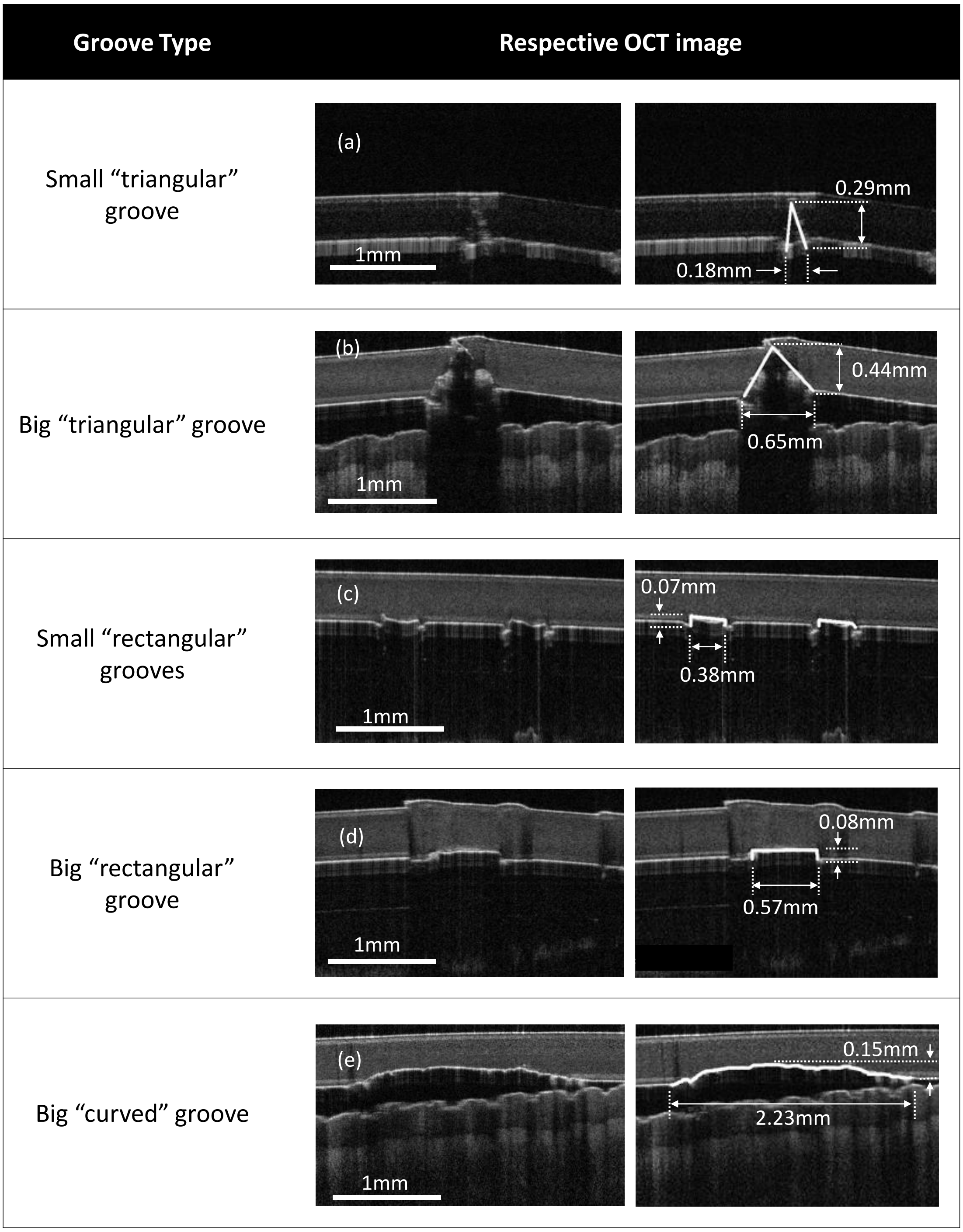


Figure 1: Images obtained for a finger in contact with different types of grooves using OCT and the dimensions of the grooves

2.2 Experimental protocols

The plate specimen (counter-face) was held using a support rig, as shown in Figure 2, while the finger pad was slid against it. The normal force and sliding speed were kept constant at around 2N and 2mm/s respectively throughout the experiment.

