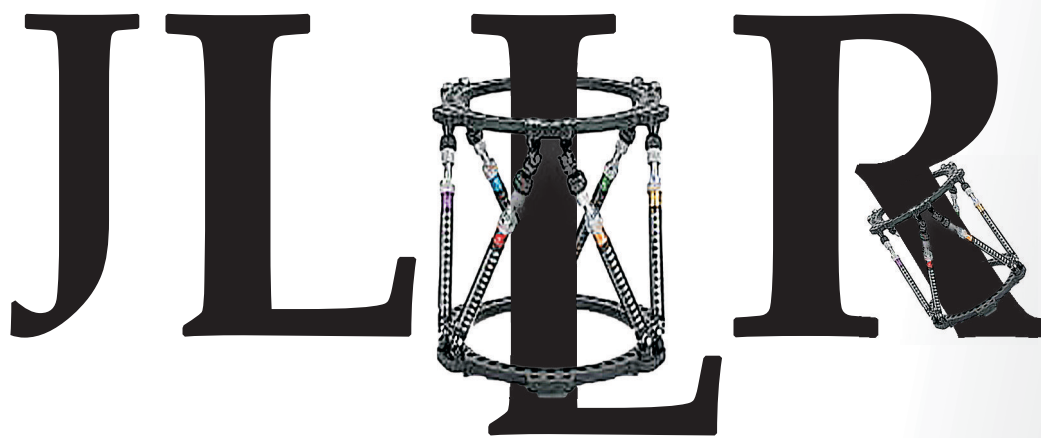


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# Identification of Fine Wire and Half-pin Loosening for External Fixators: A Systematic Review

## Abstract

**Introduction:** This review article discusses the published methods of identification of fine wire and half-pin loosening. The evidence is reviewed and presented for the clinical, radiological and histological analysis of the half-pin and fine wire to bone interface. **Materials and Methods:** A Preferred Reporting Items for Systematic Reviews and Meta-Analyses compliant systematic review was conducted. Studies investigating the use of external fixators with descriptions on measurement of half-pin and fine wire loosening were included in this review. **Results:** Eight studies were eligible and included. No randomized controlled trials were identified. Torque measurement was most frequently used to quantify the half-pin to bone interface, histological analysis was performed by three studies, and radiographic analysis was performed by five papers including plain film and micro-computed tomography (CT) techniques. **Discussion:** The available evidence was of poor quality, with a lack of homogeneity in quantitative data for torque measurements and a prevalence of arbitrary figures for the definition of loosening. There was no mechanical analysis of fine wire loosening, and the most common clinical measure used for loosening was a scale validated for infection. Micro-CT was validated against torque figures and appears to be the most repeatable measure which could be applied clinically, however has only been used in canine studies. We recommend a study to compare the clinically relevant measurement of loosening against a standard model to provide a validated method of identification or prediction of half-pin and fine wire loosening.

**Keywords:** External fixation, fine wire, half-pin, loosening, systematic review

## Introduction

Fine wire and half-pin use are integral to the application of external fixators and frames for management of a number of different pathologies in orthopedic and limb reconstruction surgery.<sup>[1,2]</sup> The identification of fine wire and half-pin loosening during the use of such techniques is important to maintaining the efficacy of the construct. Failure to recognize and treat wire and pin loosening can increase the risk of infection and result in the failure of the construct.<sup>[2-5]</sup>

The bone half-pin interface remains a weak link in the stability of an external fixation construct. Half-pin loosening and pin tract infection are intimately related, but the pathophysiology and relationship are not clearly understood. It has been hypothesized that loosening results in increased inflammatory change and fluid accumulation, which could increase the risk of pin tract infection.<sup>[6,7]</sup> However, other authors have shown that in the absence of

infection, there is a progressive reduction in the pin extraction torque over time.<sup>[8,9]</sup>

The recognition of fine wire and half-pin loosening within published literature includes clinical and radiographical findings; however, there appears to be no consensus on the best method to define or classify this. Due to a lack of homogeneity in the definitions of loosening, the clinical frequency of half-pin and wire loosening is hard to determine.

The aim of this study was to systematically review the current evidence describing the methods and techniques used for the identification of half-pin and fine wire loosening.

## Materials and Methods

A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) compliant systematic review<sup>[10]</sup> was conducted to determine what extent is external fixator loosening present in the reported literature, and how is it identified and quantified.

