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Research paper

Screw-Bone Implant Loosening: Complication, Cause and Assessment

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Abstract

Bone fracture has become more common in this era of vehicular modernization. Internal fixation has been used in the treatment of such cases. The use of screw and plate in internal fixation has been proven to provide more stability to fracture to promote better healing. The use of screw also carries certain risk such as self-loosening that can cause non-union and prolong healing. The complication of self-loosening is studied to comprehend the danger of self-loosening in screw-bone implant. The review on self-loosening in bolted joint is done in this paper to gain better understanding on the nature of self-loosening phenomena. The factor that affects the screw self-loosening in bone is further studied in the screw-bone implant environment. The identification of the screw loosening can be done with radiography, CT scan, MRI and ultrasound. This article have done a brief review on the complication of screw self-loosening, the cause of screw loosening in bolted joint and screw-bone implant and the assessment of screw loosening done by ultrasound and radiography.

Keywords: *screw loosening; ultrasound; radiography; bolted joint; screw penetration*

1. Introduction

Injuries regarding bone fracture are one of the common injuries for the musculoskeletal system [1]. As the modernization of motorize vehicle have been developed there are many instance of trauma and life-threatening bone fracture. For the fracture to heal it involves many cellular and mechanosensitive processes [2].
Internal fixation have been used to provide the fracture with biomechanical stability [3]. One of the common treatment for fracture is by using screw to provide better healing to the bone fracture [4]–[9]. The use of screw advantages are it superior torsional stability, minimally invasive insertion and limited disruption of femoral head blood supply. It is also beneficial to surgeon as the use of screw will limit blood loss, operating time, and damage to the soft tissue that will promote better healing to the patient [10]
The fracture fixation achievement depend on the screw-bone interface stability [11]. The stability of the fixation will support the fracture to increase it vascularity and tissue differentiation, accelerate the fracture union and promote early callus formation [12]. In spine surgery the transpedicular fixation have been commonly used to repair the deformity and stabilize the spine [13].
The advantages of identifying the screw loosening early on is to prevent the patient to have complication such as screw breakage, painful spasm, late macromovements and severe neural damage [14]. The complication, cause and method to discern screw loosening must be studied to understand screw-bone implant loosening. In this paper, the aim is to provide a review on the problems due to screw-bone implant loosening, the cause of screw loosening and the assessment of screw loosening by utilizing ultrasound and radiography.
The common failure involving the internal fixation is the screw self-loosening and the screw thread breakage [15]. Screw self-loosening will lead to fixation failure that could pose a hazard to the fixation stability and cause severe complication [13]. The failure of fixation create a great risk for non-union, malunion and reduction loss [16].There are various causes for non-union to occur at the fractured bone [3], [6], [17], [18] and one of the reasons is the biomechanical instability [7], [12], [17].
Harwood et al. [3] described non-union as when the fracture have passed a certain time frame but there are no sign of union at the fractured bone and the progress of the fracture remain unknown. The effect of non-union is the time taken for the bone to be healed would be much longer and that will affect the patient with unhealthy mental state, the loss of functioning limb and have an effect to the psychological responses to injury [17], [19]. The cell differentiation is affected by the fracture stability as the time taken for bone fracture to heal is longer when the fixation is less rigid. Farnell et al. [20] have stated that the risk on non-union in all fracture is up to 10% while for Einhorn [21] is about 5 to 10%

2. Screw Self-Loosening in Bolted Joints

In this particular section the papers regarding the screw loosening in bolted joint have been presented to further gain knowledge on the cause of screw loosening.
A paper done by Jiang et al. [22] reported that when a bolted joints are exposed to cyclic loading two main failure mode can be observed that is fatigue and loosening. Bolted joint faced fatigue failure when it is subjected to tensile load. The first phase of self-loosening happen when the relative rotation of the bolt and nut does not occurs and has been confirmed to be caused by the local cyclic plasticity that present at the root of the engaged thread. The second phase of self-loosening is caused by the local plastic deformation that lead to gradual decrease in the clamping force

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Table 1: Summary of cause for screw loosening in bolted joints

