Robot-assisted fracture fixation in orthopaedic trauma surgery: a systematic review

Henk Jan Schuijt, MDab,e, Dennis Hundersmarck, MDc, Diederik Pieter Johan Smeing, MD, PhD, Detlef van der Velde, MD, PhD, Michael John Weaver, MD

Objective: To investigate the applications of robot-assisted surgery and its effect on surgical outcomes in orthopaedic trauma patients.

Data Sources: A search was performed in PubMed and Embase for articles in English, Dutch, German, or French, without restrictions on follow-up times, study size, or year of publication.

Study Selection: Studies were included if they investigated patients undergoing robot-assisted fracture fixation surgery for orthopaedic trauma.

Data Extraction: Outcomes studied were operating time, fluoroscopy time/frequency, complications, functional outcomes, intraoperative blood loss, fracture healing, and screw placement accuracy. Critical appraisal was done by using the Methodological Index for Non-Randomized Studies.

Data Synthesis: Narrative review.

Conclusions: A total of 3832 hits were identified with the search and 8 studies were included with a combined total of 437 included patients, 3 retrospective cohort studies, 2 prospective cohort studies, 1 cohort study not otherwise specified, 1 case series, and 1 randomized controlled trial. Four studies investigated pelvic ring fractures, 3 studies investigated femur fractures, and 1 study investigated scaphoid fractures. Seven investigated percutaneous screw fixation and 1 studied intramedullary nail fixation. One robotic system was used across all studies, the TiRobot, and all procedures were performed in China. The limited evidence suggests that robot-assisted orthopaedic trauma surgery may reduce operating time, use of fluoroscopy, intraoperative blood loss, and improve screw placement accuracy, but the overall quality of evidence was low with a high risk of bias. Robot-assisted fracture fixation does not appear to lead to better functional outcomes for the patient.

Level of evidence: III

Keywords: fracture fixation, orthopaedic trauma, robot-assisted, systematic review, trauma surgery

1. Introduction

Robotic surgery techniques are emerging in many specialties, such as surgical oncology, urology, endocrine surgery, and cardiac surgery.\textsuperscript{[1–4]} There are many advantages to the use of surgical robots. In general surgery, they improve dexterity and hand-eye coordination, they can provide the surgeon with a more ergonomic position and make surgical approaches possible that were previously thought technically impossible.\textsuperscript{[1,5]} Other advantages include a wider range of motion, better three-dimensional (3D) visualization compared with laparoscopic procedures, and the ability to perform telesurgery that minimizes radiation exposure.\textsuperscript{[1,6]} Most surgical robots cost between $1 and $2.5 million, making the required initial investment one of the major obstacles for the widespread implementation of robotic surgery.\textsuperscript{[3,7]} Other disadvantages are the loss of haptic sensation, size of the machines, and the required trained staff in the operating theater.\textsuperscript{[1]} It is possible that these disadvantages will improve over time, as is often the case with technological advance.\textsuperscript{[1]}

For the purpose of this review, the difference between robot-assisted surgery and computer-assisted surgical navigation should be clarified. Computer-assisted surgical navigation comprises any type of computer-based procedure that uses advanced technology such as 3D imaging or augmented reality in planning performing surgical procedures. Robotic surgery involves the use of an advanced surgical robot, where the surgeon may or may not be present at the operating table. A surgical robot is a computerized system that can assist with surgical navigation, often with an arm capable of performing certain surgical tasks with the help of instruments attached to the arm such as a guidance sleeve. Robots may be controlled by the surgeon or partially autonomous, and sometimes the surgeon does not have to be present in the operation theatre at all (i.e.,
telesurgical procedures). It should be noted that most robotic systems are designed to be compatible with computer-assisted navigation systems.\cite{2,6,8} In summary, robots in surgery are used for assistance in surgical navigation, but not all computer-assisted surgical navigation systems are robots.

