Eurographics Workshop on Visual Computing for Biology and Medicine (2015)
K. Bühler, L. Linsen, and N. W. John (Editors)

Haptics-based Modelling of Pigmented Skin Lesions

A. Granados[1] J. Bryan[1] T. Abdalla[1] G. Osborne[2] and F. Bello[1]

[1]Centre for Engagement and Simulation Science, Imperial College London, Chelsea & Westminster Hospital, London, UK
[2]Dermatology, Imperial College Healthcare NHS Trust, St. Mary's Hospital, London, UK

Abstract

Dermatology is under-represented in medical undergraduate education with newly graduated doctors not being able to identify common and important skin conditions. In order to become competent in diagnosing skin lesions, it is important to encounter multiple examples of a condition, as they vary between individuals. Three popular lesions have been identified due to their importance, including nodular melanoma, seborrhoeic keratosis and cherry haemangioma. In this paper we propose a haptics-enabled learning tool for pigmented skin lesions based on haptic texturing. Geometrical modelling, skin deformation and haptics modelling are described. Results of the implementation are presented along with an initial validation study comparing the haptics-based simulator with other methods, including temporary tattoos and silicon made models.

Categories and Subject Descriptors (according to ACM CCS): I.6.5 [Simulation and Modeling]: Model Development—Modeling methodologies H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O

1. Introduction

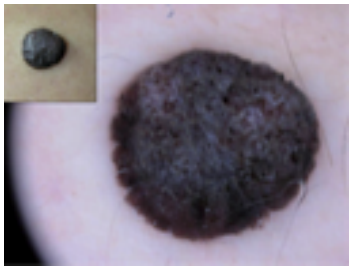
Dermatology is under-represented in medical undergraduate education [Bur02]. This leaves a significant proportion of newly graduated doctors not able to identify common and important skin conditions [AMR12]. Some of these important conditions can be rare and not encountered in a trainee's standard clinical experience. Spending long periods on a dermatology rotation has the most profound effect on the ability to identify skin lesions [ROCB15]. Less complex and less time consuming methods such as simulation produce a lower but still significant effect [CHB*11]. Models or simulation can be used to bridge the gap between exposure to these conditions and necessary competence [MOH*12, LTO*09, GHH10, JAP*13]. Temporary tattoos and moulage (special effects using cosmetics) on simulated patients are used to simulate the skin exam in entirety, including history taking [LTO*09, GHH10]. Simulation focusing solely on technical skills as with the silicon back skin models described by MacGregor et al. has also been employed [MOH*12]. In order to become competent in diagnosing skin lesions, it is important to encounter multiple examples of a condition, as they vary between individuals. This builds up pattern recognition, which is one of the most important skills in dermatology. In this respect, the aforementioned models can be limited by their lack of variation, often only showing one example of a lesion.

Similar to other clinical examinations, diagnosis of skin lesions encompasses information gained from the history such as chronology of the lesion, visual examination of colouration, organisation, relationship and placement of a lesion or lesions, and finally physical examination of texture, attachment and consistency. The importance of each of these aspects varies between each lesion. It has been identified that tactile information can significantly improve diagnostic accuracy of pigmented skin lesions [PDCW14].

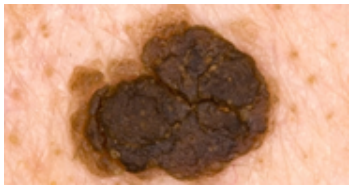
Three popular lesions have been identified as important to simulate and these are: nodular melanoma, because it is a rare subtype of malignant melanoma and often carries a high mortality and greater thickness at diagnosis [DCMG05]. Seborrhoeic keratosis, although it is common, it is also often mistaken for malignant melanoma and tactile aspects have been identified as a key part of diagnosis [PDCW14, AMA*14]. Finally, cherry haemangioma as it is a common pigmented skin lesion. We now briefly describe each in more detail.

Nodular melanoma. This would often be a dark brown-black colour and may not have a symmetrical outline. Raised

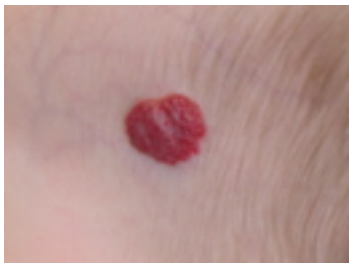
DOI: 10.2312/vcbm.20151219



(a)



(b)



(c)

Figure 1: Image samples of pigmented skin lesions: a) nodular melanoma, b) seborrhoeic wart, and c) haemangioma.

and smooth, it sometimes has a broken surface. It is less compressible than the skin around it, and there is often slight blurring where the lesion meets the skin. It usually appears as a single lesion (1cm approx. diameter and 3-4mm approx. in height) (Fig. 1a).

