

Robotics in trauma and orthopaedics

Recent advances and review of literature

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Robot-assisted orthopaedic surgery is gaining momentum and being gradually adopted and incorporated into our routine practice. With recent innovations in surgical applications of robots, newer techniques are developed and its applications rapidly expanding in orthopaedics. This article reviews the current state of robotics and the development of future robotic technology for trauma and orthopaedics.

Materials and methods

A comprehensive analysis of the English literature was performed using Elton B Stephens Co (EBSCO, Birmingham, Alabama) hosted Medline, CINAHL, PEDro, Cochrane and PubMed databases between 1966 and February 2018. All articles with full text were retrieved and their bibliographies hand-searched for further references. Non-indexed materials on the worldwide web and the System for Information on Grey Literature in Europe (SIGLE) were also included in the review. Initial search yielded 15,204 studies, which were assessed based on relevance, duplication and inclusion and exclusion criteria (Table 1, Fig 1). Eighty-two studies were included in the final analy-

sis and their findings are narrated by subspecialty.

Review

Musculoskeletal problems account for more than 25% of all surgical interventions in the NHS and account for more than £4.76 billion of NHS spending each year.¹⁻³ With the increase in ageing population and childhood obesity, this is set to rise significantly during the next ten years.^{3,4} *Getting It Right First Time (GIRFT)*⁴ and the available literature has stressed the need for conducting orthopaedic procedures with precision and accuracy to obtain reliable and reproducible outcomes.

Orthopaedics is gradually adopting and incorporating robotic surgery in its armamentarium to help surgeons to achieve the aforementioned goal by improving the spatial accuracy.

Knee

The total number of knee replacements has increased from 13,546 in 2003 to 98,147 in 2016 and during the same period the number of knee revisions has increased from 630 to 5,932 in England, Wales and Northern Ireland.⁵ The majority of the revisions (>60%) are for malalignment, implant

wear/fracture and aseptic loosening. Robotic surgery has the potential to reduce these complications and increase the survivorship of the implants.⁵

Unicompartmental knee arthroplasty

Between eight and ten per cent of knee replacements in UK are Unicompartmental Knee Arthroplasties (UKA) and this is predicted to grow.⁶ UKA is more conservative than Total Knee Arthroplasty (TKA) and has a better kinematics, lower perioperative morbidity, earlier functional recovery and better functional outcome than TKA.⁷ Despite these advantages, UKA have a higher revision rate than TKA and the reasons are multifaceted.⁶ Component alignment is a significant factor for the survivorship of the implant and indirectly influenced the ligamentous imbalance and properties of the implant.^{8,9} Accomplishing near-normal coronal plane alignment is a significant factor that influences the long-term results and ultimately the survival of UKA.⁹⁻¹¹ Studies have shown that 40%–60% of UKA using conventional technique are outliers beyond the 2° of desired alignment, even in experienced hands.^{12,13} The problems become worse in patients having minimally invasive UKA.^{14,15} With computer navigation, the outliers (2° of desired alignment) are less than conventional technique (15%) and the results obtained from robot-assisted UKA are impressive.^{12,13,16} This was proven in a study by Karia *et al* where 16 inexperienced surgeons were randomised to constrained robot-assisted or conventional unicompartmental knee replacement on dry bones for a period of 3 weeks.¹⁷ In the three weeks, the surgical time decreased in both groups; however, the rotational and translational errors were lower in

the robot-assisted group, which suggests robots reduce errors irrespective of experience.

A prospective randomised control trial (RCT) assessed the accuracy of implant position and limb alignment in 62 patients who had UKA implanted by the MAKO Robotic Interactive Orthopaedic Arm (RIO) system vs 58 patients who had a conventional surgical procedure. All the patients had an Oxford Phase-3 unicompartmental knee replacement with traditional instrumentation. The accuracy of component positioning is significantly better in the robotic group, with regard to the femoral component sagittal position (57% compared with 26%, $p=0.0008$), femoral component coronal position (70%

compared with 28%, $p=0.0001$), femoral component axial position (53% compared with 31%, $p=0.0163$), tibial component sagittal position (80% compared with 22%, $p=0.0001$), and tibial component axial position (48% compared with 19%, $p=0.0009$).¹⁶ An earlier prospective double-blinded RCT compared conventional and robot-assisted UKA using the Acrobot system (The Acrobot Co Ltd, London, UK), which had better results than the MAKO RIO system (Cobb *et al*). The Acrobot group achieved coronal alignment within 2° of the planned position in all their UKAs, with a mean of 0.65° (-1.6° to 0.3°; standard deviation [SD] 0.59). However, in the conventional group only 40% achieved this level of accuracy, with a mean of -0.84° (-4.2°

