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Review of Bone Fracture Detection and Characterization Techniques

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Abstract: ***Background: Bone fracture is a common medical condition that brings about discontinuity in the skeletal structure. A reliable diagnosis of bone fracture depends on various imaging techniques. Detection and characterization of bone fracture is primarily achieved by imaging techniques such as X-ray, and CT scans which are expensive, technologically complex and beyond the reach of most of the world population. According to the World Health Organization, 75% of the world population does not have access to imaging diagnostic service. Objectives: We aim to explore the various existing alternatives to X-Ray and CT based diagnostics imaging for fracture detection and characterization. We will try to identify a low cost and accessible method that can be used. However, in order to do this, it is essential to review all alternative methods and compare the cost and accuracy of each. Search Strategy: We conducted an extensive literature search in Medline/PubMed, Google Scholar and Cochrane Central in the period from January to March 2017. We used the following keywords "Bone Fractures, Detection Technology, ultrasound sonography, Acoustic scanning, Cost, Cheep Methods". All types of publications were included with no limits regarding the date of publication. We augmented our databases by searching the reference lists of identified related reviews. Conclusion: Acoustic scanning, a non-imaging technique in which, similar to non-destructive techniques employed in the detection of defects and flaws in metal and composite materials, ultrasonic waves are transmitted through the human bone and analyzed after going through the bone, offers accuracy comparable to an ultrasound imaging at very little cost. The traditional method does depend on the expertise of a physician for correct diagnosis. However, this shortcoming is now easily negated. Integrating electronic circuitry, software and acoustic scanning can provide an alternative that is reasonably accurate at very low cost. It is also very simple to use and it is possible to train field workers to use the same. Such a product can make significant differences in the world, and provide millions of people with affordable fracture detection technology.***

Keywords: Bone Fractures, Detection Technology, ultrasound sonography, Acoustic scanning, Cost, Cheep Methods

1. Introduction

Bone fracture is a common medical condition that brings about discontinuity in the skeletal structure. Fractures can from result trauma or diseases such as osteoporosis or bone cancer. Whatever the type of fracture or its cause, treatment of bone fractures usually involves immobilizing the part involved and at times, surgical interventions. A reliable diagnosis of bone fracture depends on various imaging techniques. Detection and characterization of bone fracture is primarily achieved by imaging techniques such as X-ray and CT scans. These imaging techniques, though reliable, often increase the cost treatment. While this may not be an issue in developed countries with affordable medical care, these costs are often beyond the reach of people in the developing world. The world health organization reports that as of 2012, nearly two third of the world population had no access to medical diagnostic imaging. In fact, trauma and broken bones are a leading cause of death in many developing countries (Zirkle 2008). Fracture from fall is the leading cause of disease burden among children in most developing countries (of Toronto 2004). Simple fracture treatment could prevent nearly 10% deaths in such economies(University of Toronto, 2004). However, at present, a fracture could entail lifelong disability and dependence in most of these countries. Affordable fracture detection methods could play a key role in making fracture treatment more accessible to people with low income. With rapid motorization and poor road conditions along with an aging population, the number of fractures to be treated is predicted to increase (Amin, 2014). Since 90% of severe fractures occur in the developing world (Zirkle 2008), an effective and affordable fracture detection technique is of great relevance.

One approach to solving this gap in diagnostic imaging is to develop low cost imaging alternatives such as cheaper X-Ray machines. This option is being explored by researchers across the globe(India Tech Online,'" 2015, Hazelton, 2015). However, given that radiology technicians are not readily available in most parts of the world, this approach alone will not solve the diagnostics crisis. It is equally important to develop other cheaper diagnostics alternatives to X-rays. Simple diagnostic equipment that is capable of detecting and characterizing a fracture has the potential to make fracture treatment accessible to the majority of the world population. Such an option is also important in the developed world, given the adverse effects of ionized radiation. In that light, this paper explores the various existing alternatives to X-Ray diagnostics imaging for fracture detection and characterization. Various options found in literature will be reviewed and their characteristics will be discussed in detail. The objective here is to identify a low cost and accessible method that can be used in fracture detection. However, in order to identify that method, it is essential to review all alternative methods and compare the cost and accuracy of each.

