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Thermal Imaging in Early Detection of Surgical Site Infections in Orthopaedics

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Abstract:
Surgical site infection is one of the most common complication faced by surgeons in postoperative patients. Infrared thermography measures the temperature of the surgical wound non-invasively. The aim of this study is to provide early diagnosis of surgical site infection in post-operative patients by using Infrared Thermal imaging when compared to clinical diagnosis. To evaluate the accuracy of this technique new thermographic variables are added to those commonly analysed such as the difference of temperature between non-infective and infective area.

MATERIALS AND METHODS:
Prospective study was conducted between 2019 and 2020 at Dr. PSIMS & RF for diagnosing surgical site infection in post-operative patients in Orthopaedics ward from POD-1 to POD-20 at the time of wound dressing and patient visits with the help of "SEEK Thermal" camera and IOS mobile phone in normal room temperature.

RESULTS:
About forty adult post-operative patients in orthopaedic ward aged between 21 -90 years were observed. Surgical Site Infection rate (within 20 days) was 10%. Two regions of interest were observed; Surgical wound site and juxta surgical site. The difference between the sites was significantly associated with odds of infection with about 2^oC widening in temperature associated with Surgical Site Infection.

CONCLUSION:
Infrared thermal imaging of surgical wound site in postoperative patients in orthopaedics ward provides better information when compared to visual wound assessment done by doctor. The temperature difference noted by thermal imaging camera of surgical site and its surroundings makes thermal imaging as a good surgical site infection prognostic tool.

Keywords: *Surgical Site Infection, Infrared thermal image, Post Operative Day (POD)*

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I. Introduction

Necessity of thermal imaging:

- New ways to study wounds and underlying tissue metabolism noninvasively[1], effectively, accurately and rapidly are required.
- As a diagnostic tool for early diagnosis[2] and better management
- For evaluating good time for optimal treatment

As a prognostic and diagnostic tool for febrile conditions, Infection, Wound-healing, Graft uptake, Circulation impairments, Raynauds/peripheral vascular diseases, identification of hot and cold nodules, cellulitis, Acute Arthritic conditions and Re-implantation surgeries.

The purpose of blood circulation is Transportation of oxygen, waste products, nutrients and to convey heat thus acting as a part of thermoregulation[1]. *Hippocrates* wrote aptly, *'In whatever part of the body excess of heat or cold is felt, the disease is there to be discovered'*[1]. Body surface temperature and its infrared radiation correlates to the blood flow volume to the part and the temperature of limbs depend on the peripheral blood volume[1,2,9]. The changed body surface temperature may be an indication of infection, deep inflammation or

repetitive trauma[10,11]. Skin temperature correlates directly to the physiologic processes of circulation and underlying metabolic activity. In medical practice, the inspection of a wound is mainly based on the visual evaluation by the physician. There are no standardized instruments to evaluate the moisture of a wound, the swelling of the surrounding healthy tissue or the colour or the amount of the granulation tissue in the wound or the temperature of the wound[1]. Infrared thermometry has an advantage over the traditional assessment tools[1]. In wound healing, thermal imaging may give systematic extra information about the amount of tissue involved, the edges of a wound, the level of infection and moisture of the wound[1]. Thermal imaging has been used on dermatological diseases, In patients with diabetes mellitus having foot ulceration, inflammatory state studies and to diagnose arthritis[2,11,12]. It has been used in the screening of fever, to detect vascular disorders in diabetic subjects, in arterial blood pressure monitoring and in the diagnosis of rheumatic diseases[2]. SSI (surgical site infections) attracts attention from national and international organizations with publications for guidelines on prevention and consensus for best practice[3]. Obesity emerges consistently as a significant risk factor for SSI. Currently there is no wound imaging diagnostic available in clinical practice. Inaccurate and untimely diagnosis of wound infection often complicates treatment and increases the cost of care. Typically, diagnosis of infection and inflammation is based on the presence of the classic signs: rubor, calor, dolor, tumor, and functio laeso (redness, heat detected by palpation, pain, swelling, and loss of function)[4]. When infection is suspected by a clinician, investigations like cultures, biopsies, and radiographs can be ordered, and then the treatment can be initiated; however, these tests can be painful, time consuming, and expensive.