Seborrhoeic wart. A seborrhoeic keratosis usually appears as a brown, black or light tan growth on the face, chest, shoulders or back. The growth has a waxy, scaly, slightly elevated appearance (2-3mm approx.) with an irregular, wobbly, random outline. It normally appears with a rough, hard, warty, crusty and irregular surface and it has edges that recess in on themselves, which makes them appear "stuck on". Occasionally, it appears single, but multiple growths are more common. Seborrhoeic keratoses do not become cancerous, but they can look like skin cancer (Fig. 1b).

Haemangioma. Cherry red-purple coloured with a smooth surface and symmetrical (although not perfect). It is palpable, but not overly raised (1mm max in height). It appears as a single lesion (4-5mm approx. diameter). Pigmentation is clearly defined within the lesion itself and not blurring into the skin (Fig. 1c).

Simulation has played a crucial role in medical and surgical training during the last decade [CMJ11]. Research in virtual environments and haptics technology in medicine has brought new ways of mimicking surgical procedures, yet further research is required as to how to most adequately use these tools for learning. Haptics mainly refers to touch interactions. Haptics Rendering is analogous to Graphics Rendering and becomes necessary when interacting with virtual objects. The main goal of haptics rendering is to convey information about the object(s) (e.g. shape, weight, texture, elasticity, amongst others). This information is captured by the user's sensorial system as stimuli via the sense of touch. Therefore, the goal of haptic rendering is to enable a user to touch, feel, and manipulate virtual objects through a haptic interface, which is a small device-body robot that exchanges mechanical energy with the user.

Four methods for rendering textures via haptics are briefly described here based on the work by Otaduy et al. [OL]: a) textures on a plane, b) 3-DoF haptic rendering, c) height-field methods, and d) probabilistic methods. Initial work was done by Minsky in a 2D plane by computing forces based on the gradient of a texture height field at the location of the haptic device [Min95]. Subsequently, constraint-based methods in 3D started to model textures by controlling the position of a god-object or proxy [RKK]. Height-field methods use texture mapping techniques commonly found in computer graphics to render textures based on coarse 3D meshes that define the surface of the virtual object, and images storing displacement information (height fields), as well as normal gradient information (bump mapping), which help compute magnitude and direction of the reaction force [HBS99]. Procedural haptic texturing has been also proposed using textures generated mathematically (e.g. stochastic texture generated from noise). Lastly, probabilistic methods enhance constraint-based approaches by using statistical properties of surfaces, for example by using Gaussian distributions for generating roughness [SP96] or by dynamically modifying the coefficient of friction of a surface [PVDDJ*01]. More recent approaches use 2D images and depth information to haptically render geometry, textures and physical properties [RS11]. However, information captured by depth sensing cameras often requires enhancements to smooth out noise and interpolate missing data.

Related to haptics modelling of human skin, a single image has been used to create 3D surfaces based on a perceptual psychophysical study suggesting that different models need to be used for visual and haptics rendering due to differences in modal sensitivity [KL15]. They also take into consideration biomechanical properties of the skin from previous studies for stiffness (40 N/m) and skin friction (0.6). Applying the principles of a stochastic process, Markov/Gibbs random fields have been used on grayscale height map im-

ages to model healthy (homogeneous) skin and psoriasis skin lesions [BHY07]. However, prominent features of the human skin such as wrinkles and line-like features are heterogeneous and were not modelled successfully.