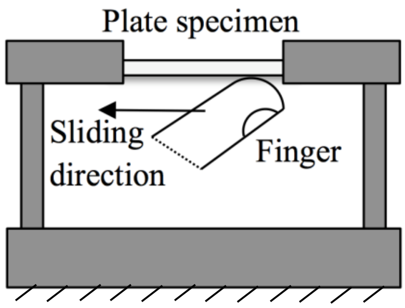


Figure 2: Experimental set-up of finger pad sliding against plastic specimen

2.3 Optical Coherence Tomography

Optical Coherence Tomography (OCT) is a non-invasive imaging technique that can capture images showing surface and subsurface morphology of biological tissues. A clinically-approved Vivosight® OCT system (Michelson Diagnostics, Kent) has a Fourier domain with a 20 kHz swept source laser at 1300 nm centre wavelength, 7.5 µm lateral and 5 µm axial resolution. This system was used to visualise the interaction between the finger pad and a plate specimen from the static state to the dynamic state. Continuous B-scans [11] were captured to identify the cross-sectional image of the specimen in real-time. The image capturing rate was 20 frames per second and the resolution of each image was 1342×460 pixels. The OCT assembly (shown in (a)) was similar to that used in the study by Maiti et al. [10] in assessing deformation in forearm skin during natural stretching.

Videos for each grooved specimen were captured before and during finger pad contact with the plates and at two positions of the finger pad, close to the finger-tip and over the interphalangeal joint. Each video was converted into a total of 194 Images using the “image sequence function” in ImageJ [12].

Morphological parameters (thickness of stratum corneum, top surface roughness and stratum corneum – stratum lucidum undulation as shown in Figure 3(c)) were computed from six consecutive OCT images at each of the following conditions: no contact, contact near interphalangeal joint and contact near fingertip as shown in Figure 3 (b). This is done using an image processing algorithm presented by Maiti et al. in [10]. The parameters are presented as mean ± standard deviation for each condition.

