Correlation of skin temperature with time since injury in paediatric wrist injuries: An infrared thermal image analysis

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Correlation of skin temperature with time since injury in paediatric wrist injuries: An infrared thermal image analysis

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Abstract: This pilot study explored the correlation of skin temperature at the site of a wrist fracture or sprain with the time since injury (TSI). TSI is the time from the occurrence of an injury to when the infrared thermal (IRT) image recording was performed. IRT images of 40 children (mean age 10.5 years, standard deviation 2.63 years) with wrist injuries were recorded at a Children's Accident & Emergency department. The wrist region of interest (ROI) associated with the injury location was segmented, and its temperature was quantified by its mean value. The mean temperature was correlated with the TSI for both injury types. There were 19 children with a wrist fracture and 21 with a wrist sprain. For a fracture, there was no significant correlation between TSI and ROI temperature for the first 3.3 hours post-injury, however a moderate correlation was observed (correlation coefficient 0.680) thereafter till the time of last IRT image recording (i.e., TSI=125.3 hours). For a sprain there was no significant correlation between temperature and TSI (correlation coefficient= -0.245). The findings are indicative of the differences in the pathological processes of fractures and sprains and the manner they affect the temperature of the soft tissues around them.

Keywords: fracture; sprain; infrared thermal imaging; fracture and sprain physiology

1 . Introduction

Bone is a mineralized connective tissue consisting of osteoblasts, osteocytes and osteoclast cells within a periosteal lining [1]. A variety of extrinsic and intrinsic insults could cause a bone fracture. The extrinsic aetiologies include compression, tension, shear or a combination of these. Intrinsic effects are associated with bone composition, e.g., the relative amounts of cortical and cancellous bone [2]. A bone fracture disrupts the bone integrity and damages the blood vessels and surrounding soft tissues [3]. The healing process begins with an inflammatory phase followed by reparative and remodeling phases [4-5]. During the inflammatory phase, a hematoma is formed at the fracture site caused by bleeding from the damaged bone and periosteal vessels [6]. Vasoactive mediators are released by the activated coagulation system from platelets in the hematoma [6]. The inflammatory phase peaks at 48 hours from the onset of the injury and almost completely disappears by one week [7]. The reparative phase begins within the first few days of the injury, overlapping the inflammatory phase, and lasts for several weeks [7]. It results in the development of a callus around the fracture, enhancing its mechanical stability [7]. During the repair phase, the fracture gap is bridged by soft callus which is replaced with bone by the process of endochondral ossification [8].

The damage caused to the vascular network following a fracture is accompanied by increased metabolic demands of repair and a decreased perfusion leading to hypoxia near the fracture site [9,10]. The change in blood flow at the fracture site can contribute to a change in the skin temperature of the region. Skin blood flow and skin temperature has been reported to have a non-linear relationship [11]. Similarly, muscle and skin blood flow following a lower leg fracture in 19 patients were studied [12] and showed significantly higher blood flow in the calf muscles and the acral skin bed of the foot compared to the healthy leg.

A sprain is caused when a ligament within a joint is torn or stretched by a sudden forceful movement and like a fracture, it results in pain, swelling and a temperature increase at the injury site [13,14]. A ligament injury initiates an acute inflammatory phase within minutes and continues over the next 48 to 72 hours [15]. A complex healing process begins that involves blood collecting at the site of injury, platelet cells changing the shape of certain matrix components and initiating clot formation. Growth factors are released by the platelet-rich fibrin clot as part of the healing process [15]. However, because there is no injury to the bony structures, the amount of inflammatory change is potentially less than with a fracture.