In orthopaedics, a few review studies have been done investigating the application and efficacy of robotics.\cite{9-12} Robots have been extensively used in spine surgery for the placement of pedicle screws and have been shown to give better outcomes than conventional techniques.\cite{9,10} Robots have also been used in hip arthroplasty and total knee arthroplasty, but there is no conclusive evidence that robots are superior to the conventional technique, since surgery times are much longer, costs are high, and complication rates are higher in robotic surgery groups.\cite{9,10} Although these review papers also claim to investigate trauma, their primary focus was elective orthopaedic surgery.\cite{9-11} This review investigating robot-assisted fracture fixation in orthopaedic trauma surgery provides an overview of the current applications in traumatology. The aim of this study is to investigate the application of robot-assisted surgery and its effect on surgical outcomes in orthopaedic trauma patients.

2. Methods

This systematic review was written in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses PRISMA guidelines.\cite{13} The study protocol was registered in the international prospective register of systematic reviews (PROSPERO ID CRD42020167808). This was a literature review, hence no patients were included in this study. The study was deemed exempt from Institutional Review Board and Animal Use Committee Review.

2.1. Literature search and study selection

A systematic search was done in PubMed and EMBASE on July 26, 2019 using search terms and synonyms for orthopaedics, trauma, fracture, and robotics. A professional medical librarian helped build the search syntax (Supplement 1, http://links.lww.com/OTAI/A20). No filters were applied for the search. Authors HJS and DH independently assessed title and abstracts for eligibility. Full-text screening was done when at least one of the authors deemed a study eligible. Disagreements between authors were solved by consensus. For all included studies, forward and backward citation tracking was done to identify any possible additional studies. Screening was done using the Rayyan application by Qatar Computing Research Institute, Doha, Qatar.\cite{14}

2.2. Eligibility criteria

Studies were included if they met the inclusion criteria: the studied population was made up of trauma patients undergoing surgery for orthopaedic trauma (i.e., traumatic fractures of the appendicular skeleton or pelvis, nonpathological). Surgical procedures studied were robot-assisted fixation or partially robot-assisted fixation of the fracture. Study designs were either randomized controlled trials, observational cohort studies (comparative and noncomparative), case-series, or retrospective cohort studies. Studied outcome was at least one of the following: operation time, fluoroscopy time, fluoroscopy frequency, postoperative mortality, postoperative complications, postoperative physical performance and functional outcomes, patient-reported outcomes, ergonomic outcomes for the surgeon, perioperative blood loss (mL), fracture healing, and screw placement accuracy for percutaneous interventions (Grag-Marintschev, Hamelinck, or Liebergaal classification).\cite{15-17} Full text was available in English, Dutch, French, or German. Papers studying computer-assisted surgical navigation without the use of a robot were excluded. There were no restrictions regarding follow-up times, study size, patient age, or year of publication.

2.3. Data extraction, quality assessment, and data synthesis

Data was extracted by author HJS. In addition to the outcomes specified in the inclusion criteria, the following general study information was collected: first author name, year of publication, country, study design, mean/median age, percentage of female participants, sample size, fracture type, and length of follow-up. The level of evidence for each study was determined by using the guidelines of the American Academy of Orthopaedic Surgeons.\cite{19} Data on surgical procedures were extracted; type of procedure, type of robot used, robot planning time (i.e., time required to set up system and complete surgical planning by the robot), duration of surgical procedure, fluoroscopy time (i.e., total time in seconds that the fluoroscope was emitting ionizing radiation), and fluoroscopy frequency (i.e., the number of times that fluoroscope imaging was used intraoperatively).

For quality assessment, the studies were rated using the Methodological Index for Non-Randomized Studies.\cite{19} The principal approach to data synthesis was a narrative review of the results. A meta-analysis was not performed due to the heterogeneity of the results.

3. Results

3.1. Study selection

A total of 3832 hits were identified with the search (Fig. 1). After removal of duplicates and title and abstract screening, 24 full-text articles were reviewed, 8 of which were included in this systematic review.\cite{20-27} After forward and backward citation tracking of the selected articles, no additional studies were identified that met the inclusion criteria.