2. Method

Electronic searches were undertaken to identify both established and unestablished technologies used for bone fracture detection. The search was conducted for the period 2017 to 2007, considering studies that documented specificity and sensitivity values of each technology. The study also evaluated costs involved in each method. The PRISMA diagram below figure 2.1 shows how literature was analyzed.

3. Results

The results obtained were tabulated as shown in table1 below. Although four alternative technologies within a confidence interval (CI) of 95%, used for fracture detection are examined, focus is on Ultrasound and Acoustic Scanning due to their potential as low and simple methods. Their scientific principles have varying cost and degree of accuracy are looked at in details.

3.1 Comparison of Alternatives

The first method presented is a bone scintigraphy or a bone scan. A bone scintigraph is obtained by introducing a radioactive dye into the patient and then tracking the gamma radiation emitted by the dye as it decays. The major advantage of this method is its accuracy. Scintigraphs have an accuracy of over 95% and are more accurate than X-rays and are capable of picking up minute fractures that an X-ray is likely to miss. However, the equipment needed for scintigraphy is more expensive that an X-ray. A single bone scan can cost a patient around $300. It is also more complicated to use, and needs a trained radiologist. In addition, as it involves a radioactive dye, it is not suitable for children, or pregnant women. Clearly, scintigraphy is not the low cost, accessible alternative to X-rays for fracture detection. The next method explored was thermography which basically reads the thermal signature of the patient. Thermography is in general less accurate than an X-ray and thermography alone cannot confirm a fracture. As thermography measures the heat generation, fractures usually show up as hot spots of areas of high heat generation. However, tissue damage may give very similar heat signature. Therefore, thermography alone cannot be used to confirm a fracture. However, reported accuracy from most studies is above 90%. It also has no radioactive emissions associated with it and a thermograph can even be obtained without making physical contact with the patient. The equipment is basically a camera that operates in the infrared spectrum and it relatively easy to use. It is also safe for children and pregnant women as it is radiation free. However, the cost of obtaining a single thermograph can be around $400. The equipment involved is also expensive. Therefore, even though thermography has many applications in fracture detection, especially for children who should not be subjected to radiation and athletes who are susceptible to hairline stress fractures, it is not a method that can be cheap and accessible enough to replace an X-ray.

The next alternative considered was ultrasound. Though typically used to study soft tissue, ultrasound has also been used to detect fractures. As the sound waves used in ultrasound do not permeate bone, the image of the bone surface is studied in order to assess the state of the bone and identify a fracture. The obvious advantages of ultrasound are that it is radiation free and portable. However, ultrasounds cannot work if the injured bone is located behind another. It is also difficult to judge the severity of a fracture from an ultrasound as only the bone surface is visible. It is also relatively inaccurate, with typical accuracy values of around 85%. In addition, while getting an ultrasound is relatively inexpensive, the equipment costs in the range of $4000. It is also painful as pressure needs to be applied over the injured body part. Therefore, while ultrasound can be used for primary screening in a hospital, especially with children and for bones that are in the extremities, it is not an alternative to X-ray. It is not cheaper than an X-ray, and it is less accurate. Such an alternative does not make medical or economic sense.

3.2 Ultrasound

Unlike most other imaging techniques, ultrasound imaging is done in real time. A physician can use to study the state of a patient during examination, and there is no delay in processing the image. In addition, its portability and relatively low cost has made it a very popular diagnostic instrument. A number of techniques have now developed form ultrasounds (sonography) such as Doppler sonography which utilizes the Doppler Effect, contrast sonography which utilizes a contrast medium and elastography which utilizes the variation in elasticity of soft tissue. Sonography or ultrasound is recognized by the world health organization as such: "Diagnostic ultrasound is recognized as a safe, effective, and highly flexible imaging modality capable of providing clinically relevant information about most parts of the body in a rapid and cost-effective fashion (WHO Report 1998). Before understanding how ultrasound can be used for fracture detection, it is essential to understand its basic operating principle.