Figure 1 Flow diagram

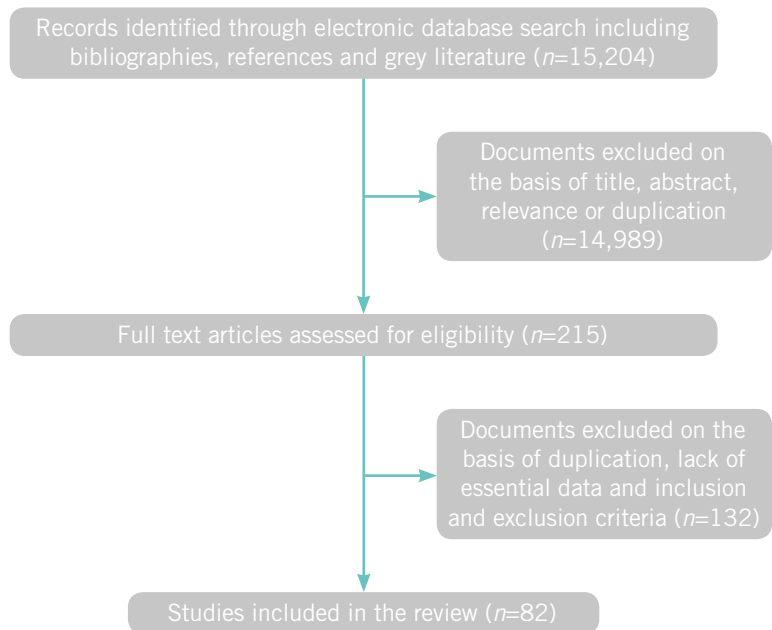


Table 1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Robot assisted/performed orthopaedic surgery	Orthopaedic surgeries not using fully active robots including computer navigated surgeries Expert opinion, letter to editors and case reports Experimental studies on animals

to 4.2°; SD 2.75).¹³ A recent multicentre prospective study assessed 909 knees (robotic-assisted medial UKA) at an average follow-up of 2.5 years (range: 22–52 months). 92% of the patients were either very satisfied or satisfied with their knee function – with a survivorship of 96 to 98.8%.¹⁸

Lonner *et al* evaluated the precision and accuracy of Navio PFS (NAVIO system, Blue Belt Technologies, Plymouth, MN) – a semi-autonomous robot, unlike Mako/Acrobat, which are autonomous robots.¹⁹ In 25 cadaveric specimens the ‘planned’ and ‘actual’ angular, translational, and rotational positions of the components were assessed. The RMS angular errors were 1.42°–2.34° for the 3 directions for the femoral implant and 1.95°–2.60° for the 3 directions of the tibial implant. The RMS translational errors were 0.92–1.61 mm for the femoral implant and 0.97–1.67 mm for the tibial implant. However, the authors stressed the advantages of low radiation dose, less conversion to conventional surgery, and no soft-tissue injuries on using this system. Yet there is no peer-reviewed publication in the literature to support these findings from cadaveric lab.

Various studies have emphasised that the accuracy of robot-assisted UKAs is better with regard to the tibial slope and valgus-varus alignment.^{19–22} Robot-assisted UKA allowed accurate soft-tissue balancing and helped restore natural knee kinematics, with positive implications for implant survival and functional outcomes.²³

An experimental study by Wolf *et al* using an image-free system mini-bone attached robotic system

(MBAR) could resect the bone more accurately and precisely than mechanical guides/freehand-cutting in patella-femoral arthroplasty (PFA).²⁴ The system performs the planning intraoperatively in the robot coordinate system and thus eliminating the need for external tracking systems in the operating room. Their study recommended that PFA could be done with a small incision and less operating time. Turktas *et al* retrospectively analysed 30 knees that had robotically-assisted PFA.²⁵ At a mean follow-up of 15.9 months, the patients made significant functional improvement. The robotic technique had numerous advantages, which include a smaller incision, faster rehabilitation, preservation of bone stock, and implantation without malalignment.