3.2. Study characteristics

All studies originated from China and were published between 2017 and 2019 (Table 1). Sample size ranged between 10\cite{25} and 91\cite{26} patients with a combined total of 437 patients. The aim of the identified studies was to report the application and initial results of robot-assisted fracture fixation. Mean/median age ranged between 31\cite{25} and 76\cite{21} years (unweighted average 48 years) and there were between 0%\cite{25} and 62%\cite{20} female patients (weighed average 45%). The same robotic system was used across all included studies, the TiRobot (TINAVI, China).\cite{20-27} There were 6 cohort studies,\cite{20,21,23,24,26,27} 1 case series,\cite{25} and 1 randomized controlled trial.\cite{22} Four studies investigated pelvic ring fractures,\cite{22-24,26,27} 3 studies investigated proximal femur fractures,\cite{20,21,27} and 1 study investigated nondisplaced scaphoid fractures.\cite{25} Two surgical procedures were described; 7 studies investigated percutaneous screw fixation,\cite{20,22-27} and 1 study investigated intramedullary nailing.\cite{21} Six studies compared robot-assisted surgery to a cohort of patients undergoing conventional surgery.\cite{20-23,26,27}
3.3. Study quality and risk of bias assessment

The authors identified 1 level II study,[22] 6 level III studies,[20,21,23,24,26,27] and 1 level IV study.[25] The overall risk of bias was considered high across all studies (Table 2). The mean Methodological Index for Non-Randomized Studies score was 14.4 (range 8–19).[22,23] None of the studies reported a sample size calculation and were likely underpowered.[20–27] Since all but one study lacked a detailed description of outcome measurement collection, studies were prone to data collection bias. Except for the study by Liu et al,[23] it was not reported whether patients were included consecutively, resulting in a high risk of selection bias.[20–22,24–27] Although He et al[20] claimed to conduct a randomized trial, the study design was a retrospective cohort study, and no explanation was given as to how randomization was achieved; therefore, the authors classified this study as a retrospective cohort.

3.4. Outcomes

The studies reported the following outcomes: robot planning time, operating time, fluoroscopy time/frequency, screw placement accuracy, intraoperative blood loss, postoperative physical performance and functional outcomes, and wound/fracture healing time (Tables 3 and 4).[20–27]

3.4.1. Robot planning time. Three studies reported planning time for the robot, ranging between 2.8 and 7.8 minutes.
| Author year | Study design     | Type of fracture studied          | Surgical procedure          | Lvl | Mean/median age (in years) | Female (%) | Sample size | Length of follow-up (mo) |
|-------------|------------------|-----------------------------------|-----------------------------|-----|---------------------------|------------|-------------|--------------------------|
| Tao Long 2019 | Prospective cohort | Posterior pelvic ring fractures    | Percutaneous screw fixation | III | Mean 36 ± 8               | 42%        | Total: 91 participants | 8–32                     |
| Hua-shui Liu 2019 | Retrospective cohort | Anterior and posterior pelvic ring fractures | Percutaneous screw fixation | III | Mean 40.2 ± 13.6          | 34%        | Total: 86 participants | 3–6                      |
| Jun-Qiang Wang 2017 | RCT | Posterior pelvic ring fractures    | Percutaneous screw fixation | II  | Robot group median 43.0 IQR (35–52) | 40%        | Total: 45 participants | N/A                      |
| Hua-shui Liu 2018 | Cohort | Unstable pelvic ring fractures    | Percutaneous screw fixation | III | Robot group mean 37.4 ± 6.6 | 38%        | Total: 45 participants | 3                        |
| Hai Lan 2019 | Retrospective cohort | Intertrochanteric femur fractures  | Intramedullary nail fixation | III | Mean 76                   | 51%        | Total: 51 participants | 12–24                    |
| Sheng-jun Duan 2019 | Prospective cohort | Femoral neck fractures            | Percutaneous screw fixation | III | Robot group mean 61.7 ± 5.2 | 59%        | Total: 49 participants | N/A                      |
| Meng He 2019 | Retrospective cohort | Femoral neck fractures            | Percutaneous screw fixation | III | Robot group mean 56 (range 39–82) | 62%        | Total: 60 participants | 12–24                    |
| Bo Liu 2019 | Case series       | Nondisplaced scaphoid fractures    | Percutaneous screw fixation | N   | Mean 31 (range 27–56)     | 0%         | Total: 10 participants | 6–8                      |
In the robot-assisted group, there was a statistically significant reduction in operating time compared to the conventional group. For example, Duan et al. reported a mean operating time of 33.25 minutes for the conventional surgery group versus 29.2 minutes for the robot-assisted surgery group. This reduction was also observed in other studies, where the mean operating time was reported as 35.0 mL in the conventional group versus 26.7 mL in the robot group, showing a statistically significant difference (Table 3).