In 2015, the Institute of Medicine underscored the need to reduce diagnostic error, challenging the medical community to decrease the rate of delayed or inaccurate diagnosis. To address this pressing need, researchers sought to determine whether thermography would be useful in obtaining objective data for assessing, screening for, and/or diagnosing wound infections.

Long wave infrared Thermometer (LWIT) can measure radiant heat from a body surface and has been accepted as a valuable adjunct to standard investigations in the early detection of inflammation and infection[4].

Previous studies have demonstrated that thermography has been safely used on humans and animals as a non-invasive method for measuring changes in body surface temperature resulting from a number of conditions, including physiologic and pathologic (infection and inflammation).

Thermographic images showing an elevated temperature pattern of $1.2^{o}C$ may be predictive for impending pressure injuries 24 to 96 hours prior to their appearance on the skin. These studies suggest that thermography can play an important role in screening and early detection of wound and soft tissue infection[4]. Thermography is also sensitive in detecting prosthetic knee infection, osteoarthritis, active rheumatoid arthritis, septic arthritis, sports injuries, osteomyelitis, inflammation, abscesses, wound infections, and even deep tissue pressure injury/ impending bed sores.

Thermal energy is produced when a rise in temperature causes atoms and molecules to move faster and collide with each other. The energy that comes from the temperature of the heated substance is called "Thermal *energy"* which is emitted in the form of infrared radiation which is not visible to naked eye but can be recorded through specialized instruments.

The objective of this study to detect the role of thermal imaging in early detection of surgical site infection in postoperative patients using "*SEEK Thermal"* Camera with IOS mobile phone.

II. Materials And Methods

Subjects signed informed consent for imaging.

Inflammation group if they had warmth, edema, and swelling but lacked signs of infection such as purulent drainage, delayed wound healing, pyrexia, and abscess. Thermal 'mapping' was conducted during the SSI surveillance period as wound infection occurring within 20 days after surgery. The pictures were taken in freehand having a close distance from the limb.

INCLUSION CRITERIA

- Clean surgical wounds in post-operative patients of various procedures in Orthopaedics ward.
- All adults between 21-90 years.

EXCLUSION CRITERIA

- Peak summers where surrounding temperature is identical to temperature of the part examined.
- Using spirit/ liquids for cleaning the surface before recording
- Continuously soaked wounds
- Highly Contaminated wounds / Compound fractures
- Already known infected patient
- Paediatric Age group

INSTRUMENTS

1) "SEEK THERMAL" CAMERA OR SEEK INFRARED CAMERA:

SEEK Infrared camera is a 3rd generation Thermal detector that reads wave length of 7 to 14 micrometres of infrared radiation[6]. It is a smart phone based compact camera which is suitable with IOS and Android mobile phones.

HOW CAMERA WORKS???

Thermal cameras detect temperature by recognizing and capturing different levels of **infrared** radiation emitted by the subject. This radiation is invisible to the naked eye, but can be felt as heat if the intensity is high enough. All the objects above 0^{o} Kelvin emit some **infrared** radiation depending upon their temperature[5], and it is the Radiation method of heat transfer (Conduction, Convection and Radiation).

ADDITIVE ADVANTAGES OF CAMERA:

Comparing thermal image and normal image side by side.