3.2.1 Experiments of Fracture Detection using Ultrasound

Over a period of three months, Hurley, Keye & Hamilton (2004) used ultrasound to identify rib fractures in 14 patients. The median age of the group was 31, with individual age ranging between 16 and 55. It was seen that of the total of 15 fractures presented by 11 patients, the ultrasound managed to identify 14 of them. Therefore, ultrasounds performed with high accuracy, but still lower than that of an X-ray. Also, using an ultrasound for detecting rib fractures proved unnecessarily painful for the patient as some degree of pressure needed to be applied directly on the fracture. However, since then ultrasound has been employed to detect various other types of fractures. A study on using ultrasound to detect orthopedic trauma (Sinha et al. 2011) used a significantly higher sample of 133 patients. This study only involved patients above the age of 5. It was seen that the ultrasound picked up 46 of the 42 fractures that were present, with over 85 % accuracy. More interestingly, it had a positive prediction value of 100% and a negative prediction value of over 93.8%. Therefore, though it is not as accurate as an X-ray, Ultrasound does clearly have the ability to detect broken bones. Papalada et. al. (2012) extended the use of ultrasound for fracture detection to include stress fractures from sports injuries. This long term study (10 years) with 113 patients distributed between both genders. In this case, given the nature of the injuries, it was seen that the ultrasound had 81% accuracy. The positive prediction value was 99% and negative prediction value was a low 13%. Neil (2014) used ultrasound to wrist fracture in pediatric patients younger than 17 years of age. Of the 79 patients, ultrasound was able to identify 91% of the fractures that were later confirmed by X-ray. Similarly, ultrasounds were also used successfully to detect femur fractures in adults. The study included thirty patients with an average age of 40, making it one of the few cases where the effect of ultrasound based fracture detection was studied specifically for adults. The results of this study demonstrated that ultrasound was accurate enough to detect the fracture 90% of the time.

3.2.2 Advantages and Disadvantages of Ultrasound

Ultrasounds are non-invasive, relatively painless and radiation free. Ultrasounds are portable and give real time readings unlike an X-ray, which has a significant waiting time. They are ideal for detecting a fracture during emergency situations. They are, however, also less accurate. In general, when compared to X-rays, ultrasounds are only successful in identifying 90% of the fractures. Ultrasounds often do not pick up minor fractures, ant their accuracy drops further when it comes to stress injuries and other sports related fractures. In addition, ultrasounds need to be interpreted by a trained technician, and are much more user dependent than an X-ray. Ultrasounds also fail to give the depth of an injury and can often be unclear. Though getting an ultrasound may not be very expensive, the machinery itself is expensive. A portable ultrasound costs over $3500 in today's market. More complex machines are even more expensive. This limits their use to major hospitals only in many developing countries. Also, significant investments may be needed in training technicians to interpret the images generated.

3.3 Acoustic Scanning

The oldest method for detecting fractures is perhaps using acoustic scanning. For decades, physicians have used a stethoscope and a tuning fork to detect fractures (Moore 2009). This method serves as a confirmation if the signs of a fracture are obvious. In addition, it has been employed in cases where the patient is unable to articulate where the pain is, as with babies. While not as accurate as X rays, it served as a reliable and easy method for assessing bone fractures. Since the objective of this study is to identify a simple and reliable method for fracture detection, it may be possible to use the principals involved in acoustic scanning to identify a method for detecting bone fractures. The basic principle is that of wave transmission, and is explained in the next section.

3.3.1 Experiments of Fracture Detection using Acoustic Scanning

Moore (2009) used a tuning fork at 128Hz and stethoscopeto diagnose fractures. The experiment was carried out on fractures that were less than a week old on 19 males and 18 females. The time frame was chosen so as to avoid the effects of bone healing. The participants were from a diverse age group of 7 to 60 years. A study using amplitude and frequency response to identify a fracture, O' Brien (2016) built on this approach by introducing a software to read the output signals and interpret them. The software would then analyze the data and interpret the results. While no statistically significant studies have been carried out regarding this technology, the initial results are promising.