Reference	Title	Summary
Jiang et al. [22]	Investigation into the loosening mechanism of bolt in curvic coupling subjected to transverse loading: A Study of Early Stage Self-Loosening of Bolted Joints	The screw will become fatigue and loosened when exposed to cyclic loading
Pai and Hess [26]	Experimental study of loosening of threaded fasteners due to dynamic shear loads	The screw lossening occurs due to the dynamic loads that cause the screw to turn and reduce its clamping force
Zhang et al. [29]	The roles of thread wear on self-loosening behavior of bolted joints under transverse cyclic loading,	The cyclic loading will cause the bolted joint to be self-loosened
Horn and Schmitt [30]	Relaxation in Bolted Thermoplastic Compositejoints	The cyclic loading will cause fretting wear the result in the reduction of clamping force
Liu et al. [31]	Study on self-loosening of bolted joints excited by dynamic axial load	The main failure mode for bolted joint when exposed to vibrational environment is self-loosening
Housari et al. [32]	Effect of thread and bearing friction coefficients on the vibration-induced loosening of threaded fasteners	The loosening rate is affected by the use of fastener coating and lubricant

Table 2: Summary of cause for screw loosening in screw-bone implant

Reference	Title	Summary
Dinah et al. [33]	Inadvertent Screw Stripping During Ankle Fracture Fixation in Elderly Bone	When the applied torque surpass the appropriate limit of the bone-screw interface it will cause the screw loosening
Wojtków et al. [34]	Biomechanical analysis of the durability of a modified S1 vertebrae transpedicular screws insertion technique	The strength of the bone-screw interface is dependent on the local bone quality
Ricci et al. [35]	A comparison of screw insertion torque and pullout strength	The poor bone quality will cause the screw to strip before reaching a sufficient torque
Palepu et al. [36]	Impact of bone quality on the performance of integrated fixation cage screws	Bone with better quality is more resistant to screw loosening
Bachus et al. [37]	The effects of drilling force on cortical temperatures and their duration: An in vitro study	The loss of bone due to necrosis will weaken the screw purchase strength
Pallan et al. [38]	Histological changes in bone after insertdon of skeletal fixation pins	The necrosis will cause the bone around the fixation area to crumble and weaken the purchase strength of the fixation

between the nut at the bolt [23].

The common problem that causes self-loosening of the bolted joints is slippage, plastic deformation of the fastener, and fretting wear between the contact surfaces [24]–[27].

Self-loosening is the result of complete thread slip and localized slip at the screw head surface [28]. Vibration can cause loosening due to wear and hammering. The nut will begin to back off when an ample amount of friction force is lost that causes the clamp load to disappear [39]. The dynamic loads in the form of vibration, shock, or cyclic thermal loading will cause the fasteners to turn loose that reduce the clamping force and result in joint failure [26].

The main cause of failure for bolted joint when subjected to the cyclic loading is the self-loosening that have been identified by Zhang et al [29]. They found out that the fretting wear can be the source of the self-loosening of the bolted joint under transverse cyclic loading without any rotation of the nut. The fretting wears lead to steady reduction of the clamping force as the number of loading cycles increase [30].

In Liu et al. [31] papers it is stated that when bolted joints are exposed in a vibrational environment the main failure mode of the bolted joints is the self-loosening. They also studied on the self-loosening behavior of bolted joint excited by dynamic axial load at fives levels on both preload and excitation amplitude. The varying axial load can cause micro slippage between the contact thread [31]. Housari et al. [32] concluded that the friction coefficient that plays a role in the loosening rate is affected by the fastener coating and lubricant.

3. Screw Self-Loosening in Screw-Bone Implant

This section will start to lean toward the loosening at the screw-bone implant and explore the papers on the factor that affect screw loosening in such environment. There are many factors that affect the screw pullout resistance such as insertion torque, bone mineral density and screw thread design [40].

When a screw is stripped its pullout strength will be reduce by more than 80 % [41]. A paper from Mehmanparast et al. [9] have concluded from various paper that the rate for fixation failure because of screw loosening is ranged from 0.8% to 17%. Andreassen et al. [42] study have discovered that rate for at least one screw stripping in fixation of displaced lateral malleolar fracture is up to 88% for patients that are over 50 years old.

3.1. Torque

In a paper done by Cleek et al. [43] it is stated that the screw must be inserted with 70% of their maximum torque to achieve peak pullout strength. The insertion torque of a screw can be used to identifying the initial stability of the construct for pedicle screw [36]. The torque required for minimum screw insertion for construct stability is approximated to be at least 3 Nm [44]. The screw thread can lose it purchase strength because of the applied torque surpass the appropriate limit of the bone-screw interface and will turn with little resistance and the risk of screw stripping is approximately 9% and 12 % for overtightened from the insertion on 200 screws in the fixation of ankle fractures in elderly bone [33]. The rate of surgeons identifying the striping when tested with synthetic bone is less than 10% and it is only after the surgeons have significantly exceed the stripping torque [45].