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## Search strategy

We performed a systematic literature search on the July 9, 2021 to identify relevant articles. We conducted electronic searches for eligible studies within each of the following databases:

- Ovid MEDLINE (R) ALL <1946 to July 08, 2021 > date searched July 09, 2021
- Embase (OvidSP) <1974 to 2021 week 26>, date searched July 09, 2021
- Cochrane Database of Systematic Reviews, Issue 7 of 12, July 2021, date searched July 09, 2021
- Cochrane Central Register of Controlled Trials, Issue 7 of 12, July, date searched July 09, 2021
- Cochrane Clinical Answers, date searched July 09, 2021.

We conducted electronic searches of the following grey literature database using search strategies adapted from the final MEDLINE search strategy:

- Google Scholar, date searched July 09, 2021.

We searched trials register (NIH U. S. National Library of Medicine ClinicalTrials.gov (<https://clinicaltrials.gov/ct2/home>) to identify registered trials (up to July 9, 2021).

The search strategy is presented in Table 1.

## Search eligibility

We aimed to identify randomized controlled trials (RCTs) and nonrandomized studies including prospective and retrospective comparative cohort studies, case-control studies, laboratory-based studies including finite element analysis, and cadaveric, animal, and mechanical analysis studies.

We included cross-sectional studies, case series, and case reports, as we did not expect to find a significant number of trials to have been conducted in this specific field of research.

Studies published in any language were included and papers were eligible irrespective of date of publication.

## Population

Included were studies examining adults, children and biomechanical studies, laboratory studies, and animal studies. Participants included patients undergoing deformity and acute fracture management of the lower limb with external fine wire and or half-pin framing and include pin to bar external fixators.

## Study identification

Two reviewers J. N and AT independently reviewed the title and abstract of each study. Full-text papers were ordered for those studies which met the eligibility criteria. Two reviewers J. N and AT then independently reviewed each full-text paper against the eligibility criteria and included those studies which met them. If a study eligibility was

questioned or a disagreement arose between the reviewers, this was resolved with discussion between the two reviewers until a consensus was reached on its inclusion.

## Data

Data were collected from each included paper by one reviewer J. N.

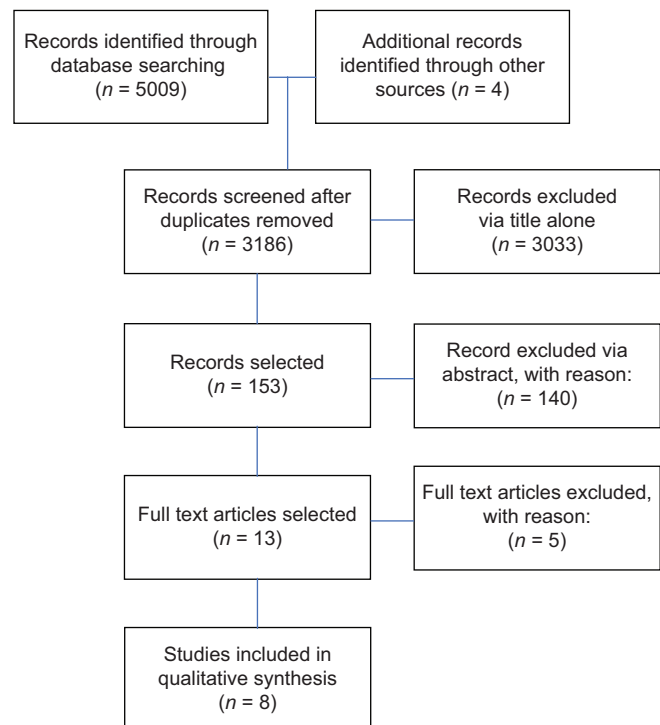
The method of wire and half-pin loosening was identified, including clinical, radiological, and histological analysis. Where possible consequences as a direct result of half-pin loosening was captured. Any previously validated method of classification was identified and explored.

## Data analysis

No statistical analysis was performed due to the inhomogeneity between study population and indication for external fixation, including the type of pins/wires used and the lack of consistency in the definition of outcome measures. Therefore, a narrative review was deemed most appropriate and was undertaken to answer the research question.

## Results

Five thousand and nine results were acquired using our search strategy. Eight studies were included in our review. The results of the search are presented in the PRISMA flow-Chart [Chart 1]. No RCTs were identified and there were significant data heterogeneity. Therefore, we present a narrative review of the included studies; the findings are summarized in Table 2.



