applying a set of weights to each of the SEM delta values of the first and second set of obtained SEM delta values; d) for each patient in the first and second plurality of patients, i) calculating a first average SEM delta value of the N least-recent weighted SEM delta values in the set of SEM delta values; ii) calculating a second average SEM delta value of the M most-recent weighted SEM delta values in the set of SEM delta values; iii) calculating a difference value between the first average and the second average SEM delta value; and iv) comparing the difference between the first average and the second average SEM delta value with a threshold value; e) creating a training set comprising a first set of difference values in the first plurality of patients and a second set of difference values in the second plurality of patients; and f) training the neural network using the training set. In an embodiment, the trained neural network outputs a) a set of optimized weights, comprising an optimized weight for each timepoint before the formation of a DTI, where the optimized weights monotonically increase with time; b) an optimized threshold; c) the value of N; and d) the value of M. In an embodiment, the predetermined frequency is once a day. In an embodiment, the first and second set of SEM delta values comprises at least six SEM delta values each taken one day apart. In an embodiment, N + M = 6. In an embodiment, N = 4 and M = 2. In an embodiment, the location on the patient's skin is selected from the group consisting of the back of the head, the sacrum, the shoulder, the elbow, the lower back, the tailbone, the buttock, the hip, the inner knee, the heel, and a combination thereof. In an embodiment, the set of optimized weights and the optimized threshold are used to predict the occurrence of deep tissue injury.

A first aspect of the present disclosure provides a computer-implemented method for predicting deep tissue injury (DTI) in a patient, the method including: receiving, via an input device, a plurality of sub-epidermal moisture (SEM) delta values associated with the patient; automatically inputting, via a processor, the plurality of SEM delta values into a trained model, wherein the trained model is configured to calculate a probability value corresponding to the likelihood of the patient developing DTI; and wherein the trained model is trained by performing the steps comprising: receiving a set of training data comprising: a plurality of SEM delta values associated with a set of patients, wherein each patient in the set of patients has a known DTI status, and a threshold value, wherein the threshold value is a number between 0 and 1; automatically inputting the training data into an optimization algorithm to receive a plurality of optimal weight values; and iii) automatically updating the trained model with the plurality of optimal weight values; and outputting, via an output device, a prediction of the likelihood of the patient developing DTI based on the probability value.

In an embodiment, training the model comprises the steps of: receiving, via an input device, a set of training data comprising: 1) a plurality of sub-epidermal moisture (SEM) delta values associated with a set of patients, and 2) a threshold value, where each patient in the set of patients has a known deep tissue injury (DTI) status, where the threshold value is a number between 0 and 1; automatically inputting, via a processor, the training data into an optimization algorithm to receive a plurality of optimal weight values; and automatically updating, via a processor, the model with the plurality of optimal weight values. In an

embodiment, the optimization algorithm is configured to: generate a plurality of increasing random numbers between 0 and 2 as a plurality of weight values; input the training data and the plurality of weight values into the model to receive a set of predicted deep tissue injury (DTI) statuses associated with the set of patients; compare the predicted DTI statuses with the known DTI statuses associated with the set of patients; calculate a true positive rate (TPR) and a false positive rate (FPR) based on the comparison, where the TPR is calculated as percentage of patients in the set of patients whose predicted DTI status matches their known DTI status, and the FPR is calculated as percentage of patients in the set of patients whose predicted DTI status does not match their known DTI status; repeat steps a) to d) for a predetermined number of times as the number of iterations; identify optimal TPR and FPR from all calculated TPRs and FPRs from the iterations; and output the plurality of optimal weight values associated with the identified optimal TPR and FPR. In an embodiment, the plurality of SEM delta values comprises the SEM delta readings from a predetermined number of days before the day of predicting deep tissue injury (DTI). In an embodiment, identifying optimal TPR and FPR comprises minimizing the objective function of 1-TPR+FPR and satisfying the constraint of TPR>>FPR. In an embodiment, the input device is a SEM scanner. In an embodiment, the SEM scanner is connected to a computer by cable or by wireless technology. In an embodiment, the DTI occurs at a location selected from the group consisting of the back of the head, the sacrum, the shoulder, the elbow, the lower back, the tailbone, the buttock, the hip, the inner knee, the heel, and a combination thereof.