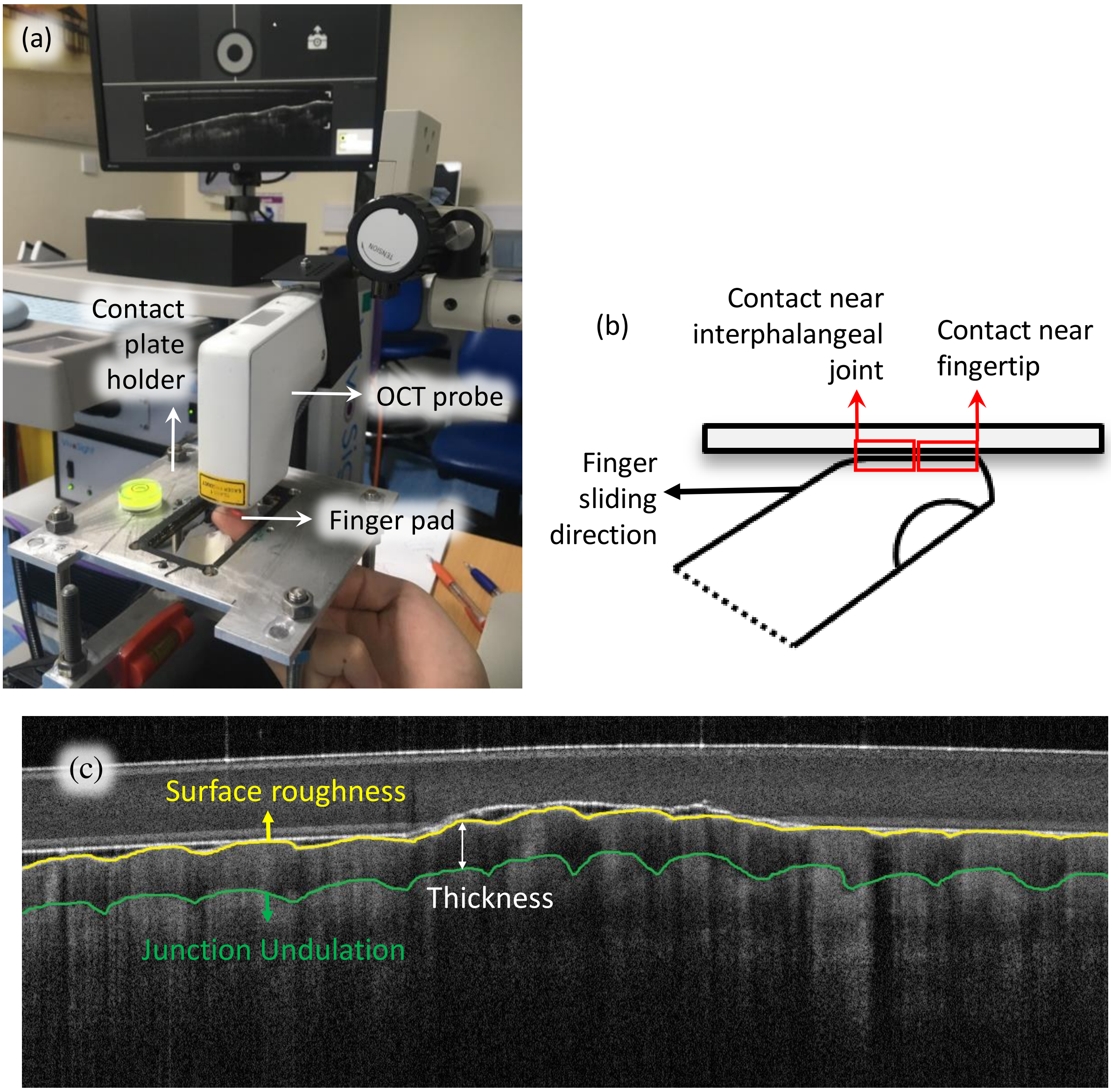


Figure 3: (a) OCT system assembly, (b) location of OCT images where the morphological images were computed and (c) illustration of morphological parameters

3 Results

3.1 Morphological change of finger pad against grooved plate during sliding

Videos, available on Biotribology Journal (Elsevier), show the morphological changes of the finger pad when it was slid against the grooves. Figure 4 shows how the finger ridge deformed when approaching and climbing over two groove specimens that have different edge geometry. The edge of the big “rectangular” groove has a rectangular and pointy edge while the edge of big “curved” groove is curved and has a rounded edge. In the first case, the finger ridge deformed and ploughed by the edge of the groove when approaching the edge. Then, the finger ridge returned to its flattened contact after climbing over the edge of the groove. In the latter, the finger ridge did not seem to deform much in terms of interlocking or ploughing.

The thickness of stratum corneum near to the interphalangeal joint reduced by 20% from 322.8 µm to 257.6 µm during sliding through the big “curved” groove as shown in Figure 5. This thickness increases significantly by 50% when the region of interest of the finger pad skin interaction with groove changes from skin closer to interphalangeal joint to skin closer to fingertip. Similarly, the surface roughness and stratum corneum – stratum lucidum junction undulation also significantly decreases from 5.17 µm to 2.36 µm and significantly increases from 4.41 µm to 6.70 µm by a factor of 50%. There was no significant difference in surface roughness or junction undulation between skin near fingertip and interphalangeal joint.