**Chart 1: PRISMA flow chart. PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses**

**Table 1: Search strategy**

Search strategies (databases and registers)			
Databases			
Medline and EMBASE search strategies can be found below			
Cochrane library search strategy			
#1 MeSH descriptor: [Lower Extremity] explode all trees 7321			
#2 MeSH descriptor: [Femoral Fractures] explode all trees 2007			
#3 MeSH descriptor: [Ankle Fractures] explode all trees 165			
#4 MeSH descriptor: [Tibial Fractures] explode all trees 356			
#5 (((“lower” NEAR/2 limb*) OR (“lower” NEAR/2 extremity*) OR foot* OR feet* OR knee* OR leg* OR thigh* OR hip* OR buttock* OR ankle OR tibia OR femur OR femoral OR fibula) NEAR/3 (fracture* OR trauma* OR deform*)):ti, ab, kw 8873			
#6 #1 OR #2 OR #3 OR #4 OR #5 16210			
#7 MeSH descriptor: [External Fixators] explode all trees 1041			
#8 MeSH descriptor: [Fracture Fixation] explode all trees 1799			
#9 ((“External fixation” NEAR/2 device*) OR (“External” NEAR/2 fixator*) OR (“External ring” NEAR/2 fixator*) OR (“External” NEAR/2 frame*) OR “external orthopaedic fixation systems” OR (“external skeletal” NEAR/2 fixator*)):ti, ab, kw 368			
#10 (Ilizarov NEAR/2 (fixator* OR frame* OR apparatus OR method OR tech*)):ti, ab, kw 50			
#11 #7 OR #8 OR #9 OR #10 2776			
#12#6 AND #11 986			
#13 MeSH descriptor: [Equipment Failure] explode all trees 2042			
#14 ((equipment OR device OR hardware) NEAR/3 (defect* OR failure* OR malfunction* OR misuse*)):ti, ab, kw 1879			
#15 (regenerate NEAR/3 collapse):ti, ab, kw 0			
#16 #13 OR #14 OR #15 2722			
#17 MeSH descriptor: [Bone Wires] explode all trees 179			
#18 ((pin* OR wire* OR (“kirschner” NEAR/2 wire*) OR (“bone” NEAR/2 wire*) OR screw*) NEAR/5 (loosen OR loose OR loosening OR break* OR remov*)):ti, ab, kw 480			
#19 #17 OR #18 645			
#20 MeSH descriptor: [Reoperation] explode all trees 1859			
#21 (“return to theatre” OR “joint revision” OR (“repeat” NEAR/2 surg*) OR (surg* NEAR/2 “revision”) OR reoperation* OR re?operation*):ti, ab, kw 6515			
#22 ((repeat OR revision) NEAR/1 (surgery OR surgical OR joint)):ti, ab, kw 1046			
#23 #20 OR #21 OR #22 6517			
#24 #16 OR #19 OR #23 9532			
#25 #12 AND #24 203			
<b>Google scholar search strategy ((lower limb deformity OR lower limb fracture)) AND ((external ring fixator loosening))</b>			
Search history results			
Line number	Source	Criteria	Results
1	Ovid MEDLINE (R) ALL	exp Lower Extremity/or exp Femoral Fractures/or ankle fractures/or tibial fractures/	225944
2	Ovid MEDLINE (R) ALL	((“lower limb*” or “lower extremity*” or foot* or feet* or knee* or leg* or thigh* or hip* or buttock* or ankle or tibia or femur or femoral or fibula) adj3 (fracture* or trauma* or deform*)):ti, ab, kf.	68260
3	Ovid MEDLINE (R) ALL	or/1-2	256162
4	Ovid MEDLINE (R) ALL	exp External Fixators/or exp Fracture Fixation/	81666
5	Ovid MEDLINE (R) ALL	(“External fixation device*” or “External fixator*” or “External ring fixator*” or “External frame*” or “external orthopaedic fixation system*” or “external skeletal fixator*”).ti, ab, kf.	5681
6	Ovid MEDLINE (R) ALL	(Ilizarov adj2 (fixator* or frame* or apparatus or method or tech*)):ti, ab, kf.	1753
7	Ovid MEDLINE (R) ALL	or/4-6	83908
8	Ovid MEDLINE (R) ALL	3 and 7	28246
9	Ovid MEDLINE (R) ALL	exp Equipment Failure/	89071
10	Ovid MEDLINE (R) ALL	((equipment or device or hardware) adj3 (defect* or failure* or malfunction* or misuse*)):ti, ab, kf.	5440
11	Ovid MEDLINE (R) ALL	(regenerate adj3 collapse).ti, ab, kf.	6
12	Ovid MEDLINE (R) ALL	or/9-11	93244
13	Ovid MEDLINE (R) ALL	Bone Wires/ae [Adverse Effects]	434

*Contd...*

Table 1: Contd...