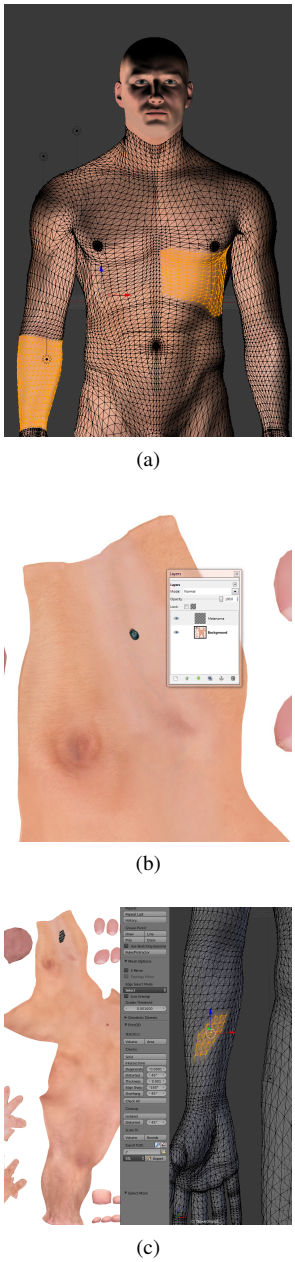
The mechanical properties of human skin have also been investigated on an arm using an electro-pneumatic pressure transducer [CCL96]. Modulus of elasticity E (stiffness) and percentage of extension ε (strain) are reported at 20mg ($E = 0.42$), 40mg ($E = 0.75$, ε = 10.2) and 100gm (ε = 15) load intensities for normal skin. However, these values depend on the direction of the load and are not representative of the anisotropic and viscoelastic properties of human skin. Finite element models have been proposed to model these properties, in particular a statistical mechanics-based constitutive model using physiological features (elastic fibres length and network collagen chain density) based on the entropy change upon stretching long-chain molecules [BAG00]. The outcome of finite element simulations concluded that the stress state of the skin is critical for an accurate model and that measures from extensometers must be taken with care when interpreting results.

In this paper we propose a haptics-enabled learning tool for pigmented skin lesions based on haptic texturing using height maps and normal maps. A haptics-based simulator has been developed considering the three important and common skin lesions discussed above, namely: a) nodular melanoma, b) seborrhoeic wart and c) symmetrical haemangioma. Contact forces are aggregated based on resulting forces due to contact with the skin and the lesion. We present geometrical, deformation and haptic models, results of our implementation, as well as results of a preliminary evaluation study comparing our simulator with other two teaching methods mentioned above.

2. Methods

2.1. Geometrical Modelling

A 3D model of the skin was used from 3DScience (www.3dscience.com) for graphics rendering ($\text{skin}_{\text{graphics}}$). Three parts of the body were extracted for haptics including the forearm, right side of the back and left thorax (Fig. 2a). These parts were also displaced a distance of maximum lesion height ($\text{skin}_{\text{haptics}}$). A pigmented skin lesion was located in each of these parts of the body and saved as an image (Fig. 2b). This image was then used to create a grayscale image and a normal map image that was sampled to find out the height of the lesion and the direction of the force due to the lesion.



(a) (b) (c)

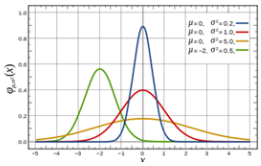
Figure 2: Geometrical modelling. a) a 3D model of the skin highlighting haptic shapes and b) texture mapping of a nodular melanoma.

2.2. Skin Deformation

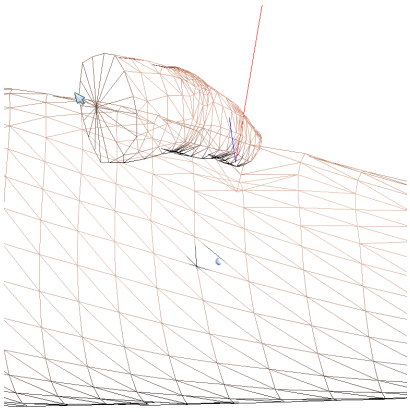
For visual purposes, the skin of the patient is deformed during palpation. The skin deforms based on a Gaussian function, with the centre of the distribution located at the position of the haptics proxy. The distance from every vertex to this centre is then used to determine which vertices need to be transformed as they lie within a pre-specified radius based on the penetration depth. If the vertex is translated, then the Gaussian function (Eq. 1 and 2) is used to estimate the amount of displacement in the direction opposite to the normal. Since skin does not deform much, a variance of 5.0 ($\sigma^2 = 5.0$) has been used (Fig. 3).

$$f(x) = a * e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (1)$$

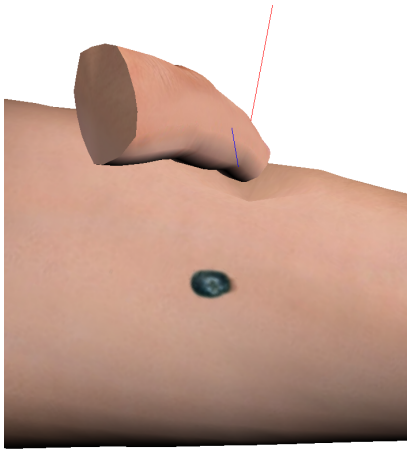
$$a = \frac{1}{\sigma\sqrt{2\pi}} \quad (2)$$



(a)



(b)



(c)

Figure 3: Skin deformation modelling. a) Different Gaussian distributions using different variances and b) and c) deformation of the skin during palpation.