Smaller grooves such as small “triangular” and “rectangular” grooves did not show any significant effect on the finger pad skin deformation (videos available electronically Figure 1(a) and (c)). As the width of the groove increased, the finger pad skin was affected by the grooves. There was distinctive loss of visualisation in OCT images of big “triangular” groove, highlighted in red circle shown in Figure 6. The extent of the image loss varies with the different grooves. The big “triangular” groove OCT images suffered the most loss of visualisation because the lights were not reflected properly due to sharp bend not giving a clear image of the finger pad skin.

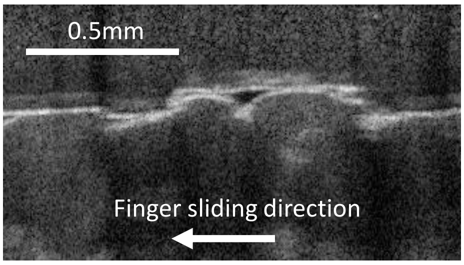
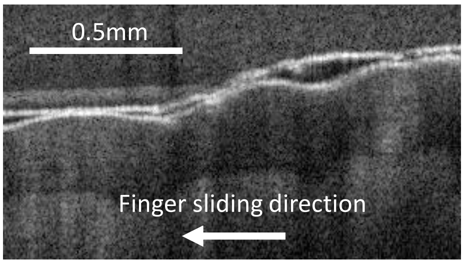
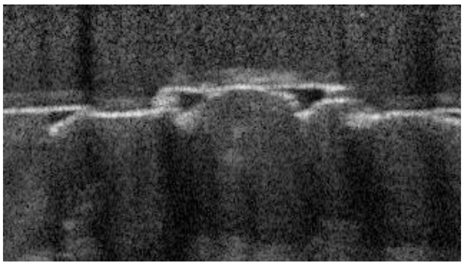
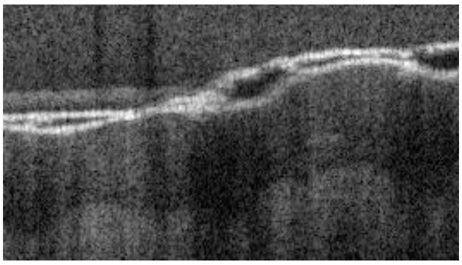
Sliding State	Big “Rectangular” Groove	Big “Curved” Groove
Approaching the edge of the groove		
After climbing over the edge of the groove		

Figure 4: Images of the deformation of finger ridges on interaction with the edge of a “rectangular” and a “curved” groove plate specimen.