A second aspect of the present disclosure provides a method for assessing risk of deep tissue injury (DTI) of a patient, the method including: obtaining a plurality of sub-epidermal moisture (SEM) delta values associated with the patient; inputting the plurality of SEM delta values into a trained model to receive a probability value, wherein the trained model is configured to calculate a probability value corresponding to the likelihood of the patient developing DTI, wherein the trained model is trained by performing the steps comprising: receiving a set of training data comprising: a plurality of SEM delta values associated with a set of patients, wherein each patient in the set of patients has a known DTI status, and a threshold value, wherein the threshold value is a number between 0 and 1; automatically inputting the training data into an optimization algorithm to receive a plurality of optimal weight values; and automatically updating the trained model with the plurality of optimal weight values; and assessing the risk of the patient developing DTI based on the probability value.

In an embodiment, the predicted future occurrence is categorized as no DTI, low likelihood of DTI, high likelihood of DTI, or suspected DTI. In an embodiment, the method further comprises selecting an intervention for the patient based on the assessed risk of DTI. In an embodiment, the intervention comprises at least one of: reducing pressure, repositioning the patient, changing the patient's support surface, providing a low-friction padded mattress, providing a silicon pad, providing a heel boot, cleaning and dressing wounds, removing damaged tissue, applying a topical cream, applying a barrier cream, applying neuro-muscular stimulation, drug administration, and surgery. In an embodiment, the DTI occurs at a

location selected from the group consisting of the back of the head, the sacrum, the shoulder, the elbow, the lower back, the tailbone, the buttock, the hip, the inner knee, the heel, and a combination thereof. In an embodiment, the method further comprises generating or updating a report from performing the method. In an embodiment, the method further comprises transmitting the report to the patient or a clinician. In an embodiment, the method further comprises storing the report on a non-transitory computer readable storage medium. In an embodiment, the method further comprises displaying the report on a computer display.

Disclosed herein is a non-transitory computer-readable storage medium comprising one or more programs for execution by one or more processors of a device, the one or more programs comprising instructions which, when executed by the one or more processors, cause the device to perform the method of any one of the preceding embodiments. In an embodiment, the non-transitory computer-readable storage medium further comprises a report generated from performing the method of any one of the preceding embodiments.

Disclosed herein is an electronic device, comprising: one or more processors; a memory; and one or more programs, where the one or more programs comprises instructions which, when executed by the one or more processors, cause the device to perform the method of any one of the preceding embodiments. In an embodiment, the electronic device further comprises one or more displays to present a report generated from performing the method of any one of the preceding embodiments.

A third aspect of the present disclosure provides a system for predicting deep tissue injury (DTI), including: a Sub-Epidermal Moisture (SEM) scanner configured to make SEM measurements; a processor electronically coupled to the SEM scanner and configured to receive the SEM measurements; and a non-transitory computer readable media that is electronically coupled to the processor and comprises instructions stored thereon that, when executed on the processor, performs the steps of: calculating a plurality of SEM delta values from the SEM measurements, automatically inputting, via a processor, the plurality of SEM delta values into a trained model to receive a probability value, wherein the trained model is configured to predict a probability value corresponding to a future occurrence of the patient developing DTI, and wherein the trained model is trained by the steps comprising: receiving, via an input device, a set of training data comprising: a plurality of SEM delta values associated with a set of patients, and a threshold value, wherein each patient in the set of patients has a known DTI status, and wherein the threshold value is a number between 0 and 1; automatically inputting, via a processor, the training data into an optimization algorithm to receive a plurality of optimal weight values; and automatically updating, via a processor, the trained model with the plurality of optimal weight; outputting, via an output device, a prediction of the future occurrence of the patient developing DTI based on the probability value.