Several studies have used infrared thermal (IRT) imaging to examine skin temperature changes at a fracture site. Infrared (wavelength 700 nm to 1 mm) is part of the electromagnetic spectrum and is emitted by objects with a temperature above absolute zero (-273.15 ^{o}C or 0 ^{o}K). The mean temperature difference of a fractured distal arm in 25 patients (mean age 65.9±10.4 years) was compared to their healthy arm [16] using IRT imaging showed an increase in temperature difference of 1.20 ^{o}C and 1.42 ^{o}C after 1 and 3 weeks respectively and a decline thereafter. IRT imaging of forearm fractures and the contralateral (uninjured) side in 19 children (aged 4 to 14 years) indicated an overall temperature difference of 0.13 ^{o}C after a day, 1.17 ^{o}C after 1 weeks, 0.83 ^{o}C after 2 weeks, 0.23 ^{o}C after 3 weeks and 0.14 ^{o}C after a month [17]. IRT imaging of 11 children aged 5-18 years diagnosed with osteogenesis imperfecta (a disorder resulting in the bones to be more fragile) could differentiate between fractured and healthy thoracic vertebrae [18]. IRT images of forty children (mean age 10.5 years), 19 with wrist fracture and 21 with wrist sprain was studied [19]. It was reported that fractured wrists had an overall significant temperature increase of 1.52% compared with the uninjured contralateral wrists. Although sprained wrists also had an increase in temperature when compared to the uninjured wrists, their temperature increase was not statistically significant. A study of IRT imaging in 113 children (aged 1 to 14 years) with traumatic injuries indicated the method can be valuable for ruling out fractures [20]. A more recent study developed multilayer perceptron (MLP) artificial neural networks to differentiate between infrared thermal images of wrist fracture and wrist sprain in paediatrics [21]. The development was based on 19 fractured wrists and 21 sprained wrists and resulted in the model's sensitivity and specificity of 84.2% and 71.4% respectively.

The contribution of this pilot study is exploration of the correlation between skin temperature at the injury site (wrist fracture or sprain) and TSI in paediatric and the manner the relationship differs in the two types of injuries. In the following sections the methodology and materials are explained, results are presented and discussed, and the study's conclusion is provided

2. Materials and Methods

The details of participants' recruitment, method of segmenting the wrist region of interest (ROI) in the IRT images, and its representation by a feature set were reported earlier [21] however for completeness they are very briefly outlined next.

Recruitment: The study had ethical approval from a National Health Service Research Ethics Committee (Sheffield, UK, identification number: 253940). The recruits were admissions to a Children's Accident and Emergency (A&E) department requiring an x-ray radiograph to determine whether their wrist injury had resulted in a fracture. Non-English speakers, patients sustaining multiple injuries or triaged above Category D and those who declined consent/assent were excluded from the study.

Participants' details: The study included forty participants, 24 males and 16 females, mean age 10.50 years (standard deviation 2.63 years), 19 with a wrist fracture and 21 with a sprain. The diagnosis was confirmed by an x-ray radiograph. Thirty participants had analgesic medication, mainly paracetamol and ibuprofen. Mean body temperature was 36.3 ^{o}C (standard deviation 0.43 ^{o}C) across all participants.

Recording: The participants waited in the recording room for 10 minutes with both wrists uncovered, to allow acclimatization to the room temperature. For recording, both hands were placed on a mat covering a table in front of them. The mat insulated the hands from temperature influence of the table. The recording room temperature was within the recommended 18-25 ^{o}C which is acceptable for human IRT recording [22]. To reduce background temperature affects, draught and external heat sources in the recording room were minimized. The IRT image recordings were carried out using a FLIR T630sc [23] handheld camera. The camera was positioned 1 m above the wrists. The camera's specifications are: noise equivalent temperature difference (i.e., minimum temperature difference resolvable by the IR camera) less than 30 mK, image resolution 640×480 pixels, spectral range 7.5 µm to 13 µm, dynamic range 14 bits and operating temperature -40 ^{o}C to 650 ^{o}C. To facilitate initial data storage, the camera was connected to a computer using a USB cable. Image capture rate was set to 30 frames per second (i.e., the camera's maximum capture rate for 640×480 pixels resolution), emissivity was set to 0.97 (this is suitable for recording from human skin). A recording duration was 10-seconds resulting in 300 images. The resulting images were averaged to reduce thermal noise, producing a single image.

Region of interest (ROI) segmentation: Image processing was perform using Matlab© package [24]. The first image of the recorded image was displayed and a region that included the carpal bones and a section of the distal radius and ulna was cropped. Template matching [25, 26] was then used (using the cropped ROI as the template) to extract and align the corresponding region from the remaining 299 images. The extracted ROIs from the images were then averaged to reduce thermal noise. This resulted in a single image for feature extraction.