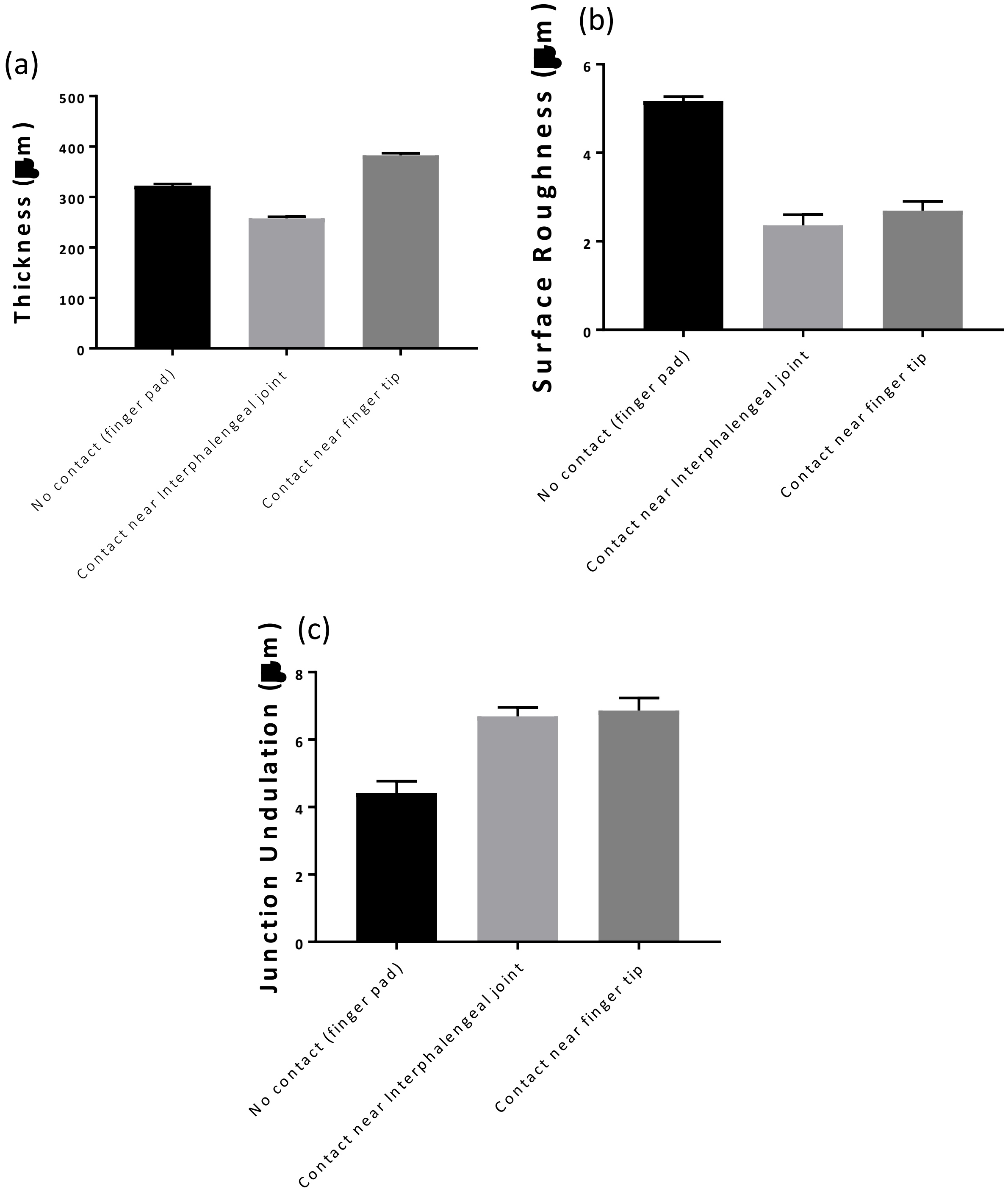


Figure 4: (a) thickness, (b) surface roughness and (c) stratum corneum – stratum lucidum junction undulation of finger pad skin at no contact and during sliding with big curve groove.