2.3. Haptics Modelling

Collision detection occurs in two different stages. First, the god-object haptic rendering algorithm reports the collision of the skin modelled for haptics $\text{skin}_{\text{haptics}}$. The next stage consists of a series of steps to find out if there is actually a collision with a lesion. Contact normal $\widehat{n_c}$ is computed related to the proxy and the haptic device. Texture coordinates are then obtained based on the point of contact and a pixel is sampled from both height map and normal map images (see Table 1). A surface point x_{SP} is computed based on the height map of the lesion and a collision occurs if the position of the haptic device x_{hd} is below a plane constructed based on contact normal $\widehat{n_c}$ and surface point x_{SP}.

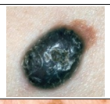
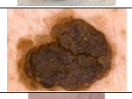
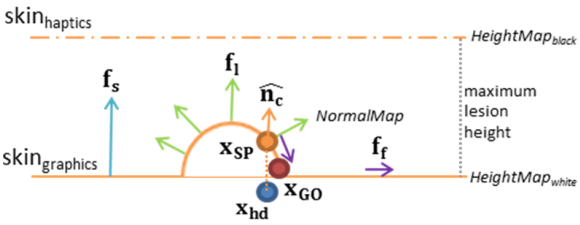
Skin Lesion	Macroscopic view	Height map	Normal map
Nodular melanoma			
Seborrhoeic wart			
Symmetrical haemangioma			

Table 1: Haptics texturing images including a height map and a normal map for each pigmented skin lesion.



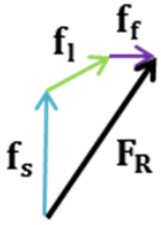


Figure 4: Reaction forces F_R are composed of a) forces due to contact with the skin f_s, b) forces due to the normal map of the lesion f_l, and c) forces due to friction f_f.

Reaction forces f_s, f_l and f_f are computed, aggregated as F_R and sent to the haptic device for feedback. Forces due to

contact with the skin f_s are computed as a spring with stiffness constant k_s between the haptic device position x_{hd} and the surface point x_{SP} (Eq. 3). Forces due to the normal map of the lesion f_l are computed as a spring with stiffness constant k_l in the direction of a vector sampled from a normal map $\widehat{n_{nm}}$ = 2*pixel-1 (Eq. 4). An empirical scaling factor of 0.01 ensures that the unit vector $\widehat{n_{nm}}$ falls within the haptic scale of 3D positions used for computing the other two force components (see Eq. 3 and 5). Forces due to friction f_f are computed as a spring with stiffness constant k_f between the previous surface point x_{GO} and the current surface point x_{SP}, with a scaling factor related to the height map sampled c_{hm} (Eq. 5).

$$f_s = k_s * (x_{SP} - x_{hd}) \tag{3}$$

$$f_l = k_l * \widehat{n_{nm}} * 0.01 \tag{4}$$

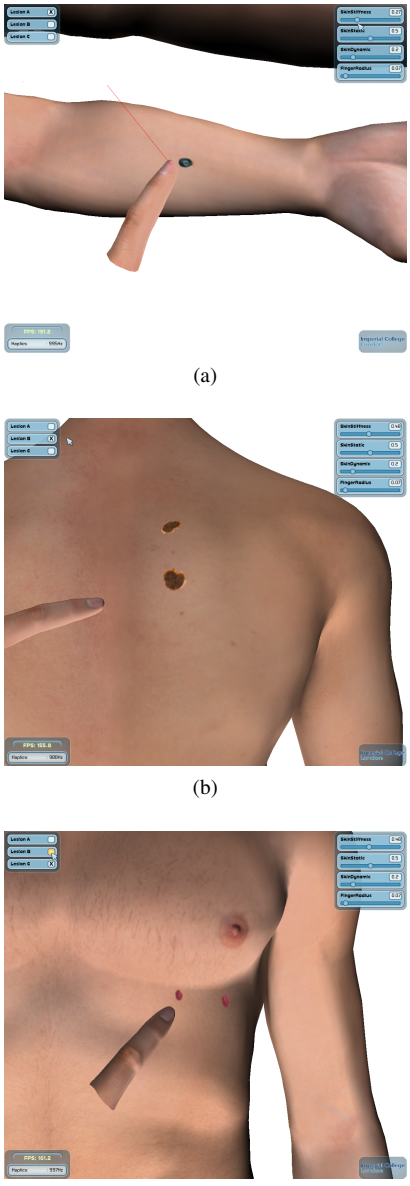
$$f_r = k_f * (1.0 - c_{hm}) * (x_{GO} - x_{SP}) \tag{5}$$