Search history results			
Line number	Source	Criteria	Results
14	Ovid MEDLINE (R) ALL	((pin* or wire* or “kirschner wire*” or “bone wire*” or screw*) adj5 (loosen or loose or loosening or break* or remov*)).ti, ab, kf.	7570
15	Ovid MEDLINE (R) ALL	or/13-14	7922
16	Ovid MEDLINE (R) ALL	Reoperation/	90421
17	Ovid MEDLINE (R) ALL	(“return to theatre” or “joint revision” or “repeat surg*” or “surg* revision” or reoperation* or re?operation*).ti, ab, kf.	42091
18	Ovid MEDLINE (R) ALL	((repeat or revision) adj1 (surgery or surgical or joint)).ti, ab, kf.	17895
19	Ovid MEDLINE (R) ALL	or/16-18	123073
20	Ovid MEDLINE (R) ALL	12 or 15 or 19	209247
21	Ovid MEDLINE (R) ALL	8 and 20	3478
1	Embase	exp *lower limb/or leg fracture/or ankle fracture/or foot fracture/or knee fracture/or hip fracture/or tibia fracture/or fibula fracture/or femur fracture/	181698
2	Embase	((“lower limb*” or “lower extremity*” or foot* or feet* or knee* or leg* or thigh* or hip* or buttock* or ankle or tibia or femur or femoral or fibula) adj3 (fracture* or trauma* or deform*)).ti, ab, kw.	83484
3	Embase	or/1-2	219546
4	Embase	exp *fracture external fixation/or exp *external fixator/or exp *fracture fixation/	41027
5	Embase	(“External fixation device*” or “External fixator*” or “External ring fixator*” or “External frame*” or “external orthopaedic fixation system*” or “external skeletal fixator*”).ti, ab, kw.	6530
6	Embase	(Ilizarov adj2 (fixator* or frame* or apparatus or method or tech*)).ti, ab, kw.	2026
7	Embase	or/4-6	44812
8	Embase	3 and 7	14925
9	Embase	exp *device failure/	1242
10	Embase	((equipment or device or hardware) adj3 (defect* or failure* or malfunction* or misuse*)).ti, ab, kw.	8497
11	Embase	(regenerate adj3 collapse).ti, ab, kw.	6
12	Embase	or/9-11	9553
13	Embase	exp *bone wire/	1838
14	Embase	((pin* or wire* or “kirschner wire*” or “bone wire*” or screw*) adj5 (loosen or loose or loosening or break* or remov*)).ti, ab, kw.	9307
15	Embase	or/13-14	10911
16	Embase	exp *reoperation/	6731
17	Embase	(“return to theatre” or “joint revision” or “repeat surg*” or “surg* revision” or reoperation* or re?operation*).ti, ab, kw.	59104
18	Embase	((repeat or revision) adj1 (surgery or surgical or joint)).ti, ab, kw.	24023
19	Embase	or/16-18	76814
20	Embase	12 or 15 or 19	95898
21	Embase	8 and 20	1308

## Determining half-pin site loosening

### Torque measurement

The most common method of evaluating pin loosening in the studies reviewed was to measure the extraction torque of a pin with a digital or analog torque wrench and compare it with the corresponding insertion torque. This was first described by Pettine *et al.* and subsequently by Moroni *et al.*<sup>[12,18,19]</sup> Using a torque meter [Figure 1], the authors were able to present reproducible results; however, we note that units presented varied between papers, from N mm, N cm, and N m.

Placzek *et al.* offered a new and more transferable index for measuring the difference between insertion and extraction

torque.<sup>[16]</sup> The “Fixation Index” [Figure 2] is the quotient maximum extraction torque over maximum insertion torque.

The authors stated that this allows appreciation of the specific screw fixation strength and eliminates the influence of multiple variables including varying half-pin–bone contact, coating, roughness, diameter, cone size, thread depth, and the contact zone along the half-pin.

Finally, Pieske *et al.* used a similar digital torque wrench to ascertain the extraction strength; however, the authors formed their own group stratification split into four groups: (1) “strong” (>0.8 N m); (2) “good” (0.4– 0.8





Figure 1: An Image of a commercially available Digital Torque Wrench

N m); (3) “low” (<0.4 N m but not “loose”); and (4) “loose” (the half-pin could be extracted manually because of complete loosening of the pin–bone interface).<sup>[17]</sup>

We were unable to tabulate and compare different torque figures and provide a definitive comparison chart for loose versus secure half-pins as described in our review papers, as there were too many unaccountable variables, including half-pin size, site, and duration of treatment.

#### Radiological analysis

Five papers used plain film radiography as a measure of half-pin–bone loosening and one paper described the use of micro-computed tomography (CT).