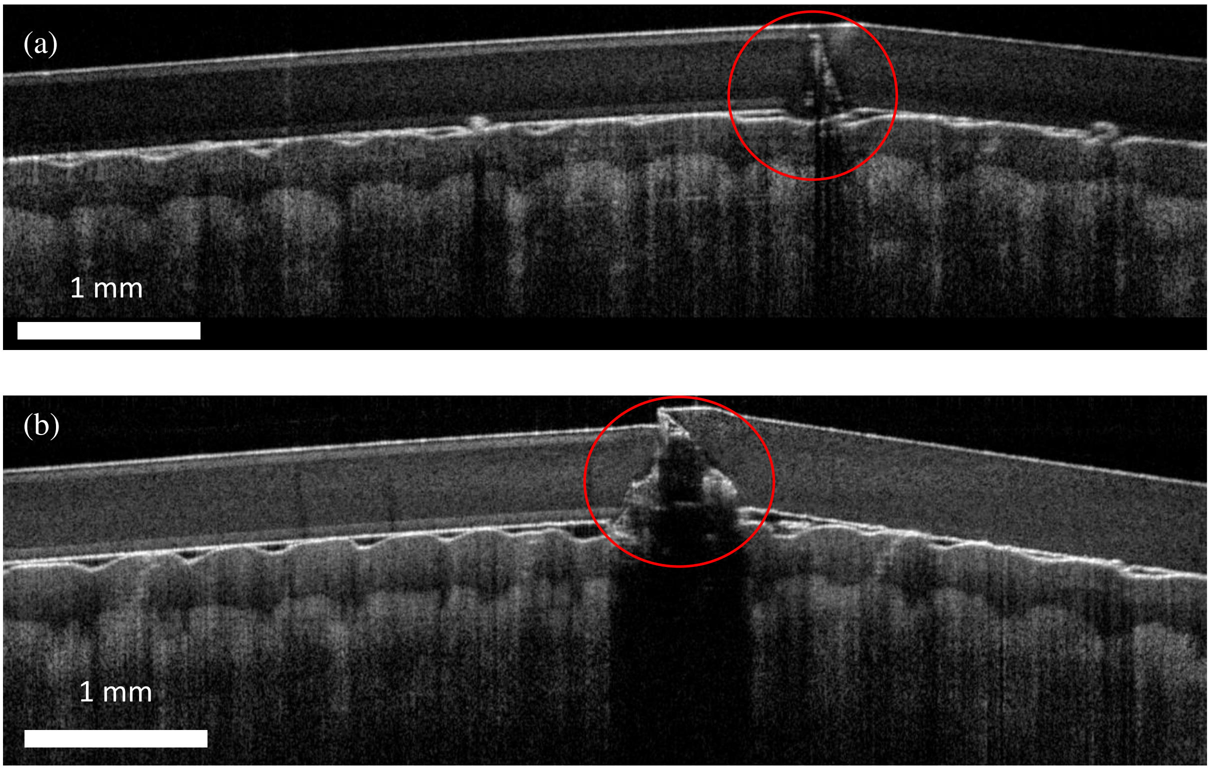


Figure 5: OCT image with (a) partial image loss and (b) total image loss

4 Discussion

The thickness of the finger pad near interphalangeal joint reduced on the application of normal load. However, the increase in thickness closer to finger pad can be attributed to the bulging of the skin layer near the tip. The decrease in the gap between finger ridges and plate resulted in higher roughness in both positions of the finger pad. The increase in junction undulation within the sub-surface of finger pad may due to the friction during sliding.

4.1 Friction mechanisms

When the finger pad was sliding against the plate specimen with big “curved” groove, the interlocking effect or ploughing friction effect on the finger pad were not obvious because the edge of the groove was more rounded and circular. Therefore, adhesion seems to be the predominant friction mechanism of the finger pad sliding interaction, which is similar to the sliding interaction between a finger pad and a shallow triangular ridge in a study by Tomlinson et al. [1]. On the other hand, the finger pad ridges were ploughed by the edge of the groove when sliding against the plate specimen with the big “rectangular” groove. The was due to the rectangular shape edge that provides a platform to plough .

The importance of the geometry of the edge of the groove is shown because the friction mechanisms of a finger pad are different between a “rectangular” and a “curved” groove plate. This could extend to the dimensions of the triangular, rectangular and curved grooves because the width and the depth of the grooves will affect the frictional behaviour of finger pad and the predominant friction mechanisms. This study attempted to investigate the role of groove dimensions as shown in the small and big “rectangular” groove plate specimens. Both have the same ploughing phenomenon at the edge of the groove although it is less obvious in the small “rectangular” groove video due to the partial image loss under the edge of the groove.

4.2 Feasibility of OCT in studying finger pad – grooved plate interaction

Although this pilot study mostly studies the visual results of the experiments, it has successfully shown that OCT system can be used to study the morphological change of the finger pad ridges when sliding across the grooves of the plate specimens.

Most videos show partial or total image loss regions under the grooves. These regions were caused by the light diffraction phenomenon as OCT relies on the light reflection signal to produce the OCT images. It is also observed that these regions normally occurred at the grooves that have a sudden change of plate thickness. In the case of the big “curved” groove-finger pad sliding interaction, there are no image loss regions because the plate thickness did not decrease as dramatically as other grooves that gave severe light diffraction.