### Screw Placement Accuracy

Liu et al. reported a position error of 2.3 ± 1.03 mm and an angular error of 2.24 ± 1.32 degrees for robot-assisted insertion of percutaneous screws for pelvic ring fractures. Wang et al. used the Gras-Marinitschev classification to measure screw placement for posterior pelvic ring fractures and reported superior screw placement in the robot group (P < .001). Duan et al. used the Hamelinck classification in their study investigating percutaneous pinning of femoral neck fractures and found a statistically significant difference in favor of the robot-assisted group.

### Intraoperative Blood Loss

For pelvic fractures, Long et al. reported a mean intraoperative blood loss of 33.89 mL (± 16.4) for the robot group, versus 43.04 mL (± 12.34) in the conventional group. This difference was statistically significant (P < .001). Liu et al. also reported a blood loss of 35.0 mL (± 7.2) for the robot group and 46.2 mL (± 9.3) for the conventional group (P < .001) (Table 4). Duan et al. reported a loss of 98.8 mL (± 14.98) in the robot group and 118 mL (± 32.31) in the conventional surgery group for the intramedullary nailing of intertrochanteric femur fractures. These results suggest that robot-assisted surgery may be more effective in reducing blood loss compared to conventional surgery.

### Summary

The findings from this review indicate that robot-assisted surgery offers several advantages over conventional surgery, including reduced operating time, improved screw placement accuracy, and lower blood loss. However, more studies are needed to establish clear clinical endpoints and to further explore the potential benefits of robot-assisted surgery.
| Author          | Year     | Outcomes studied                                                                 | Operating time (min) | Robot planning time (min) | Fluoroscopy frequency | Fluoroscopy time (min/s) | Screw placement |
|-----------------|----------|-----------------------------------------------------------------------------------|----------------------|--------------------------|------------------------|--------------------------|-----------------|
| Tao Long        | 2019     | Operating time, planning time, fluoroscopy frequency, fluoroscopy time (min), length of incision, intraoperative blood loss (mL), anesthesia time (min), wound healing and fracture results, fracture reduction (Matta standard), Majeed function, Harris hip score | Robot group: 33.23±6.46 conventional group: 63.55±6.62 | Robot group: 6.71±4.19 | Robot group: 8.49±2.37 Conventional group: 10.87±4.18 | Robot group: 5.88±1.29 (min) Conventional group: 11.06±2.98 (min) | N/A             |
| Hua-shui Liu    | 2019     | Operating time (min), fluoroscopy frequency, fluoroscopy time (sec), screw placement accuracy, incision length, blood loss, fracture healing time, Majeed score, Harris hip score | Robot group: 175±32.6 | N/A                      | 29.1±10.5 per screw   | 6.1±0.2 (s) per screw   | Positioning error 2.31 ± 1.03 mm Angular error 2.24 ± 1.32 |
| Jun-Qiang Wang  | 2017     | Operating time after reduction of the pelvis, robot planning time, fluoroscopy time after reduction pelvic (sec), screw placement accuracy (GrasMarintschev), number of guidewire attempts | Robot group: median 150.0 IQR (75–230) Conventional group: median 104.0 IQR (60.0–154.0) | Median 7.8            | N/A                    | N/A                      | N/A             |
| Hua-shui Liu    | 2018     | Operating time, fluoroscopy frequency, total number of drills, intraoperative blood loss, fracture healing, Majeed score, activities of daily living, pain, gait, walking distance, standing, presence of nerve damage | Robot group: 65.4±10.9 Conventional group: 86.7±14.7 | N/A                      | Robot group: 29.2±7.6 Conventional group: 52.3±12.4 | N/A                      | N/A             |
| Hai Lan         | 2019     | Operating time, fluoroscopy frequency, total number of drills, intraoperative bleeding, fracture healing, Harris hip score | Robot group: 65.44±8.01 Conventional group: 77.50±16.64 | N/A                      | Robot group: 10.28±0.61 Conventional group: 13.23±1.75 | N/A                      | N/A             |
| Sheng-jun Duan  | 2019     | Operating time, fluoroscopy frequency, screw placement accuracy (Hamelink), total number of drills, intraoperative bleeding, fracture healing, Harris hip score | Robot group: 77.3±9.3 Conventional group: 79.9±9.8 | Included in total operation time for robot group | N/A                    | N/A                      | Screw pararellism (points) robot group 24.9±0.6 conventional group 21.5 ± 1.2 (P<.001) Triangular area (mm²) robot group 72.0±6.7 conventional group 53.8 ± 10.4 (P<.001) Anteroposterior dispersion (%) for robot group 35.13; for conventional group 85.29 (P value < 0.01) Lateral dispersion (%) for robot navigation group 70.08; for conventional group 58.29 (P value <.01) Anteroposterior screw shaft angle (%) for robot group 1.08; for conventional group 1.2 (P value .438) Lateral screw shaft angle (%) for robot group 1.25; for conventional group 1.82 (P value .028) |
| Meng He         | 2019     | Robot planning time, fluoroscopy time, total number of drills, screw placement (Liebergl), Harris hip score | N/A                  | 2.8                      | N/A                    | N/A                      | N/A             |
| Bo Liu          | 2019     | Operating time, fracture healing time, Mayo wrist score | N/A                  | Included in total operation time for robot group | N/A                    | N/A                      | N/A             |
intraoperative blood loss, and the Standardised Endpoints for Perioperative Medicine collaborative is currently conducting a review to reach consensus on this matter.[28] The authors of this review do not consider the blood loss as reported in the included papers of this review to be clinically important.