Plain film radiography analysis was commonly performed using two different view radiographs taken at intervals during treatment. Pettine *et al.* and Aro *et al.* performed radiological analysis of the half-pin–bone interface at weekly intervals. Rarefaction of bone around a half-pin site was arbitrarily chosen by both authors at 0.5 mm or more, this was correlated with the torque value and histological analysis performed.

Pieske *et al.*<sup>[17]</sup> considered a half-pin as loose when a radiolucent line was present around the threaded half-pin and grouped the results into monocortical (“minor loosening”) and bicortical (“major loosening”).

Pettine *et al.* showed statistical significance when radiographic rarefaction exceeded 1 mm around the half-pin–bone interface, it was noted that no half-pins had rarefaction of the exit cortex without entry cortex rarefaction.

Micro-CT was utilized by Zheng *et al.* as a measure of bone quality at the half-pin–bone interface.<sup>[11]</sup> Scanned slices were reconstructed to show cutaway views of the implanted half-pins [Figure 3]. These cross-sectional images were perpendicular to the longitudinal axis of half-pin.

Designated regions of interest 6 mm in size were defined; these included the central area of implanted half-pins and surrounding bone tissues and were subsequently compared with histomorphometry parameters discussed in the basic science analysis section below.

$$\text{Fixation Index} = \frac{\text{Maximum extraction torque}}{\text{Maximum insertion torque}}$$

The fixation index: The quotient maximum extraction torque over maximum insertion torque allows to appreciate the specific screw fixation strength because of elimination of the influence of the varying pin–bone contact.

Figure 2: How to calculate the 'Fixation Index'

#### Determining fine wire site loosening

No papers provided a discernible measure of mechanical loosening of fine wire external fixation; however, three papers<sup>[13–15]</sup> made reference to the Checketts and Ottenburn classification used for the prevention and management of external fixator pin track sepsis.<sup>[20]</sup>

Described in the year 2000, this system classifies pin site infections into two groups, and makes assumptions on the pin to bone interface through clinical findings, it is therefore used as a proxy measure for loosening. The two groups are minor (Grades 1-3) and major (Grades 4-6), major infections are deemed at risk of sepsis and osteomyelitis and also deemed loose, and were used in all three papers as a proxy measure of wire and pin site loosening.

#### Basic science

Three papers were identified with a basic science theme.

Pettine *et al.* and Aro *et al.* performed a clinical, radiological, and histological analysis of the half-pin–bone interface using *in vivo* loading conditions on canine subjects.<sup>[8,12]</sup> Pettine *et al.* used 5 mm titanium self-tapping threaded half-pins in predrilled (3.5 mm diameter) tibia. Aro *et al.* used 6 mm stainless steel half-pins which were predrilled to 3.2 mm.

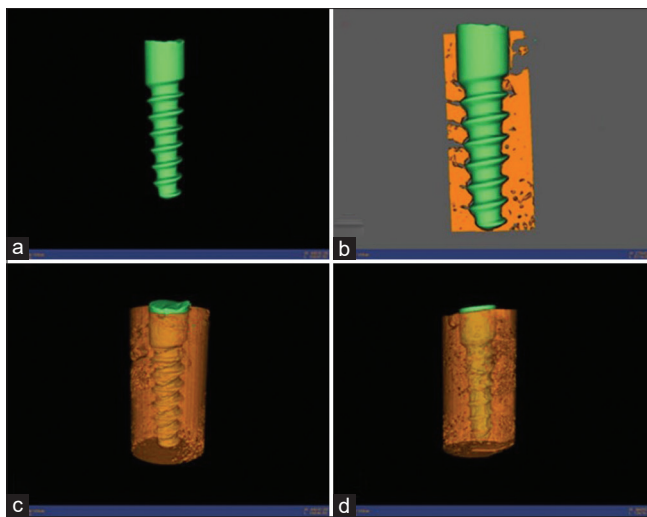
Both papers conducted a clinical evaluation using the previously described torque wrench method to measure the maximum insertional torque of half-pins. Pettine *et al.* found that of 168 half-pins inserted, 69% with an initial torque resistance of less than 67.8 Ncm developed gross clinical loosening, whereas only 9% with an initial torque resistance >67.8 Ncm became grossly loose.

Histological analysis of the half-pin–bone interface was performed after termination of both experiments, this was performed using combined tetracycline labeling and microradiography, and the results compared with the torque values for each pin. The method of tetracycline labeling was first described by Vanderhoeft *et al.*<sup>[21]</sup> and enables clear identification of new bone formed. Pettine *et al.* used the method to identify where bone had formed or resorbed around the half-pin threads in 6 different zones along the treaded half-pin. Statistically significant results were found in the histology of bony “thread triangles” between the grossly loose and tight half-pins. It was also noted that the “entry cortex” sample zone showed more bone resorption when compared with the “exit cortex” zone.