A fourth aspect of the present disclosure provides a system for assessing risk of deep tissue injury (DTI), including: a Sub-Epidermal Moisture (SEM) scanner configured to make SEM measurements; a processor electronically coupled to the SEM scanner and configured to receive the SEM measurements; and a non-transitory computer readable media that is

electronically coupled to the processor and comprises instructions stored thereon that, when executed on the processor, performs the steps of: calculating a plurality of SEM delta values from the SEM measurements, automatically inputting, via the processor, the plurality of SEM delta values into a trained model to receive a probability value, wherein the trained model is configured to predict a probability value corresponding to a future occurrence of the patient developing DTI, and wherein the trained model is trained by the steps comprising: receiving, via an input device, a set of training data comprising: a plurality of SEM delta values associated with a set of patients, and a threshold value, wherein each patient in the set of patients has a known DTI status, and wherein the threshold value is a number between 0 and 1; automatically inputting, via a processor, the training data into an optimization algorithm to receive a plurality of optimal weight values; and automatically updating, via a processor, the trained model with the plurality of optimal weight; outputting, via an output device, a likelihood of future occurrence of DTI based on the probability value.

BRIEF DESCRIPTION OF THE FIGURES

Some aspects of the disclosure are herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and are for purposes of illustrative discussion of embodiments of the disclosure. In this regard, the description, taken with the drawings, make apparent to those skilled in the art how aspects of the disclosure may be practiced.

FIG. 1A: An example apparatus according to the present disclosure, comprising one coaxial electrode.

FIG. 1B: An illustration of an example method using an example apparatus according to the present disclosure to measure SEM delta values, in order to detect potential DTIs.

FIG. 2A: Sample SEM delta values taken from patients who were diagnosed with DTIs (left) and patients who were not diagnosed with DTIs (right).

FIG. 2B: An illustration of an example method for detecting DTIs according to the present disclosure.

FIG. 3: Sample SEM delta values taken from patients.

FIG. 4: Example ways of dividing data for processing.

FIG. 5A: A flowchart illustrating an example method for predicting DTI according to the present disclosure.

FIG. 5B: A flowchart illustrating an example method for optimizing weights according to the present disclosure.

FIG. 6: Sample optimized weights and threshold according to the present disclosure.

FIG. 7: Example method for predicting formation of DTIs according to the present disclosure.

FIG. 8: Results of example prediction and detection methods according to the present disclosure.

FIG. 9: An example system in accordance with an aspect of the present disclosure.

CLAIMS

1. A computer-implemented method for predicting deep tissue injury (DTI) in a patient, the method comprising:

a) receiving, via an input device, a plurality of sub-epidermal moisture (SEM) delta values associated with the patient;

b) automatically inputting, via a processor, the plurality of SEM delta values into a trained model,

wherein the trained model is configured to calculate a probability value corresponding to the likelihood of the patient developing DTI; and

wherein the trained model is trained by performing the steps comprising:

i) receiving a set of training data comprising:

1) a plurality of SEM delta values associated with a set of patients, wherein each patient in the set of patients has a known DTI status, and

2) a threshold value, wherein the threshold value is a number between 0 and 1;

ii) automatically inputting the training data into an optimization algorithm to receive a plurality of optimal weight values; and

iii) automatically updating the trained model with the plurality of optimal weight values; and

c) outputting, via an output device, a prediction of the likelihood of the patient developing DTI based on the probability value.

2. The method of claim 1, wherein the optimization algorithm is configured to:

a) generate a plurality of ascending random numbers between 0 and 2 as a plurality of weight values;

b) input the training data and the plurality of weight values into the trained model to receive a set of predicted DTI statuses associated with the set of patients;

c) compare the predicted DTI statuses with the known DTI statuses associated with the set of patients;

d) calculate a true positive rate (TPR) and a false positive rate (FPR) based on the comparison, wherein the TPR is calculated as percentage of patients in the set of patients whose predicted DTI status matches their known DTI status, and the FPR is calculated as percentage of patients in the set of patients whose predicted DTI status does not match their known DTI status;

e) repeat steps a) to d) for a predetermined number of iterations to obtain a plurality of TPRs and FPRs;
f) identify an optimal TPR and FPR from the iterations; and
g) output the optimal plurality of weight values associated with the optimal TPR and FPR.