### 3.4.7. Postoperative physical performance and functional outcomes.

For pelvic ring fractures, 3 studies reported patient outcomes after a follow-up period using the Majeed score (Table 4).[23,24,26,29] The overall outcomes were excellent or good in both the robot and conventional surgery group, and there were no statistically significant differences between groups.[23,24,26] For hip fractures, the Harris Hip Score was used to measure functional outcome in 3 studies investigating hip fractures.[20,21,27,30] Lan et al found a statistically significant difference in favor of the robot group; the mean Harris Hip Score was 86.68 ($\pm$ 6.23) in the robot group and 82.69 ($\pm$ 6.85) in the conventional group ($P = .034$); however, this difference is not clinically significant.[21,31] The other 2 studies by He et al and Duan et al reported no significant difference between the robot-assisted surgery group and the conventional control group.[20,27] Liu et al reported a mean Mayo wrist score of 96 (range 85–100) for scaphoid fractures treated with robot-assisted percutaneous screw fixation at follow-up.[25,32]

### 3.4.8. Fracture-healing time.

Six studies reported fracture-healing times.[21,23,26–27] Of which made a comparison with a conventional surgery control group, none of these studies found a significant difference in fracture-healing time between groups (Table 4).[21,23,26,27]

| Author | Year | Intraoperative blood loss (mL) robot group | Intraoperative blood loss (mL) conventional group | $P$ value | Fracture-healing time robot group (mo) | Fracture-healing time conventional group (mo) | $P$ value | Functional outcomes | $P$ value |
|--------|------|------------------------------------------|-------------------------------------------|----------|-------------------------------------|------------------------------------------|----------|---------------------|----------|
| Tao Long | 2019 | 33.89±16.4 (15–80) | 43.04±12.34 (30–80) | $<.001$ | 4.61±0.68 (3.5–6.3) | 4.56±0.78 (3.4–6.2) | .53 | Majeed function | NS |
| Hua-shui Liu | 2019 | 35.2±3.6 (5–60) | N/A | N/A | 3 mo | N/A | N/A | N/A | N/A |
| Jun-Qiang Wang | 2017 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Hua-shui Liu | 2018 | 35.0±7.2 | 46.2±9.3 | $<.001$ | 4.3±0.7 | 4.5±1.1 | .45 | Majeed function | N/A |
| Hai Lan | 2019 | 90.80±14.98 | 118±32.21 | $<.001$ | Fracture healing rate 100% at follow-up | Fracture healing rate 100% at follow-up | NS | Harris hip score | .034 |
| Sheng-jun Duan | 2019 | 9.5±6.8 | 41.3±12.4 | $<.001$ | 4.6±1.9 | 5.3±2.1 | .223 | Harris hip score | .559 |
| Meng He | 2019 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Bo Liu | 2019 | N/A | N/A | N/A | mean 8 wks (range 7–10) | N/A | N/A | N/A | N/A |

### 4. Discussion

This review identified 8 studies that reported on the application of robot-assisted surgery in orthopaedic trauma.[20–27] The overall quality of evidence was considered low with a high risk of bias.