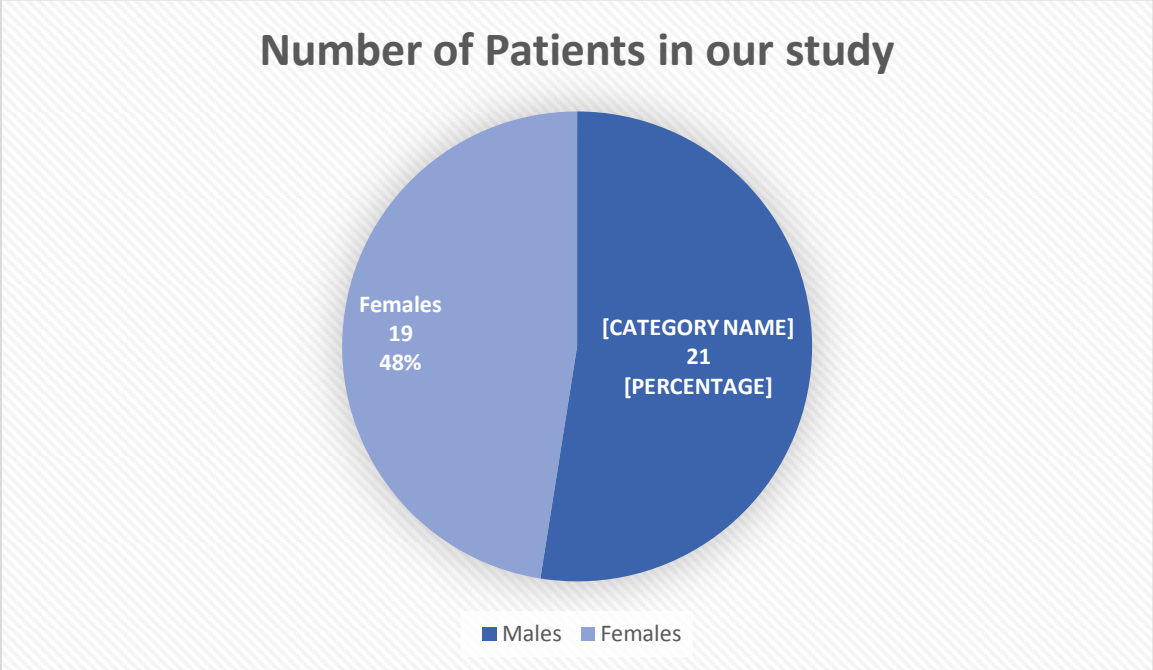
Different templates providing different colour codings for different temperatures.

Measurement of temperature at a particular point of study.

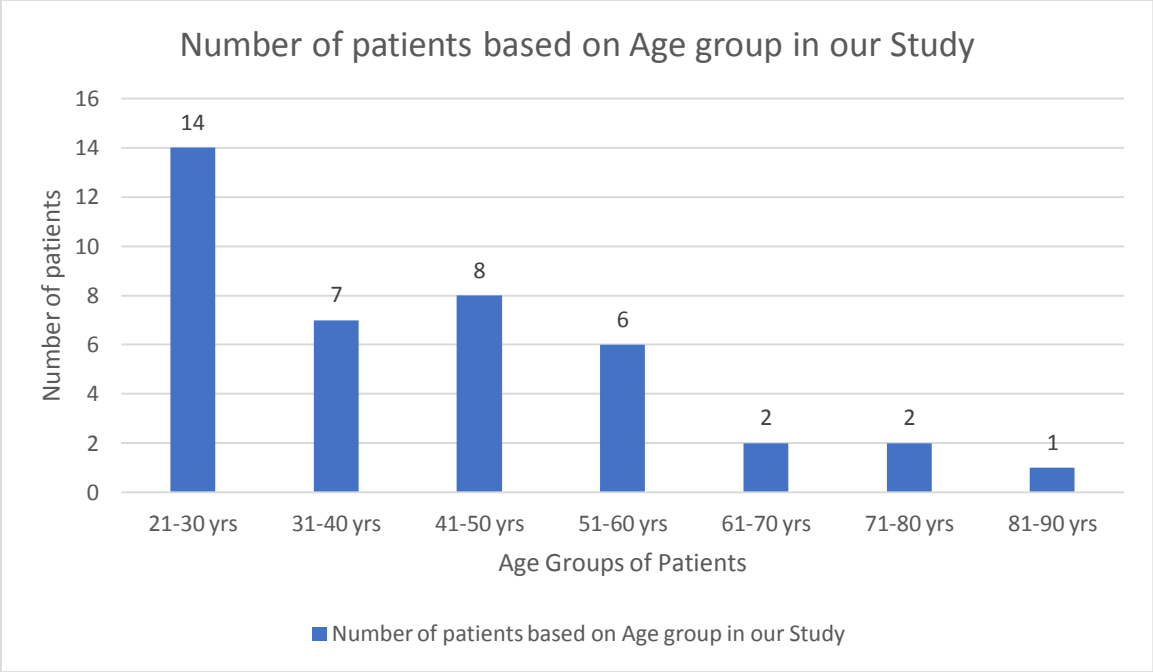
2) IOS MOBILE PHONE: We installed SEEK thermal camera app and related software in our IOS mobile phone. Now we can save all our Thermal images in our IOS mobile phone.