3. Model Implementation and Validation

We have integrated Ogre3d as a graphics engine and HAPI for haptics. We use a proxy-based model as haptic rendering to interact with the skin. Haptic texturing is used to model different lesions by loading height map images and normal map images generated in GIMP. A Sobel 5x5 filter with a scale of 0.5 was used to generate normal map images. A friction model based on static and dynamic friction has also been implemented. During contact, the position of the haptic device is used to sample a pixel from texture images. If a lesion is palpated, friction models and haptic rendering use information from these pixels to model the amount of deformation of the skin and to model the texture of the lesion.

The values of the stiffness constants used in Equation 1-3 (Table 2) were the result of semi-structured interviews and practical sessions with a consultant in dermatology interacting with the virtual skin lesions models (Fig. 5 and 6).

We conducted a pilot study considering these haptics-enabled models in comparison with stick-on-silicon models (Health Cuts, UK), similar to those described by Garg et al. and temporary tattoos as described by Langley et al. [LTO*09,GHH10]. Dermatologists (n=18) and dermatology registrars with over 3 years of experience (n=6) were recruited from St. Mary's Hospital, London and from a dermatology meeting at the Royal Society of Medicine. They were asked to complete a questionnaire on the perceived realism of the simulation modalities. Participants had to gauge their agreement (on a 5-point Likert scale, 1 being strongly disagree and 5 being strongly agree) to the statement *"this accurately simulates a real lesion"* for visual and tactile domains separately, and for each of the three simulations. We found no significant difference in perception of realism in the visual domain between any of the simulators (median=4). However, the dermatologists admitted the silicon models were the most realistic in tactile domains (median=4) and there was no significant difference between the computer model and the temporary tattoos (median=3).



(a) (b) (c)

Figure 5: Three different lesions at different locations on the body: a) nodular melanoma on arm, b) seborrhoeic wart on back, and c) symmetrical haemanigioma below chest.

Figure 6: Haptics-based simulator for pigmented skin lesions using a SensAble Premium haptic device.

Skin Lesion	Location	k_s	k_l	k_f	u_s	u_d
Nodular melanoma	Forearm	0.33	0.21	0.07	0.12	0.11
Seborrhoeic wart	Back	0.34	0.09	0.18	0.22	0.16
Symmetrical haeman-gioma	Thorax	0.18	0.09	0.0	-	-

Table 2: Skin (k_s), lesion (k_l) and friction (k_f) stiffness constants as well as static (u_s) and dynamic (u_d) friction coefficients chosen for haptics modelling of pigmented skin lesions.

4. Discussion and Conclusions

An ideal model would simulate all three aspects of the diagnosis of skin lesions: historical, visual and tactile. However, the procedure can be broken down into history and examination, and therefore simulation can also be broken down. We focussed on the examination of pigmented skin lesions in isolation. It must be recognised that, in the context of a patient, simulated or otherwise, the skills needed may have to be modified accordingly. The importance of this so called "hybrid simulation" has been highlighted in work by Kneebone et al. [KNY*06, KNW*06]. Nevertheless, skills learnt from a more simple simulation (e.g. technical skills or diagnosis) may also be applied to a complex setting that includes patient interaction. The patient limits the complexity of this type of simulation fundamentally as models need to be applied to the skin. This means that lesions with presence under the skin cannot be simulated effectively. Models applied to a simulated patients skin can't be varied easily in order to build up pattern recognition and often need a skilled individual to apply them.