3.3.2 Advantages and Disadvantages of Acoustic Scanning

Using sound for detecting fractures is among the oldest techniques for fracture detection. It requires no special equipment and can be carried out anywhere inside or outside a hospital provided a stethoscope is present. Acoustic method has been used to detect fractures, especially in bigger bones. It requires no expensive equipment and poses no risk of radiation or allergic reactions. It is also real time, much like an ultrasound. It can also be employed during pregnancy unlike an X-Ray. However, it is not the most accurate method for assessing fractures. On average, the experimental results show accuracy close to 80%. This is significantly lower than that of most diagnostic methods. In addition, the accuracy of the diagnosis depends heavily on the experience and expertise of the physician involved, as it is a skill that has to be developed over time. Unlike with an X-ray, the results obtained in an acoustic scan are not tangible and cannot be shared with other physicians for a second consult or re-examined at a later time. In addition, the diagnosis is made by comparing the output of a broken bone with that of a normal bone. This may cause additional observational error. This is also the only non-visual method of fracture detection in use.

4. Discussion

As mentioned earlier, X-rays and CT scans are the common diagnostic imaging tools used for fracture detection and characterization. However, most of the world has no access to such equipment. In fact, while 96% of US hospitals are equipped with diagnostic imaging tools, a person in Nepal may have to travel for two days and expend a month's income to have access to the equipment (Silverstein, 2016). Nearly 50% of the X-ray machines available in the developing world are either outdated or not functional (Perry and Malkin 2011). Manpower shortage is also a critical problem. In 2015, the entire country of Liberia had exactly two radiologists and Kenya with a population of over 40 million, has 200 radiologists (Ali et al. 2015) .In addition, even when both equipment and a technician is available, electricity may not be (Silverstein, 2016). Given the lack of personnel and equipment, and the unpredictability of power supply, it often becomes difficult to impose required safety norms while using diagnostic equipment. For example, a study of three hospitals in Duhok (Egypt) found that only one of the hospitals had X-ray equipment that provided safe and reasonable entrance surface dose of radiation. The values in the other two hospitals were much above the reference value, especially for chest and cervical imaging (Yacoob and Mohammed 2017). The International Atomic Energy Agency recently identified that due to lack of proper quality control measures in diagnostic imaging, over 50% of X-rays from the developing world had substandard quality (Muhogora et al. 2008). Naturally, such imaging is likely to hamper the diagnostic process. The case with CT equipment is not very different. Medical CT scanners cost in the range of 60,000 Euros to 300,000 Euros and is out of the reach of most hospitals in developing countries. In fact, Nepal got its first CT scanning machine in 2014, though it is primarily used for cancer treatment (The Himalayan Times, 2016). A CT scanner is a significant investment even in the developed world, and a hospital acquiring one is often news. In addition, the risks associated with radiation from over use of CT scanner are also a real concern in the developed world, with the US Food and drug administration reporting that over 30% of such tests are medically unnecessary (Timbie et al. 2015).

5. Conclusion

Four technologies used to detect bone fracture were examined with a view of finding a cheap alternative to X-ray, Thermography and Scintigraphy are more expensive than an X-ray and were therefore eliminated. The cost of a portable ultrasound is rather high for wide spread use and its accuracy is relatively low. Acoustic scanning offers accuracy comparable to an ultrasound at very little cost. The traditional method does depend on the expertise of a physician for correct diagnosis. However, this shortcoming is now easily negated. With the advancement in computing and development of computer software, there is high potential of combining acoustic scanners technology and mathematical models/ algorithms to not only detect but to accurately predict the type and location of the fracture. Therefore, it is essential that the more research should be done on developing and testing acoustic scanners and mathematical models that are suitable for use in resource poor hospital setting.

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