ROI Representation: For the contralateral (uninjured wrist), the background section of the averaged ROI (cropped from the original image) was excluded by thresholding. The background following the cropping process were all zeros and so the threshold level was set accordingly. The remaining pixel values represented the ROI temperature and were averaged to obtain an overall reference temperature. For the injured wrist (fractured or sprained), the averaged ROI was converted to a grid of cells with dimension 10 × 10 pixels. Each cell was expressed by its mean value. The 50 largest average values were selected, and the mean temperature of the uninjured contralateral wrist was subtracted. The subtraction of the contralateral ROI temperature was carried out to deal with variations of skin temperature across the participants. The resulting values were then represented by their overall mean temperature difference value (Δ_T).

3. Results

The histograms of Δ_T values for fracture and sprain are shown in Figures 1(a) and 1(b) respectively. For fractures, most Δ_T values were between 0.5 to 1 °C. For sprain, Δ_T values were more uniformly spread across their range. These indicate that fracture tends, in general, cause a more consistent skin temperature increase at the site of injury than sprain This may be because of the relatively fixed amount of energy required to cause a fracture and hence the amount of damage and resultant inflammatory changes is more homogenous. Because sprains are more variable in terms of the trauma required to cause them, the resulting inflammation, the IRT change is more heterogenous.

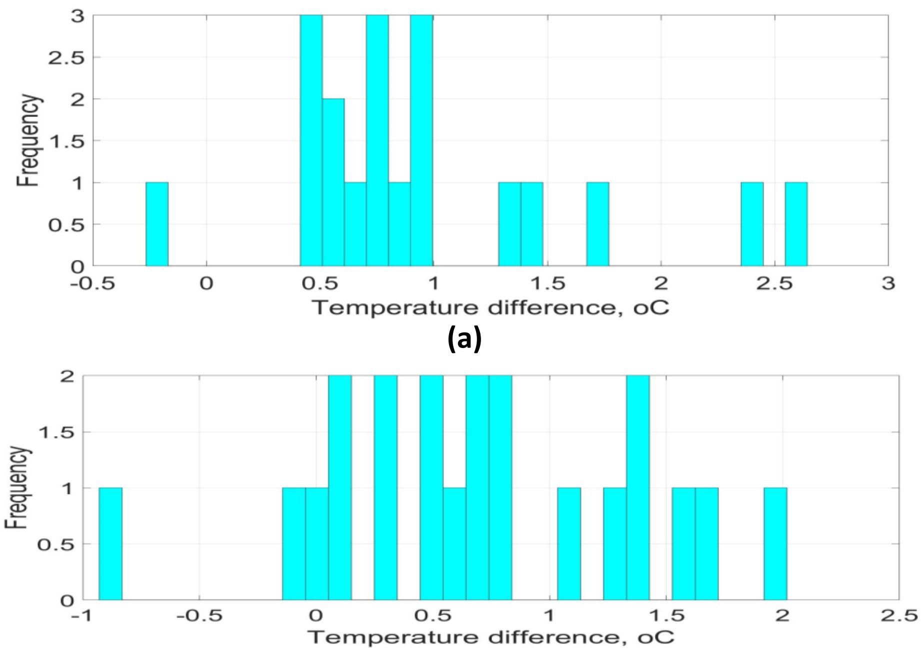

Figure 1. Histograms of Δ_T for (a) fracture, (b) sprain.

Figures 2(a) and 2(b) show the TSI histograms for fracture and sprain respectively.