The haptics-enabled model theoretically overcomes the aforementioned shortcomings. It does this by allowing simulation of many lesions in a short time frame and being able to simulate tactile elements below the surface of the skin. However, the perceptions of participants related to the current haptics-based simulator prototype were similar to the temporary tattoos and less realistic in terms of tactile feedback than stick-on-silicon models. Our simulator only renders force feedback and not tactile feedback and therefore those pigmented lesions smaller than the fingertip scale were more difficult to perceive. Participants were also expecting tactile feedback when they inserted their index finger into the thimble of the haptic device, which may have affected the experience of the users.

In spite of the shortcomings of the present implementation, we found haptic texturing to be a flexible method that is able to generate a diverse range of lesions based on images commonly found in the literature. This allowed us to start modelling force feedback based on the contact with the skin, the height of the lesion via grayscale images, rendering force based on normal maps from images, and aggregating forces related to friction. Our method focuses on the modelling of the lesions rather than the geometrical properties of the body. Therefore, generic 3D models of the body are used instead of extracting geometrical properties from depth information. Although simple, our skin deformation model based on Gaussian distribution was sufficient for providing visual cues during palpation.

5. Future Work

Results from our evaluation study suggest that the visual aspects of the proposed learning tool could be improved. To address these, our system is currently being migrated to Unreal Engine 4 in order to improve visual rendering. We are now employing subsurface scattering techniques to add realism to the skin surface texture.

We will investigate how biomechanical properties of the skin [CCL96] can better inform the computation of reaction forces and skin deformation, as well as explore the use of a more accurate deformation model of the skin based on finite element methods, which should not only improve the visual aspects of the deforming skin, but also its mechanical behaviour.

Future work also includes further studies and characterisation of forces that would be investigated through the use of pressure sensors while palpating these types of lesions on real patients. These experiments will allow us to quantitatively validate our haptic models against these force profiles. Experimentation with tactile feedback and customised finger-scale end effectors will enhance the perception of the lesions. Lastly, we will explore the design of a learning tool that will assist graduate medical students by generating a series of scenarios with different levels of complexity.

References

[AMA*14] ARGENZIANO G., MOSCARELLA E., ANNETTA A., BATTARRA V., BRUNETTI B., BULIGAN C., CANTISANI C., CAPIZZI R., CARBONE A., CARLINO A., CORSETTI V., DAMIANO A., DE SALVO V., DE SIMONE P., DI CATERINO P., FARGNOLI M., FERRARI A., FOSSATI B., FRASCIONE P., GHIGLIOTTI G., GONZÃALEZ INCHAURRAGA M., GUERRIERO C., LANDI C., MAZZONI L., MIRIZZI S., PALAZZO G., PEDRETTI A., PERIS K., PIEMONTE P., ROSSI A., SATTA R., SAVOIA F., SCALVENZI M., STANGANELLI I., STINCO G., ZAMPIERI P., ZALAUDEK I.: Melanoma detection in italian pigmented lesion clinics. *Giornaleitaliano di dermatologia e venereologia :organoufficiale, Societaitaliana di dermatologia e sifilografia 149*, 2 (2014), 161–166. 1

[AMR12] ALDRIDGE R., MAXWELL S., REES J.: Dermatology undergraduate skin cancer training: a disconnect between recommendations, clinical exposure and competence. *BMC medical education 12*, 27 (2012), 1–9. doi:10.1186/1472-6920-12-27. 1

[BAG00] BISCHOFF J., ARRUDA E., GROSH K.: Finite element modeling of human skin using an isotropic, nonlinear elastic constitutive model. *Journal of Biomechanics 33* (2000), 645–652. 3

[BHY07] BATOOL N.-E., HANI A., YAP V.: Markov-gibbs random field modeling of 3d skin surface textures for haptic applications. *ICCSA 4706*, 2 (2007), 694–705. 3

[Bur02] BURGE S.: Teaching dermatology to medical students: a survey of current practice in the uk. *British Journal of Dermatology 146*, 2 (2002), 295–303. 1

[CCL96] CLARK J., CHENG C., LEUNG K.: Mechanical properties of normal skin and hypertrophic scars. *Burns 22*, 6 (1996), 443–443. 3, 6

[CHB*11] COOK D., HATALA R., BRYDGES R., ZENDEJAS B., SZOSTEK J., WANG A., ERWIN P., HAMSTRA S.: Technology-enhanced simulation for health professions education: a systematic review and meta-analysis. *JAMA 306*, 9 (2011), 978–988. 1