3.2. Bone Quality

The important factor in the success of fixation is the used implantation technique and the quality of the osseous tissue of the bone [34]. McAndrew et al. [11] describe that the bone mineral density (BMD) is a widely used standard in the measurement of bone mass and can be used to identifying the bone strength. They also reported that the strength of the bone-screw interface is dependent on the local bone quality. Their research discovered that the BMD is the most suitable parameter in determining the maximum screw torque at the metaphysis and for diaphysis the Reference Point Indentation is the best criteria in obtaining the maximum screw torque.

Table 3: Summary of literature on the assessment of screw-bone implant

Reference	Title	Criteria	Rate of detection	Assessment
Pihlajamaki et al. [15]	Complications of transpedicular lumbosacral fixation for non-traumatic disorders	Detection of screw loosening	18/102 patients	X-ray
Vernet et al. [48]	Detection of penetration of the dorsal cortex by epiphyseal screws of distal radius volar plates: Anatomical study comparing ultra-sound and fluoroscopy	Detection of long epiphyseal screws	43.33%	Ultrasound
Bianchi et al. [49]	Screw impingement on the extensor tendons in distal radius fractures treated by volar plating: sonographic appearance	Detection of screw protruding from radial cortex	12 screw from 9 patients	Ultrasound
Sugun et al. [50]	Screw prominences related to palmar locking plating of distal radius	Detection of screw protruding from dorsal cortex	59/230 screws	Ultrasound
Gurbuz et al. [51]	Comparison of ultrasound and dorsal horizon radiographic view for the detection of dorsal screw penetration	Detecting dorsal cortical screw penetration of the distal radius	87%	Ultrasound
Gurbuz et al. [51]	Comparison of ultrasound and dorsal horizon radiographic view for the detection of dorsal screw penetration	Detecting dorsal cortical screw penetration of the distal radius	71%	X-ray
Haug et al. [52]	A new radiological method to detect dorsally penetrating screws when using volar locking plates in distal radial fractures	Detection of screw penetration through dorsal cortex	86.7%	X-ray
Sanden et al. [53]	The significance of radiolucent zones sur-rounding pedicle screws	Detection of screw loosening	64% with specificity of 100%	X-ray
Vernet et al. [48]	Detection of penetration of the dorsal cortex by epiphyseal screws of distal radius volar plates: Anatomical study comparing ultra-sound and fluoroscopy	Detection of long epiphyseal screws	96.97%	X-ray
Ko et al. [54]	Screw loosening in the Dynesys stabilization system: radiographic evidence and effect on outcomes	Detection of screw loosening	17/368 screws	X-ray
Stoll et al. [55]	The dynamic neutralization system for the spine: a multi-center study of a novel non-fusion system Received:	Detection of screw loosening	3.6%	X-ray

In a previous study, the rate for defective fixation is 26-37% due to the poor bone quality for patients with unstable or displaced ankle fractures [46], [47]. The screw stripping can happen before reaching the sufficient torque due to the poor bone quality [35]. The lumbar integrated fixation cages that are placed into a section with better bone quality will have more resistant to screw loosening [36].

3.3. Necrosis

The bone necrosis can be defined as the death of the bone cell because of the rise of temperature that exceed the threshold for thermal osteonecrosis and the condition for necrosis to occur is when drill site temperature reaches 47ºC for 1 minute [5]. In Bachus et al. [37] paper it is explained that the purchase strength of screw and pin may be reduced by the loss of bone at the implantation site due to necrosis. The necrosis can cause the fixation to be loosened due to the disintegration of bone around the implantation site [38]. The excessive heat generated from the drilling the bone can cause necrosis that will result in screw self-loosening due to the death of bone cell surrounding the screw.

4. Assessment of Screw-Bone Implant

There are many way to identify the screw-bone implant such as radiography, CT scan, MRI and ultrasound. For this section only two of the method is to be focused on which is the ultrasound and radiography. Vernet et al. [48] have reported that by the use of ultrasound the rate of detecting long epiphyseal screw was 43.33%. Sugun et al. [50] stated the use of ultrasound has detected 59 screws that were protruding with 0.5mm or more from the dorsal cortex of distal radius from the 230 locking screw that were located at the distal rows of the locking plate.