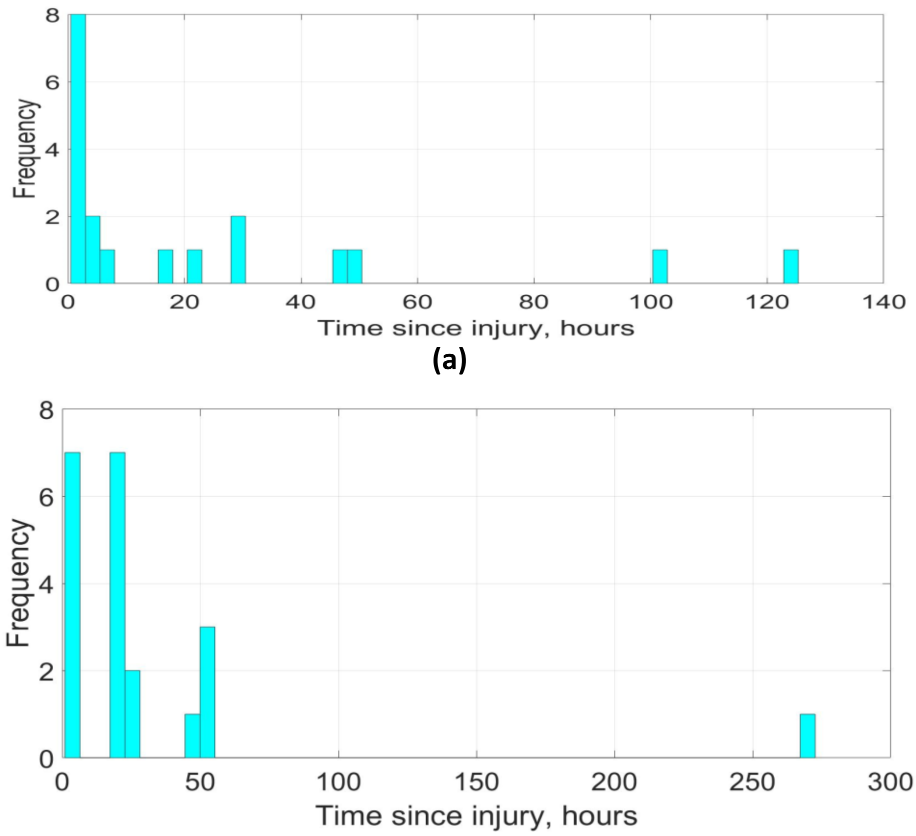

Figure 2. Histograms of time since injury for (a) fracture, (b) sprain.

As indicated in Table 1, the mean TSI for fracture and sprain were 23.7 and 32.8 hours respectively.

Table 1. Mean and standard deviation of time since injury for fracture and sprain.

Injury type	Time Since Injury	
	Mean	**Standard deviation**
Fracture	1419 (minutes) 23.7 (hours)	2130 (minutes) 35.5 (hours)
Sprain	1966 (minutes) 32.8 (hours)	3450 (minutes) 57.5 (hours)

As indicated in Table 2, the mean of Δ_T for fracture and sprain were 0.962 and 0.707 °C respectively. Therefore, fracture had a higher mean Δ_T a lower standard deviation for Δ_T than sprain.

Table 2. Mean and standard deviation of temperature difference representing the ROI (Δ_T).

Injury type	ROI temperature representation (Δ_T, °C)	
	Mean	Standard deviation
Fracture	0.962	0.690
Sprain	0.707	0.699

Figure 3 shows the plot of Δ_T against the TSI for wrist fracture. Two distinct phases were observed.

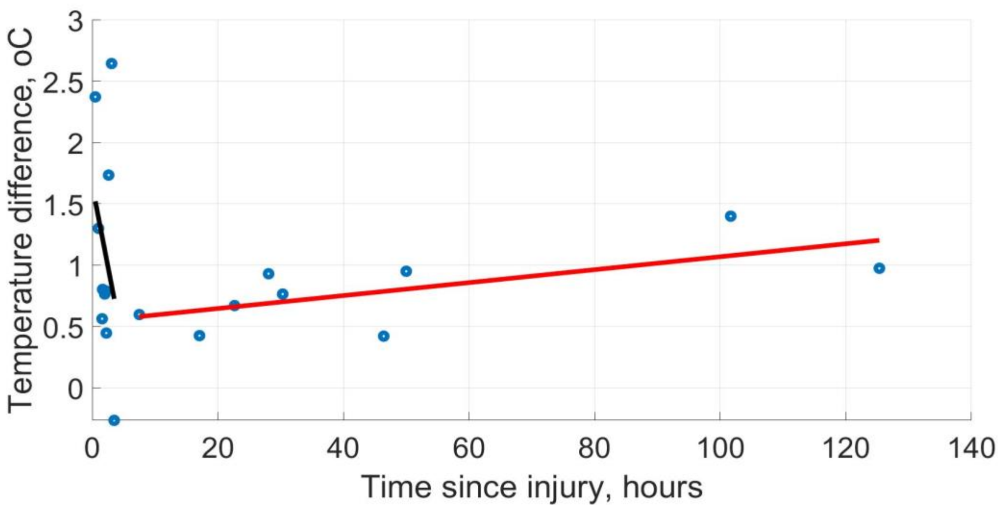

Figure 3. Plot of Δ_T against TSI for fracture.