[CMJ11] COLES T., MEGLAN D., JOHN N.: The role of haptics in medical training simulators: A survey of the state of the art. *IEEE Transactions on Haptics 4*, 1 (2011), 51–66. 2

[DCMG05] DEMIERRE M., CHUNG C., MILLER D., GELLER A.: Early detection of thick melanomas in the us: beware of the nodular subtype. *Archives of Dermatology 141*, 6 (2005), 745–750. 1

[GHH10] GARG A., HALEY H., HATEM D.: Modern moulage: evaluating the use of 3-dimensional prosthetic mimics in a dermatology teaching program for second-year medical students. *Archives of Dermatology 146*, 2 (2010), 143–146. 1, 5

[HBS99] HO C.-H., BASDOGAN C., SRINIVASAN M.: Efficient point-based rendering techniques for haptic display of virtual objects. *Presence 8*, 5 (1999), 477–491. 2

[JAP*13] JAIN N., ANDERSON M., PATEL P., BLATT H., DAVIS L., BIERMAN J., MCGAGHIE W., BRUCKER J., MARTINI M., ROBINSON J.: Melanoma simulation model: promoting opportunistic screening and patient counseling. *JAMA Dermatology 149*, 6 (2013), 710–716. 1

[KL15] KIM K., LEE S.: Perception-based 3d tactile rendering from a single image for human skin examinations by dynamic touch. *Skin Research and Technology 21* (2015), 164–174. 2

[KNW*06] KNEEBONE R., NESTEL D., WETZEL C., BLACK S., JACKLIN R., AGGARWAL R., YADOLLAHI F., WOLFE J., VINCENT C., DARZI A.: The human face of simulation: patient-focused simulation training. *Academic Medicine : Journal of the Association of American Medical Colleges 81*, 10 (2006), 919–924. 6

[KNY*06] KNEEBONE R., NESTEL D., YADOLLAHI F., BROWN R., NOLAN C., DURACK J., BRENTON H., MOULTON C., ARCHER J., DARZI A.: Assessing procedural skills in context: exploring the feasibility of an integrated procedural performance instrument (ippi). *Medical Education 40*, 11 (2006), 1105–1114. 6

[LTO*09] LANGLEY R., TYLER S., ORNSTEIN A., SUTHERLAND A., MOSHER L.: Temporary tattoos to simulate skin disease: report and validation of a novel teaching tool. *Academic medicine : journal of the Association of American Medical Colleges 84*, 7 (2009), 950–953. 1, 5

[Min95] MINSKY M.: *The Sandpaper System for Synthesizing Texture for a Force-Feedback Device*. PhD thesis, MIT, 1995. 2

[MOH*12] MACGREGOR C., O'DONNEL M., HALEY A., MARTINI M., ROBINSON J., VOZENILEK J.: Melanoma trainer using simulated back skin: an innovative design. *Simulation in Healthcare: Journal of the Society for Simulation in Healthcare 7*, 4 (2012), 251–254. 1

[OL] OTADUY M., LIN M.: Introduction to haptic rendering. recent advances in haptic rendering and applications. In *ACM SIGGRAPH 2005 Courses*. 2

[PDCW14] PUNJ P., DEVITT P., COVENTRY B., WHITFIELD R.: Palpation as a useful diagnostic tool for skin lesions. *Journal of Plastic, Reconstructive and Aesthetic Surgery 67*, 6 (2014), 804–807. 1

[PVDDJ*01] PAI D., VAN DEN DOEL K., JAMES D., LANG J., LLOYD J., RICHMOND J., YAU S.: Scanning physical interaction behaviour of 3d objects. *SIGGRAPH* (2001). 2

[RKK] RUSPINI D., KOLAROV K., KHATIB O.: The haptic display of complex graphical environments. In *SIGGRAPH*. 2

[ROCB15] ROURKE L., OBERHOLTZER S., CHATTERLEY T., BRASSARD A.: Learning to detect, categorize, and identify skin lesions: a meta-analysis. *JAMA Dermatology 151*, 3 (2015), 293–301. 1

[RS11] RASOOL S., SOURIN A.: Haptic interaction with 2d images. *VRCAI* (2011), 13–22. 2

[SP96] SIIRA J., PAI D.: Haptic texturing - a stochastic approach. *International Conference on Robotics and Automation* (1996), 557–562. 2