3. The method of claim 1 or 2, wherein the plurality of SEM delta values comprises SEM delta values from a predetermined number of days preceding the prediction.

4. The method of any one of claims 1-3, wherein identifying the optimal TPR and FPR comprises minimizing the objective function of 1-TPR+FPR and satisfying the constraint of TPR>>FPR.

5. The method of any one of claims 1-4, wherein the input device is a SEM scanner.

6. The method of claim 5, wherein the SEM scanner is connected to a computer by cable or by wireless technology.

7. A method for assessing risk of deep tissue injury (DTI) of a patient, the method comprising:
a) obtaining a plurality of sub-epidermal moisture (SEM) delta values associated with the patient;
b) inputting the plurality of SEM delta values into a trained model to receive a probability value,
wherein the trained model is configured to calculate a probability value corresponding to the likelihood of the patient developing DTI,
wherein the trained model is trained by performing the steps comprising:
i) receiving a set of training data comprising:
1) a plurality of SEM delta values associated with a set of patients, wherein each patient in the set of patients has a known DTI status, and
2) a threshold value, wherein the threshold value is a number between 0 and 1;
ii) automatically inputting the training data into an optimization algorithm to receive a plurality of optimal weight values; and

iii) automatically updating the trained model with the plurality of optimal weight values; and

c) assessing the risk of the patient developing DTI based on the probability value.

8. The method of claim 7, further comprising selecting an intervention for the patient based on the assessed risk of DTI.

9. The method of claim 8, wherein the selected intervention is selected from the group consisting of reducing pressure, cleaning and dressing wounds, removing damaged tissue, drug administration, and surgery.

10. The method of claim 8 or 9, wherein the intervention comprises at least one of: reducing pressure, repositioning the patient, changing the patient's support surface, providing a low-friction padded mattress, providing a silicon pad, providing a heel boot, cleaning and dressing wounds, removing damaged tissue, applying a topical cream, applying a barrier cream, applying neuro-muscular stimulation, drug administration, and surgery.

11. The method of any one of claims 7-10, wherein the DTI occurs at a location selected from the group consisting of the back of the head, the sacrum, the shoulder, the elbow, the lower back, the tailbone, the buttock, the hip, the inner knee, and the heel.

12. The method of any one of claims 7-11, wherein the plurality of SEM delta values associated with the patient is obtained periodically over a predetermined time interval preceding the risk assessment.

13. The method of claim 12, wherein the predetermined time interval is 6 days.

14. The method of any one of claims 7-13, wherein the plurality of SEM delta values associated with the patient is obtained once daily for 6 days preceding the risk assessment.

15. The method of claim 14, further comprising transmitting the risk to the patient or a clinician.

16. The method of any one of claims 7-15, further comprising selecting a treatment for the patient based on the assessed risk of DTI.

17. The method of any one of claims 7-15, further comprising transmitting the selected treatment to the patient or a clinician.

18. A system for predicting deep tissue injury (DTI), comprising:

a) a Sub-Epidermal Moisture (SEM) scanner configured to make SEM measurements;

b) a processor electronically coupled to the SEM scanner and configured to receive the SEM measurements; and

c) a non-transitory computer readable media that is electronically coupled to the processor and comprises instructions stored thereon that, when executed on the processor, performs the steps of:

i) calculating a plurality of SEM delta values from the SEM measurements,

ii) automatically inputting, via a processor, the plurality of SEM delta values into a trained model to receive a probability value, wherein the trained model is configured to predict a probability value corresponding to a future occurrence of the patient developing DTI, and wherein the trained model is trained by the steps comprising:

1) receiving, via an input device, a set of training data comprising:

A) a plurality of SEM delta values associated with a set of patients, and

B) a threshold value, wherein each patient in the set of patients has a known DTI status, and wherein the threshold value is a number between 0 and 1;

2) automatically inputting, via a processor, the training data into an optimization algorithm to receive a plurality of optimal weight values; and

3) automatically updating, via a processor, the trained model with the plurality of optimal weight;

iii) outputting, via an output device, a prediction of the future occurrence of the patient developing DTI based on the probability value.