**Table 2: Descriptive summary of included studies**

Author	Year published	Number of patients/pins	Methods listed to identify loosening	Consequences
Zheng <i>et al.</i> <sup>[11]</sup>	2011	24 dogs 96 half-pins	Extraction torque Radiological assessment two view X-ray Micro-CT Histological analysis	N/A <i>in vivo</i> canine study
Aro <i>et al.</i> <sup>[8]</sup>	1993	57 dogs 342 half-pins	Torque-fixation index Radiological assessment two view X-ray Histological analysis	N/A
Pettine <i>et al.</i> <sup>[12]</sup>	1993	14 dogs 84 half-pins	Torque-fixation index Radiological assessment two view X-ray Histological analysis	Bone necrosis <i>n</i> =3
Toksvig-Larsen and Aspenberg <sup>[13]</sup>	2013	20 patients	Torque insertion Checketts-Otterburn	Infection <i>n</i> =2 patients
Gathen <i>et al.</i> <sup>[14]</sup>	2019	4 patients 4 cadavers	Torque-Fixation index Checketts-Otterburn	Infection <i>n</i> =2 patients
Pizà <i>et al.</i> <sup>[15]</sup>	2014	23 patients 161 half-pins	Torque-Fixation index Checketts-Otterburn Radiological assessment two view X-ray	Infection <i>n</i> =13 pins Cortical osteolysis <i>n</i> =72 Skin necrosis <i>n</i> =26
Placzek <i>et al.</i> <sup>[16]</sup>	2006	21 patients	Torque-Fixation index Schmidt pin-track infection classification	Infection <i>n</i> =9
Pieske <i>et al.</i> <sup>[17]</sup>	2010	38 patients 152 half-pins	Extraction torque Radiological assessment two view X-ray	Infection <i>n</i> =6

N/A: Not available

**Figure 3:** Micro CT analysis. (a) Threaded Pin 3D render. (b) Cross section of Bone to Pin interface. (c) Volumetric render 1. (d) Volumetric render 2

Zheng *et al.* also used canine subjects but performed a different form of histological analysis, using a combination of decalcified and undecalcified preparation with toluidine blue staining.<sup>[3]</sup> Three blinded individuals then performed histological analysis reporting on bone mineral content, bone mineral density, tissue mineral density, tissue mineral content, and bone volume/tissue volume.

Pieske *et al.*<sup>[17]</sup> performed a comparative study between two half-pin material types, within their analysis patient's age found to correlate to an increase in the rate of loose half-pins, ( $P = 0.018$ ). Other demographic data including gender, ASA score incidence of open fracture were not correlated to loosening ( $P \geq 0.05$ ).

### Consequences of half-pin and fine wire loosening

Of the 8 studies included, 7 detailed consequences of pin site loosening. These include bone necrosis, infection, skin necrosis and cortical osteolysis were all directly implicated following pin loosening.<sup>[12,15]</sup> However, all papers detailed in their discussion that there is no consensus as to which forms first infection or half-pin loosening, and that rarely does one exist without the other.

### Discussion

Identification of fine wire and half-pin loosening is an important part of the management of patients undergoing treatment with all types of external fixation. A consensus agreement on what defines a loose wire or half-pin remains elusive. Defined criteria, clinically, radiologically, or biomechanically, would serve to allow more homogeneity in reporting outcomes in published data.

Providing clinicians with defined criteria or measurement tools for fine wire and half-pin loosening would aid in maintaining the efficacy of the construct. Inconsistencies in measurement or lack of scientific grounding in techniques already used, may result in failure to recognize and treat wire and pin loosening which can increase the risk of infection and result in the failure of the construct.<sup>[2,4-6]</sup>

Almost all studies identified as suitable for this review, included fine wire or half-pin loosening as a secondary measure, few listed rationale for their chosen method and almost none provided peer reviewed data on why one method was chosen over another. We found no studies

which provided meaningful analysis or measurement of fine wire loosening. Historical references occurred frequently, with little modification or update on historic techniques for defining half-pin or wire loosening. Techniques such as two view plain film radiography with arbitrary measurement of rarefaction or extraction torque measurement into general categories, were without apparent scientific basis but served to present the study findings.<sup>[8,12]</sup>

There was no comparative trial between two types of measurement using the same half-pin or fine wire to bone interface.

Technological advances including the use of digital torque meters or micro-CT were not compared with existing technology, only correlations were drawn between the results of such measures with broader definitions of loosening.