### 4.1. The robotic system

Only 1 robotic system was identified in this review, the TiRobot (TINAVI Medical Technologies, Beijing, China).[33] The TiRobot is a robotic surgical guidance system that uses an intelligent algorithm to calculate guidance wire and screw trajectories, using a combination of 3D imaging reconstructed from radiography and optical real-time guidance and navigation. It does not perform other surgical tasks besides navigation and guidance.

This robotic system consists of 3 parts (Fig. 2).[34] First, a robotic arm with 6 degrees of freedom, which can hold surgical tools and guide screw insertion. It is designed for maximum reach and a small footprint in the operating theatre and can be operated both automatically and manually. Second, an optical tracking station that uses an infrared stereo camera and 1 or more reference frames that are attached to the patient to help guide the positioning of the robotic arm. Third, an integrated navigation and planning station, which uses intraoperative fluoroscopy images made with a 3D C-arm (Siemens Medical Solutions, Erlangen, Germany).[33,35]

The authors of this paper assume that the TiRobot system is not available outside of China, but were unable to confirm this with the producer. On their website, DePuy Synthes (Johnson & Johnson Medical Devices, Shanghai, China) announced their
future collaboration with TINAVI. This might indicate that steps are being taken to introduce this technology to the rest of the world. Other orthopaedic robotic systems, such as the Robodoc and MAKO, are being used in arthroplasty, but not in orthopaedic trauma surgery.

4.2. Interpretation of results

4.2.1. Operation time and robot planning time. It was unclear for most studies whether robot planning time was included in the calculation of total operating time. Studies that made a comparison between a robot group and a conventional group reported operating times of approximately 1 or 2 hours in both groups. The (unweighted) pooled reduction was 21 minutes, which seems low, considering the cost of robotic systems and the required time investment for training surgeons and other OR-personnel.

4.2.2. Fluoroscopy time and frequency. The occupational health hazard that results from radiation in orthopaedic trauma surgery is often underestimated. The overall evidence found in this review suggests that robot-assisted surgery can help reduce the total amount of radiation exposure for both the surgeon and the patient. The TiRobot still requires the surgeon to be present at the operating table. This review did not identify papers describing robotic systems that could be completely controlled remotely, a feature that could potentially eliminate radiation exposure for the surgeon entirely.

4.2.3. Screw placement accuracy. Robot-assisted procedures showed more accurate percutaneous screw placement across all papers that studied this outcome. Although accurate screw placement is of vital importance in percutaneous fixation, it remains unclear whether this improved accuracy is clinically important. Nevertheless, more accurate screw placement may be an important advantage of this technique. For example, insertion of sacroiliac screws is a relatively uncommon procedure. It is a difficult procedure with a steep learning curve that carries with it the risk of iatrogenic injury of neurovascular structures with aberrant screw placement.