19. The system of claim 18, wherein the optimization algorithm is configured to:

a) generate a plurality of ascending random numbers between 0 and 2 as a plurality of weight values;

b) input the training data and the plurality of weight values into the model to receive a set of predicted DTI statuses associated with the set of patients;
c) compare the predicted DTI statuses with the known DTI statuses associated with the set of patients;
d) calculate a true positive rate (TPR) and a false positive rate (FPR) based on the comparison, wherein the TPR is calculated as percentage of patients in the set of patients whose predicted DTI status matches their known DTI status, and the FPR is calculated as percentage of patients in the set of patients whose predicted DTI status does not match their known DTI status;
e) repeat steps a) to d) for a predetermined number of times as the number of iterations;
f) identify optimal TPR and FPR from all calculated TPRs and FPRs from the iterations; and
g) output the plurality of optimal weight values associated with the identified optimal TPR and FPR.

20. The system of claim 19, wherein the plurality of SEM delta values comprises SEM delta values from a predetermined number of days before the day of predicting PI.

21. The system of claim 19 or 20, wherein identifying optimal TPR and FPR comprises minimizing the objective function of 1-TPR+FPR and satisfying the constraint of TPR>>FPR.

22. The system of any one of claims 18-21, wherein the input device is the SEM scanner.

23. The system of any one of claims 18-22, wherein the input device is a database or computer.

24. The system of any one of claims 18-23, wherein the DTI occurs at a location selected from the group consisting of the back of the head, the sacrum, the shoulder, the elbow, the lower back, the tailbone, the buttock, the hip, the inner knee, the heel, and a combination thereof.

25. The system of any one of claims 18-24, wherein the prediction of the future occurrence of the patient developing DTI comprises likely to develop DTI and not likely to develop DTI.

26. A system for assessing risk of deep tissue injury (DTI), comprising:

a) a Sub-Epidermal Moisture (SEM) scanner configured to make SEM measurements;

b) a processor electronically coupled to the SEM scanner and configured to receive the SEM measurements; and

c) a non-transitory computer readable media that is electronically coupled to the processor and comprises instructions stored thereon that, when executed on the processor, performs the steps of:

i) calculating a plurality of SEM delta values from the SEM measurements,

ii) automatically inputting, via the processor, the plurality of SEM delta values into a trained model to receive a probability value, wherein the trained model is configured to predict a probability value corresponding to a future occurrence of the patient developing DTI, and wherein the trained model is trained by the steps comprising:

1) receiving, via an input device, a set of training data comprising:

A) a plurality of SEM delta values associated with a set of patients, and

B) a threshold value, wherein each patient in the set of patients has a known DTI status, and wherein the threshold value is a number between 0 and 1;

2) automatically inputting, via a processor, the training data into an optimization algorithm to receive a plurality of optimal weight values; and

3) automatically updating, via a processor, the trained model with the plurality of optimal weight;

d) outputting, via an output device, a likelihood of future occurrence of DTI based on the probability value.

27. The system of claim 26, wherein the likelihood of future occurrence of DTI is the calculated probability of developing PI.

28. The system of claim 26 or 27, wherein the non-transitory computer readable media further performs the step:

a) selecting, via the processor, a treatment for the patient based on the likelihood of future occurrence of DTI, and
b) outputting, via the output device, a notification of the selected treatment.

29. The system of any one of claims 26-28, wherein the selected treatment is selected from the group consisting of reducing pressure, cleaning and dressing wounds, removing damaged tissue, drug administration, and surgery.

30. The system of any one of claims 26-29, wherein the DTI is deep tissue pressure injury (DTPI).

31. The system of any one of claims 26-30, wherein the DTI occurs at a location selected from the group consisting of the back of the head, the sacrum, the shoulder, the elbow, the lower back, the tailbone, the buttock, the hip, the inner knee, the heel, and a combination thereof.

32. The system of any one of claims 26-31, wherein the non-transitory computer readable media further performs the steps of generating or updating a report from performing the method of assessing risk and storing the report.

33. The system of any one of claims 26-32, further comprising transmitting the report to the patient or a clinician.

34. The system of any one of claims 26-33, wherein the output device is a computer display.