III. Results

About 40 post-operative patients were observed between age group of 21 to 90 years in Orthopaedics Department of Dr. PSIMS and RF. Among 40 patients, 21 patients were male and 19 patients were female (mentioned in pie chart).



In our study max number of patients were of age group 21 to 30 years whose number where 14 out of 40 patients (mentioned in below Bar Chart). The etiology of most of the patients in our study were Trauma.



Based on data mentioned in below Table 1 and 2, About 4 patients were infected and had high temperature difference of about 2°C between surgical wound site and surrounding region of Surgical wound site. SSI rate (within 20 days) was 10%. Two regions of interest were observed; surgical wound site and surrounding region of surgical site. The maximum temperature difference between the sites was significantly associated with odds of infection with a 1.9°C to 2.2°C widening in temperature associated with SSI. After Significant temperature difference of surgical wound and surrounding skin was observed with 'SEEK THERMAL' Camera, Culture and Sensitivity of wound was sent. Staphylococcus Aureus was the Most common organism identified in our Study.

S.No.	Age of Patients	Gender	Comorbidities	Site or Region of Post-operative wound	Maximum temperature difference(°C) between Surgical wound and surrounding site between POD 1 to POD 20
1	44	F	-	Right shoulder	1°C
2	27	M	-	Right Thigh	1°C
3	59	F	DM	Left Knee	2°C
4	22	M	-	Right Hand	0.8°C
5	60	F	DM	Left Hip	1.1°C
6	55	F	-	Right leg	0.8°C
7	26	F	-	Right Arm	0.9°C
8	22	F	-	Left Thigh	1°C
9	52	F	-	Right Thumb	0.7°C
10	25	M	-	Left Knee	0.9°C
11	31	M	-	Right Knee	1°C
12	58	M	DM	Right Leg	2.2°C
13	21	F	RA	Right Hip	1°C
14	21	M	-	Right Leg	0.9°C
15	26	M	-	Right Wrist	0.9°C
16	45	F	-	Right Knee	0.9°C
17	42	M	-	Right Heel	0.8°C
18	49	F	-	Left Wrist	0.8°C
19	62	F	DM	Right Leg	0.9°C
20	29	M	-	Right Wrist	0.9°C
21	85	F	HTN	Right Hip	1°C
22	43	M	-	Right Leg	0.8°C
23	45	F	-	Left Wrist	0.9°C
24	40	F	-	Right Wrist	0.8°C
25	35	F	-	Right Wrist	0.8°C
26	30	M	-	Left Leg	0.9°C
27	39	M	-	Right Knee	0.9°C
28	46	M	-	Right Hip	1°C
29	75	F	HTN	Left Hip	1°C

30	25	M	-	Left Index Finger	0.8°C
31	37	F	DM	Left Hip	1°C
32	21	M	-	Right Shoulder	1°C
33	62	M	HTN	Left Arm	1°C
34	40	M	-	Left Heel	0.8°C
35	21	M	-	Right Forearm	1°C
36	60	M	DM	Right Hip	0.8°C
37	26	M	-	Left Thigh	1°C
38	45	F	DM	Right Ankle	2°C
39	40	M	DM	Right Ankle	1.9°C
40	78	F	HTN	Left Hip	0.9°C

TABLE-2

S.NO.	AGE	GENDER	POD-1			POD-3			POD-7			POD-10			POD-14			POD-20		
			TD	O1	O2	TD	O1	O2	TD	O1	O2	TD	O1	O2	TD	O1	O2	TD	O1	O2
1	44	F	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N
2	27	M	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N
3	59	F	1°C	N	N	2°C	N	N	2°C	R	R, S	1.7°C	N	N	1.2°C	N	N	1°C	N	N
4	22	M	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N
5	60	F	1.1°C	N	N	1.1°C	N	N	1.1°C	N	N	1.1°C	N	N	1°C	N	N	1°C	N	N
6	55	F	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N
7	26	F	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N
8	22	F	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N
9	52	F	0.7°C	N	N	0.7°C	N	N	0.7°C	N	N	0.7°C	N	N	0.7°C	N	N	0.7°C	N	N
10	25	M	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N
11	31	M	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N
12	58	M	1°C	N	N	2°C	N	N	2.2°C	R, S	R	2°C	R	R	1.3°C	N	N	2.2°C	N	N
13	21	F	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N
14	21	M	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N
15	26	M	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N
16	45	F	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N
17	42	M	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N
18	49	F	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N
19	62	F	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N
20	29	M	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N
21	85	F	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N
22	43	M	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N
23	45	F	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N
24	40	F	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N
25	35	F	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N
26	30	M	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N
27	39	M	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N
28	46	M	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N
29	75	F	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N