Gurbuz et al. [51] studies have discover that the accuracy to detect screw penetration for 1mm was 87% in ultrasonography. Bianchi et al. [49] have reported that 12 protruding screws are identified through the use of sonography with the mean length of protrusion of 2.7 mm from the radial cortex.

Radiological examination have been used in clinical situation to assess the screw bone interface [53]. The sign of screw loosening can be identified with the presence of a radiolucent area around the screw called “halo” that is produced from the generation of fibrous tissue surrounding the screw [56]. Additional observation that can be used in identifying screw loosening in radiological examination is by the use of “double halo”. It can be defined as inner radiolucent area that are encased by the rim of radiopaque dense bone [54], [56].

4.1. Ultrasound in Bone

The ultrasound diagnostic have been discovered to have the sensitivity of 97.9% with a specificity of 95% for the scan of an elbow fracture and have the accuracy to estimate the fracture displacement adequately by Eckert et al. [57]. This proves that ultrasonic imaging is an excellent alternative compared to radiography which when used periodically can cause harm to human due to the radiation emission[51], [57].

The detection of fracture the sensitivity of ultrasound is 92.9% and a specificity of 99.5% which is comparable to the detection using X-ray that have the sensitivity of 93.2 and specificity of 99.8% have been reported by Moritz et al. [58]. The accuracy of detecting periapical lesions by using ultrasound was 95.2% [59].

A paper from Mujagic et al. [60] has discovered that the rate of detecting deflection of the water-aluminum boundary from an aluminum reflector that act as specimen boundary that are located at end of the cancellous bone with the use of A-mode imaging was 83.2 % for 1 MHz and 70.1% in 3.5 MHz. The results obtained indicate A-mode imaging ability to be use through cancellous bones of thickness 16.5 to 19 mm. The author also stated that the use of ultrasound is possible in cancellous bone with frequency reaching to 3.5MHz.

4.1. Radioghraphy in Bone

Sanden et al. [53] have defined that 1mm is the threshold for screw loosening and reported that the probabilities to detect a loose screw using radiological examination was 64% with the specificity of 100%. Gurbuz et al. [51] and Haug et al. [52] stated the rate for detecting screw penetration for 1 mm by using dorsal horizontal view was 71% and 86.7% respectively.

The rate of loosening identified from the 42 patients by the use or radiographic loosening criteria is 19.7% which is equivalent to 14 patients [54]. In which a total of 17 screws is loosened from the 368 screws inserted. Stoll et al. [55] have stated that the rate of screw loosening is 3.6% from the 280 total screws which are examined in 7 patients. Schnake et al. [61] reported that from their clinical studies that only 4 patient are identified with potential implant failure due to the presence of visible progression with the mean of 4mm on plain radiographs taken from 24 patients.

Pihlajamaki et al. [15] have stated that screw loosening are observed in 18 from 102 patients with the use of radiography with the parameter of loosening defined as a radiolucent area with 1mm of size that are surrounded by a thin sclerotic zone. Ohlin et al. [62] have reported that 34 from 163 cases have the characteristic of radiolucent area from radiographic assessment which indicated that the screws are loosened.

5. Conclusion

In this article, we have done a brief review of several papers to gain understanding on the main component for screw loosening that consists of complication, cause and method to assess the screw loosening in screw-bone implant. Screw loosening can cause severe complication in fracture healing such as non-union, malunion and reduction loss.

We also review on the cause of self-loosening in bolted joint in order to learn the main cause of screw loosening. For the bolted joint screw the main failure mode is slippage, plastic deformation of the fastener and fretting wear between the contact surfaces. Through the use of radiograph and ultrasound the condition of the bone and screw can be examined. From the reviewed literatures the ultrasound technology have the potential to measure screw loosening in bone as ultrasound can accurately determine crack in fractured bone.

The amount of paper that uses ultrasound to measure screw loosening is limited. Mostly the ultrasound technology is used to measure the protruding screw and to detect bone fracture. The advantage of ultrasound is that it is free of ionization agent that could harm the patient when used frequently. Hence, through the use of ultrasound the bone fracture can be monitored constantly.

The use of ultrasound is also cost effective as it does not require complex procedure and equipment. From a clinical standpoint the use of ultrasound can reduce the exposure of ionizing radiation to the surgeon during constant monitoring of the fracture. Further studies regarding the characteristic of ultrasound in a screw-bone implant need to be done in order to determine the whether the screw is loosened or not.

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