The first phase, lasting up to around 3.3 hours, Δ_T and TSI were not significantly correlated (correlation coefficient= -0.267). This part is separately plotted in Figure 4 for further clarity.

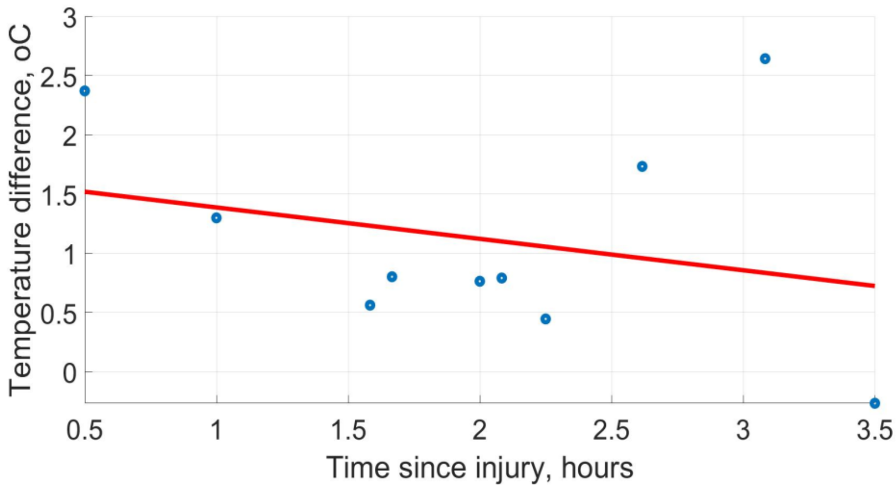

Figure 4. First phase of plot in Figure (3).

For clarity, the second phase is shown separately in Figure 5. This phase was from the end of the first phase to the time of last data recording, i.e., from 3.3 hours to 125.3 hour. For this phase, a moderate correlation existed between Δ_T and TSI (correlation coefficient = 0.680). For the full period of data recordings (i.e., the two parts combined), there was not a significant correlation between Δ_T and TSI (correlation coefficient= -0.009).

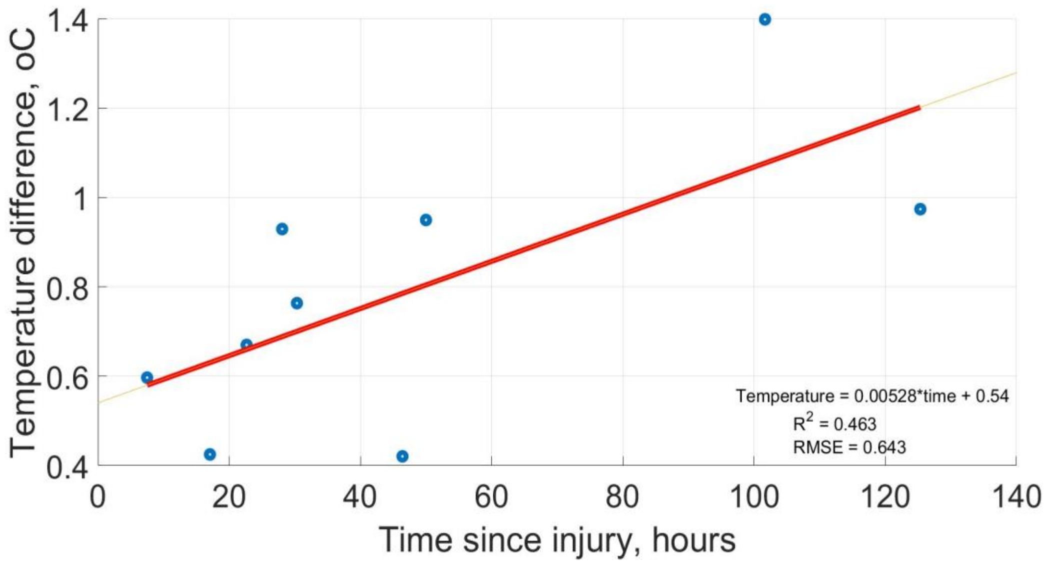

Figure 5. The second phase of plot in Figure (3).