30	25	M	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N
31	37	F	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N
32	21	M	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N
33	62	M	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N
34	40	M	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N
35	21	M	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N
36	60	M	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N	0.8°C	N	N
37	26	M	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N	1°C	N	N
38	45	F	1°C	N	N	1.9°C	N	N	2°C	R	R	2°C	R	R	1.4°C	N	N	1°C	N	N
39	40	M	0.9°C	N	N	1.8°C	N	N	1.9°C	R	R, S	1.9°C	R	R, S	1.3°C	N	N	1°C	N	N
40	78	F	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N	0.9°C	N	N

ABBREVIATIONS OF TABLE 2

N-NORMAL, S-SWELLING, R-REDNESS, O1-OBSERVER1, O2-OBSERVER2, TD-TEMPERATURE DIFFERENCE BY 'SEEK THERMAL' CAMERA, M-MALE, F-FEMALE

IV. Discussion

"SEEK Thermal" Camera reads Long Wave Infrared Radiations.

Advantages of LWIT can be attributed to Planck's law and the second law of thermodynamics. "**Planck's law**" simply stated is that the intensity of radiation emitted from an object is a function of its temperature, wavelength, and emissivity. Thermographic cameras generate images based on the amount of heat dissipated from the human skin surface in the form of electromagnetic radiation[4,7.] Human skin has an *emissivity factor of 0.98,* making it a nearly perfect emitter of infrared radiation at room temperature. According to Planck's law, the electromagnetic radiation from the skin surface is a reflection of heat generation from below the surface. "Hot goes to cold," reflecting the effect of mean temperature (T_{mean}) as a summation indicator of the heat production of contiguous areas. Thus, radiation from the skin reflects thermal activity of the skin itself and the heat generation that occurs below the surface. Scout device detectors/thermal imaging cameras can capture longer wave infrared emissions 8 to 14 micrometer range. It can detect sub-epidermal thermal activity with more accuracy and therefore support a clinician's ability to confirm the presence of infection.

In our study about 4 patients out of 40 patients were prone to Surgical Site Infection. All the patients who were prone to SSI suffered from Diabetic Mellitus. The total number of Diabetic patients in our study group were 8. Another interesting point was 3 out of 4 patients who suffered from SSI were obese. Hence based on our study we concluded that Obese and Diabetic Patients were easily prone to SSI. Similar results were observed in "Childs et al" study of Infrared imaging in obese patients who underwent caesarean section in 2019.

Consistent increase in wound site temperature of approximately 1.5 °C was evident. This increase in wound temperature fits well with the long-held observation of a local increase in blood flow consequent upon local tissue inflammation.

A new observation that the temperature of the tissue adjacent to the wound site may play a more important role in risk for SSI and one possible explanation as to the link between obesity as a biological risk factor for SSI.

'Post-antibiotic era', concerns about a crisis in antibiotic resistance, attributed to the overuse of antibiotics, makes the need for rational antibiotic prescribing. Swab results per se are not diagnostic of infection; bacterial load virulence and host factors all play a role in eventual susceptibility to infection.

Second law of thermodynamics states that when bodies initially in thermal disequilibrium are put into contact with one another, a new thermal equilibrium is achieved & it explains the dissipation of energy in the form of heat.

The benefit of the infrared thermography is, that it offers the real time temperature visualization on the body surface, is **non-invasive, cheap, fast, non-contact** (does not effect /alter the surface temperature) and **easy to use**. Thermal imaging may be used to study skin wounds which are situated in the superficial skin layers or Grafted Skin in which progressive inflammation due to increased blood flow might be more visibly observed via thermal pictures. Thermal image may give a hint of the areas of sufficient blood flow during tissue debridement. It may also help in evaluating the amount of circulation in deeper tissue.