4.2.4. Intraoperative blood loss. All studies with conventional surgery as a control group found statistically significant less intraoperative blood loss in the robot group (\(P<.001\)). Overall, intraoperative blood loss was low in both the robot-assisted surgery groups (90mL or less) and control groups (118mL or less). The biggest reduction of intraoperative blood loss (32mL) was found in the study by Duan et al, but this reduction is likely not clinically significant.

4.2.5. Postoperative physical performance and functional outcomes. Functional outcomes between robot-assisted procedures and conventional surgery were comparable, although most studies were likely underpowered to detect significant differences. Lan et al found that Harris Hip Score in the robot-assisted group was 4 points higher on average after intramedullary nailing for intertrochanteric fractures. However, the Harris Hip Score has a minimally clinically important difference of 8 points, and therefore this statistically significant difference is not clinically significant.

Figure 2. The TiRobot. The TiRobot consists of a planning station, optical tracker, and a robotic arm to assist with surgical guidance. Figure previously published under a creative commons licence.

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4.2.6. Fracture healing. Robot-assisted surgery did not affect fracture healing time in the included studies. The authors speculate that it is unlikely that the use of a robot significantly affects fracture healing, and that this outcome may not be the most relevant for future investigations.

4.2.7. Strengths and limitations. This study has several limitations. First, because this is a relatively new development in the field of traumatology, only 8 studies met the inclusion criteria for this review. The heterogeneity of the studies made it difficult to summarize the evidence in a clear and concise manner and precluded us from performing a meta-analysis. Second, papers published in Mandarin were excluded. The authors identified several papers that were written in Mandarin. These papers had no English abstract and were unavailable in full text. It is possible that this has led to selection bias. Third, the overall quality of included studies was low with a high risk of bias.

This is the first systematic review to describe the applications of robot-assisted fracture fixation surgery in orthopaedic trauma surgery and its effect on surgical and patient outcomes. This review shows that the clinical application of robot-assisted fracture fixation surgery has only recently emerged in traumatology and so far only in China. More importantly, this review identified pitfalls and limitations of current investigations and made recommendations for future research in this new field of orthopaedic trauma surgery.

4.2.8. Future perspectives and recommendations for future studies. Although extensively studied in arthroplasty, there are few publications reporting the clinical application of robot-assisted surgery in orthopaedic trauma.\(^9,10\) As shown in this review, advantages of robot-assisted trauma surgery may include reduced operating time, improved percutaneous screw placement accuracy, lower blood loss, and lower radiation exposure to both surgeon and patient. The purpose of the system is to assist with surgical guidance, but there are a few drawbacks that should be pointed out. First, the improvement of outcomes seems low considering the required investment to purchase the equipment and train personnel. Second, there is some question about the clinical relevance of the improvement of outcomes. The main advantage of the technology appears to be in increasing the accuracy of percutaneous screws. This may have a role in reducing the risk of neurovascular injury in percutaneous pelvic fracture surgery—particularly when performed by low volume surgeons. Third, this technology is new, and is currently only available in China. Fourth, as shown in this review, there is very little high-quality research in this field from which reliable conclusions can be drawn. Ergonomics might be another possible advantage of robot-assisted surgery, which may improve ergonomics for the surgeon.\(^15,42\) Unfortunately, none of the studies included in this review reported ergonomic outcomes for the surgeon, and the authors recommend that these outcomes are included in future investigations. It remains to be seen whether robot-assisted fracture fixation will be the future in orthopaedic trauma, or a solution to a nonexistent problem. The authors of this study also recommend that outcomes in future studies should be clearly defined (e.g., specify whether robot planning time is included in total operation time), and include outcomes relevant to the surgeon and/or the patient.

5. Conclusion

The emergence of robot-assisted orthopaedic trauma surgery is a new development in orthopaedic trauma. There is limited evidence that suggests that robot-assisted orthopaedic trauma surgery may reduce operating time, use of fluoroscopy, intraoperative blood loss, and improve screw placement accuracy. However, for most studies it was unclear how outcomes were measured, and there is some question about the clinical relevance of the marginally improved outcomes. There is currently no conclusive evidence that robot-assisted fixation in orthopaedic trauma surgery leads to better functional outcomes for either the patient or the surgeon. More high-quality research is needed in this field.

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