Our search strategy produced results most often surrounding the *in vivo* comparison of two half-pin types, either the material, mechanics, or coating. Measurement of insertion versus extraction torque was the most cited method of defining loosening, but again arbitrary values for loosening were regularly chosen, mostly due to the study design being a comparison between two cohorts and detecting a significant difference between groups was the main outcome measure, rather than reaching a lower set threshold for what would be considered loose.

The torque index was a measure used in five papers, displayed as a ratio of insertion versus extraction torque. This could only be calculated and measured after removal of the half-pin, and so would have little clinical benefit in ascertaining if a half-pin was loose prior to removal, or in the decision-making process for replacing a suspected loose half-pin.

One study defined an absolute measure of torque insertion which was statistically significant in reducing the rate of “grossly loose half-pins,” this is not strictly identification of loose half-pins, but could go some way to mitigate the risk of half-pin loosening to the practicing clinician. Insertion torque of greater than 68.7 Ncm<sup>[12]</sup> into a tibia resulted in only 9% of half-pins becoming grossly loose (less than 5 Ncm extraction torque) after 40 days *in vivo*.

The two papers which provided a histological analysis of half-pin sites after application of frames in canine models, gave an in-depth analysis of the basic science surrounding half-pin site loosening.

Both papers compared the half-pin–bone interface between a stable fracture configuration and an unstable one, with each reporting that frames around an unstable fracture pattern had the highest incidence of gross loosening. Within their results was the histological analysis which showed that secure half-pin tracts were characterized by a lack of bone remodeling, whereas loose half-pin tracts displayed extensive bone resorption and inflammatory infiltrates.

With respect to clinical assessment of half-pin and fine wire loosening, the Checketts and Otterburn score was used in three papers. All three used this score as a primary measure for pin site infection and made only assumptions that a pin site with a “major” infection (Grade 4-6) was at significant risk of being loose, noting that this score recommends that external fixation be abandoned with grade 4, 5 and 6 pin sites.

Radiological analysis was described with a two-view plain film radiograph. A reproducible measure of 0.5 mm of radiolucency around a half-pin–bone interface was set to define loosening. In particular if radiolucency greater than 0.5 mm was seen around the far cortex of a half-pin–bone interface this could be strongly correlated with a clinically loose half-pin. Micro-CT analysis was performed in one study, measurement of bony porosity was performed, and assumptions made on bony absorption around the half-pin based on the number of pores counted within a 6 mm sphere, these data were strongly correlated to a high torque index suggesting such analysis of bony porosity may be a reproducible and reliable proxy measure of half-pin security.

It has been noted by the authors of this study, that there were no published techniques for utilizing modern imaging software to quantify radiolucency around the pin to bone interface. Recent studies have validated the use of the pixel value ratio (PVR) for evaluating bony regenerate by comparing pixel values on plain radiographs and correlating results with DEXA scanning.<sup>[22]</sup> Such a technique could be adopted to better standardize the definition of radiolucency around a pin site.

The consequences of half-pin and fine wire site loosening included bone necrosis, cortical osteolysis, skin necrosis and infection. Infection was listed most often; however, no definitive pathway was proposed by any of the studies as to which process occurred first. A loose pin is a recognized risk factor for infection of a pin tract, just as the pins that are subsequently removed from an infected pin tract are invariably loose.<sup>[8]</sup>

## Conclusion

It is clear that various methods of clinical, biomechanical, radiological, and histological analysis have been performed and described for half-pin loosening but without comparative studies to validate the process chosen.

The torque index appears to be used most frequently; however, it fails as a clinically useful measure as it requires the extraction torque, therefore necessitates the removal of the half-pin in question. Whereas, simply recording the insertion torque may only provide a probability of loosening over a given time.

The ideal test would be one that provides a measurable index without sacrificing or risk damaging the pin–bone



interface; the measure would be reproducible and easily performed while acceptable to the patient. Only one study appeared to use such a measure, the micro-CT scan, but the authors failed to define a scale to represent loosening based on the number or volume of porosity around the pin–bone interface.

In the absence of a large multicenter trial of one method of measuring loosening versus another, further studies should be constructed to set out a standardized, evidence-based definition of loosening. We would suggest the correlation of an *in vivo* extraction torque measurement with a recent radiograph analysis of the pin site adopting a modern technique of quantifying radiolucency on plain films such as the PVR.

### Supporting information

Registration and protocol, As per PRISMA checklist, this study was not registered as was not required.

A protocol was produced and is available on request.

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### Conflicts of interest

There are no conflicts of interest.