5 Conclusions and Future work

This experiment has shown the feasibility of using an OCT system to visualise the finger pad sliding interactions with plate specimens of different grooves. It has shown the possibilities to investigate the interaction of finger pad with plate specimen of controlled surface roughness.

Due to the methodology in manufacturing the grooves was very crude, the future work will need to focus on developing a manufacturing method that can make plate specimens with grooves in a controllable manner. This would help in determining the baseline of the depth and the width of the grooves when the image loss becomes significant. Only when the image quality of the OCT images is acceptable and consistent, the roughness of the groove and the finger pad can be accurately measured and post-processed. Then, this could be tested in a large pool of participants in the future when the testing methodology is stable. With the information on the friction mechanism and skin deformation, it can help us in designing better consumer product and understand the gripping method and sports biomechanics interactions.

6 References

[1] Tomlinson, SE, Carré, MJ, Lewis, R, Franklin, SE. Human finger contact with small, triangular ridged surfaces. *Wear.* 2011; **271**: 2346-2353.

[2] Tomlinson, SE, Carré, MJ, Lewis, R, Franklin, SE. Human finger friction in contacts with ridges surfaces. *Wear.* 2013; **301**: 330-337.

[3] Derler, S, Gerhardt, L-C, Lenz, A, Bertaux, E, Hadad, M. Friction of human skin against smooth and rough glass as a function of the contact pressure. *Tribology International*. 2009; **42**: 1565-1574.

[4] Derler, S, and Gerhardt, L-C. Tribology of skin: review and analysis of experimental results for the friction coefficient of human skin. *Tribology Letter*. 2012; **45**: 1-27.

[5] Delhaye, B, Barrea, A, Edin, BB, Lefevre, P, Thonnard, J-L. Surface strain measurements of fingertip skin under shearing. *Journal of Royal Society of Interface*. **13**; 20150874.

[6] Liu, X, Maiti, R, Lu, ZH, Carré, MJ, Matcher, SJ, Lewis, R. Measuring contact area in a sliding human finger-pad contact. *Skin Research Technology*. 2017; 1-14.

[7] Liu, X, Maiti, R, Lu, ZH, Carré, MJ, Matcher, SJ, Lewis, R. New non-invasive techniques to quantify skin surface strain and sub-surface layer deformation of finger-pad during sliding. *Biotribology*. 2017; **12**: 52-58.

[8] Byers, RA, Maiti, R, Danby, SG, Pang, EJ, Mitchel, B, Carré, MJ, Lewis, R, Cork, MJ, Matcher, SJ. Sub-clinical assessment of atopic dermatitis severity using angiographic optical coherence tomography. *Biomedical Optics Express*. 2018; **9:** 2001-2017.

[9] Morecroft, R, Toomey, P, Goff, JE, Mylon, P, Carré, MJ, Matcher, SJ, Lewis, R, Maiti, R. Investigation into surface interaction between the contact lens and the upper eyelid margin using optical coherence tomography. *SPIE Conference*. Feb 2017, California, USA.

[10] Maiti, R, Gerhardt, L-C, Lee, ZS, Byers, RA, Woods, D, Sanz-Harrera, JA, Franklin, SE, Lewis, R, Matcher, SJ, Carré, MJ. In vivo measurement of skin surface strain and sub surface layer deformation induced by natural tissue stretching. *Journal of the Mechanical Behaviour of Biomedical Materials.* 2016; **62**: 556-569.

[11] Kraus, MF, Potsaid, B, Mayer, MA, Bock, R, Baumann, B, Liu, JJ, Hornegger, J, Fujimoto, JG. Motion correction in optical coherence tomography volumes on a per A-scan basis using orthogonal scan patterns. *Biomedical Optics Express.* 2012; **3**: 1182-1199.

[12] Rueden, CT, Schindelin, J, Hiner, MC, et al., ImageJ2: ImageJ for the next generation of scientific image data. *BMC Bioinformatics* 2017; **18:** 529. PMID 29187165, doi:10.1186/s12859-017-1934-z