Bedsores due to prolonged immobilization, work limitation in the muscles and the disturbance in the circulation of blood of the patient could possibly be found with a thermal camera. In a Study done by "Joseph Hardwicke et al" FLIR (similar to seek thermal) devices have been used to identify perfusion in perforator

vessels (and imaging of extremity perfusion), assessment of inflammation evaluation in diabetic foot and pressure ulcers[8]. In nursing the thermal borders from limbs and from the whole body is usually obtained with thermometers or through hand needing contact or touching the skin. Infrared energy is dependent upon radiation energy emitted from the skin (which is proportional to heat generated) but invisible to normal human eye. With modern thermal cameras it is possible to 'see' infrared energy as a temperature map together with absolute values for temperature given appropriate corrections for skin emissivity.

V. Conclusion

Infrared thermal imaging of surgical wound site in postoperative patients in orthopaedics ward using SEEK Thermal Camera is better than visual wound evaluation by Physician. Moreover, the proportion of cases classified using surgical wound site and surrounding tissue temperature difference holds promise for precision and performance of Infrared Thermal imaging as an important surgical site infection prognostic tool especially on bedside and Clinical OP.

References

[1]. Jarmo Alamesta, Markku Oikarainen, Jarmo Perttunen Jari Viik, Annikki Vaalasti. Thermal imaging in skin trauma evaluation by CAT S60 mobile phone. Finnish Journal of eHealth and eWelfare. 2018;10(2-3):192-199
[2]. Fangge Deng, Qing Tang, Yujiang Zheng, Quangqiao Zong, Nanshan Zhong. Infrared thermal imaging as a novel evaluation method for deep vein thrombosis in lower limbs. Medical Physics. 2012;39(12):7224-7231
[3]. Charmaine Childs, Nicola Wright, Jon Willmott, Matthew Davies et al. The surgical wound in infrared: thermographic profiles and early stage test- accuracy to predict surgical site infection in obese women during the first 30 days after caesarean section. Antimicrobial Resistance and Infection Control. 2019;8(7):1-15
[4]. Arjun Chanmugam et al. Relative temperature Maximum in Wound Infection and Inflammation as Compared with a Control Subject Using Long-Wave Infrared Thermography. Advances in skin and wound care. 2017;30(9):406-414
[5]. Ruben Usamentiaga et al. Infrared Thermography for Temperature Measurement and Non-Destructive Testing. Sensors. 2014;14: 12305-12348 doi:10.3390/s140712305
[6]. Kirimtat et al. FLIR vs SEEK thermal cameras in biomedicine: comparative diagnosis through infrared thermography. BMC Bioinformatics. 2020;21(88):1-10 https://doi.org/10.1186/s12859-020-3355-7
[7]. Planck M. The theory of heat radiation. P. Blakiston Son and Co 1914. Dover publications New York. 2011
[8]. Joseph Hardwicke, Omer Ahmed Osmani, Joanna M Skillman. Detection of Perforators Using Smartphone Thermal Imaging. Plastic and Reconstruction Surgery. 2015;137(1):39-41
[9]. Deng F, Tang Q, Zheng Y, Zeng G, Zhong N. Infrared thermal imaging as a novel evaluation method for deep vein thrombosis in lower limbs. Medical Physics. 2012;39(12):7224-7231
[10]. Mufti A, Coutts P, Sibbald RG. Validation of commercially available infrared thermometers for measuring skin surface temperature associated with deep and surrounding wound infection. Advances in skin and Wound Care. 2015;28(1):11-16
[11]. Adam M, Nq EYK, Tan JH, Henq ML, Tong JWK, Acharya UR. Computer aided diagnosis of diabetic foot using infrared thermography: A review. Computers in Biology and Medicine. 2017;91:326-336
[12]. Cholewka A, Stanek A, Klimas A, Sieron A, Drzazga Z. Thermal imaging application in chronic venous disease. Pilot Study. Journal of Thermal Analysis and Calorimetry. 2014;115(2):1609-1618

Dr. N. Krishna Prasad, et. al. "Thermal Imaging in Early Detection of Surgical Site Infections in Orthopaedics." *IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)*, 20(10), 2021, pp. 14-19.