### References

- Kummer FJ. Biomechanics of the Ilizarov external fixator. *Clin Orthop Relat Res* 1992;293:11-4.
- Ziran BH, Smith WR, Anglen JO, Tornetta Iii P. External fixation: How to make it work. *Instr Course Lect* 2008;57:37-49.
- Moroni A, Toksvig-Larsen S, Maltarello MC, Orienti L, Stea S, Giannini S. A comparison of hydroxyapatite-coated, titanium-coated, and uncoated tapered external-fixation pins. An *in vivo* study in sheep. *J Bone Joint Surg Am* 1998;80:547-54.
- Huiskes R, Chao EY, Crippen TE. Parametric analyses of pin-bone stresses in external fracture fixation devices. *J Orthop Res* 1985;3:341-9.
- Oni OO, Capper M, Soutis C. An investigation of the bending stiffness of and the plane stresses generated by a flanged external fixator pin. *J Orthop Trauma* 1995;9:83-8.
- Clasper JC, Cannon LB, Stapley SA, Taylor VM, Watkins PE. Fluid accumulation and the rapid spread of bacteria in the pathogenesis of external fixator pin track infection. *Injury* 2001;32:377-81.
- Aro HT, Markel MD, Chao EY. Cortical bone reactions at the interface of external fixation half-pins under different loading conditions. *J Trauma* 1993;35:776-85.
- Sarpel Y, Gulsen M, Togrul E, Capa M, Herdem M. Comparison of mechanical performance among different frame configurations of the Ilizarov external fixator: Experimental study. *J Trauma* 2005;58:546-52.
- Podolsky A, Chao EY. Mechanical performance of Ilizarov circular external fixators in comparison with other external fixators. *Clin Orthop Relat Res* 1993;61-70.
- Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, *et al.* The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Int J Surg* 2021;88:105906.
- Zheng K, Li X, Fu J, Fan X, Wang P, Hao Y, *et al.* Effects of Ti2448 half-pin with low elastic modulus on pin loosening in unilateral external fixation. *J Mater Sci Mater Med* 2011;22:1579-88.
- Pettine KA, Chao EY, Kelly PJ. Analysis of the external fixator pin-bone interface. *Clin Orthop Relat Res* 1993;(293):18-27.
- Toksvig-Larsen S, Aspenberg P. Bisphosphonate-coated external fixation pins appear similar to hydroxyapatite-coated pins in the tibial metaphysis and to uncoated pins in the shaft. *Acta Orthop* 2013;84:314-8.
- Gathen M, Ploeger MM, Jaenisch M, Koob S, Cucchi D, Kasapovic A, *et al.* Outcome evaluation of new calcium titanate schanz-screws for external fixators. First clinical results and cadaver studies. *J Mater Sci Mater Med* 2019;30:124.
- Pizà G, Caja VL, González-Viejo MA, Navarro A. Hydroxyapatite-coated external-fixation pins. The effect on pin loosening and pin-track infection in leg lengthening for short stature. *J Bone Joint Surg Br* 2004;86:892-7.
- Placzek R, Ruffer M, Deuretzbacher G, Heijens E, Meiss AL. The fixation strength of hydroxyapatite-coated Schanz screws and standard stainless steel Schanz screws in lower extremity lengthening: A comparison based on a new torque value index: The fixation index. *Arch Orthop Trauma Surg* 2006;126:369-73.
- Pieske O, Kaltenhauser F, Pichlmaier L, Schramm N, Trentzsch H, Löffler T, *et al.* Clinical benefit of hydroxyapatite-coated pins compared with stainless steel pins in external fixation at the wrist: A randomised prospective study. *Injury* 2010;41:1031-6.
- Moroni A, Faldini C, Marchetti S, Manca M, Consoli V, Giannini S. Improvement of the bone-pin interface strength in osteoporotic bone with use of hydroxyapatite-coated tapered external-fixation pins. A prospective, randomized clinical study of wrist fractures. *J Bone Joint Surg Am* 2001;83:717-21.
- Moroni A, Vannini F, Mosca M, Giannini S. State of the art review: Techniques to avoid pin loosening and infection in external fixation. *J Orthop Trauma* 2002;16:189-95.
- Chacketts R, MacEachern A, Otterburn M. Pin track infection and the principles of pin site care. In: *Orthofix External Fixation in Trauma and Orthopaedics*. Springer, London. 2000. p. 97-103.
- Vanderhoeft PJ, Kelly PJ, Peterson LF. Determination of growth rates in canine bone by means of tetracycline-labeled patterns. *Lab Invest* 1962;11:714-26.
- Bafor A, Duncan ME, Iobst CA. Evaluating the utility of the pixel value ratio in the determination of time to full weight-bearing in patients undergoing intramedullary limb lengthening. *Strategies Trauma Limb Reconstr* 2020;15:74-8.