Figure 6 shows plot of Δ_T against TSI for sprain. For sprain, unlike fracture, distinct parts were not observed and the correlation between Δ_T and TSI for the full recording duration was not significant (correlation coefficient = -0.245).

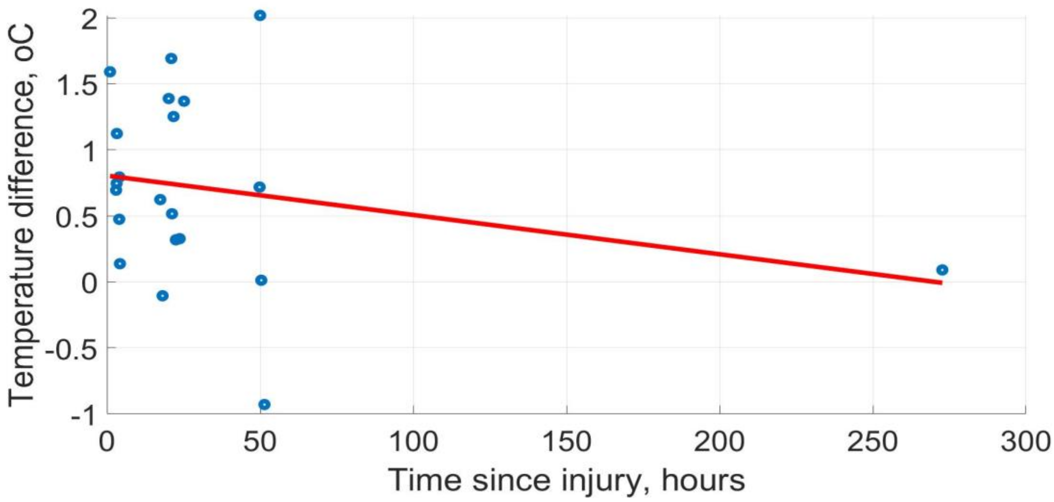

Figure 6. Plot of Δ_T against TSI for sprain

4. Discussion

This pilot study confirmed the findings of earlier studies that indicated a gradual increase in skin temperature in fractures [16,17] however it built on these finding and explored the correlation of the skin temperature increase at the injury site and TSI. The skin temperature increase at the injury site had a lower deviation (lower standard deviation) around its mean value for fracture as compared to sprain. For fracture, two phases with distinct temperature profiles were observed. For the initial phase, lasting up to around 3.3 hours after injury, there was no significant correlation between TSI and Δ_T but thereafter a moderate correlation was observed. For sprain, Δ_T did not correlate significantly with TSI. These findings may relate to differences in the inflammatory and healing processes between fractures and sprains. The correlation difference between the first and second phase observed in the Δ_T versus TSI plot, may be indicative of the manner fracture healing affects skin temperature at the injury site. To be able to more accurately establish the boundary between the two phases for the Δ_T-TSI plot in fracture, a larger sample size with a more uniform TSI would be required. Previous studies indicated that the skin temperature increase at the site of fracture subsides as the healing progresses [16,17]. Given the sample size, this phenomenon was not explored in this study. This study used a linear correlation model to explore Δ_T versus TSI relationship. For a larger sample size, a higher order polynomial could be used to detect refiner details.

5. Conclusions

This pilot study explored the manner in which the skin temperature at the site of wrist fractures and sprains correlated with the time since injury (TSI). The physiological differences between the healing processes of fractures and sprains are reflected in the manner skin temperature increased at the injury site. For fracture, there was no significant correlation between temperature and TSI initially but thereafter a moderate correlation was observed. No significant correlation was observed between these variables in sprain. The findings highlighted the way in which fractures and sprains affect the temperature surrounding tissues at the injury site and the information attained may be valuable in better understanding the healing processes in the two types of injuries. It may also be valuable for the ongoing research in the use of IRT imaging to screen for bone fractures.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Conflicts of Interest: The authors declare no conflict of interest

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