Total knee arthroplasty (TKA)

Robot-assisted TKA is believed by some surgeons to improve implant positioning, preserving bone and to protect soft tissues.²⁶ Yang *et al*²⁷ retrospectively compared 71 robotic TKAs with 42 conventional TKAs at a mean follow-up of 10 years. Although the clinical outcomes and long-term survival rates were similar between the two groups, the robotic TKA group had significantly fewer ($p < 0.001$) postoperative leg alignment outliers (femoral coronal inclination, tibial coronal inclination, femoral sagittal inclination, tibial sagittal inclination, and mechanical axis) and fewer radiolucent lines than the conventional TKA group. The mechanical axis improved from 9.0° varus to 1.9° varus in the robotic TKA group, and from 10.0° varus to 2.9° varus in the conventional TKA group. Long-term follow-up studies following TKA has shown that limb malalignment influenced survi-

vorship and outcomes.²⁸ A prospective RCT analysed the quality-of-life (QoL) measures and functional outcome between robotic-assisted and conventional TKA.²⁹ Although the robot-assisted group had a higher rate of complications, they had better SF-36 QoL measures, with significant differences in SF-36 vitality ($p = 0.03$), role emotional ($p = 0.02$) and a larger proportion of patients achieving SF-36 vitality MCID (48.4 vs 13.8 %, $p = 0.009$). However, no significant differences in KSS, OKS or satisfaction/expectation were noted between the groups.

Song *et al*³⁰ compared the outcome in patients who had bilateral simultaneous TKA with robotic assistance on one joint and a conventional surgical technique on the other. Although the mean mechanical axis (9.1° vs 10.9°) and balanced flexion-extension gaps (27 vs 23) are better in the robotic group, neither these nor the outcome scores were significantly different ($p > 0.05$). In the study by Decking *et al*,³¹ CT scans were used preoperatively and postoperatively to assess the mechanical axis. Their results showed excellent accuracy of angular component placement in all planes and a mean deviation from the mechanical axis of only 0.2° (95% confidence intervals [CI] –0.1° to 0.5°). The accurate component positioning is demonstrated in other similar studies.^{32–35}

Recent studies have demonstrated that robots are effective in restoring mechanical axis in complex knee replacements.^{36–38} Marchand *et al*³⁶ corrected 64% of patients (82 knees) with severe varus deformity (7° or greater) and 100% of severe valgus (7 knees) deformity to neutral (mean 2°,

range 0–3°). The remaining patients with severe varus deformity were corrected within a couple of degrees of neutral. Kim *et al* analysed 32 patients with haemophilia at a mean follow-up of 5 years. In spite of severe deformities and flexion contractures, the HKA axis was achieved within a range of $0 \pm 3^\circ$ in 30 knees (93.8%).³⁷ Similar results were obtained in patients with severe varus and valgus deformity.³⁸

Hip

Total hip arthroplasty (THA)

Robots have been used clinically used for THA for the past 20 years. ROBO-DOC (Integrated Surgical Systems, Davis, California) was introduced in 1992 to improve outcomes in uncemented THA by reducing technical errors.³⁹ Bargar *et al*⁴⁰ analysed patients from two US Food and Drug Administration RCTs (1994–1998 and 2001–2006) at a mean follow-up of 14 years, comparing traditional vs robotic THA. There was no statistically significant difference in probability of a revision for wear or loosening in either group ($\chi^2=1.80$; $p=0.179$). However, the robot-assisted group had statistically significant higher HSQ pain and Harris pain scores and lower Western Ontario and McMaster Universities Osteoarthritis Index scores.

Bukowski *et al*⁴¹ compared 100 primary THA in each arm (robotic vs traditional) in a retrospective cohort study. There was no statistically significant difference between the groups with regard to operative time ($R^{131} \pm 23$ min vs $T^{122} \pm 29$ min, respectively, $p=0.012$), blood loss ($R^{374} \pm 133$ mL vs $T^{423} \pm 186$ mL, $p=0.035$), and overall complication rates ($p=0.101$). However, the robotic-assisted THA demonstrated significantly higher

mean postoperative mHHS (92.1 ± 10.5 vs 86.1 ± 16.2 , $p=0.002$), mean UCLA scores (6.3 ± 1.8 vs 5.8 ± 1.7 , $p=0.033$) and there were no significant differences in SF-12 or WOMAC scores. Besides, the robotic group had a significantly higher proportion of patients with mHHS scores between 90 to 100 points (75% vs 61%, $p=0.034$) and a lower percentage with scores <70 points (6% vs 19%, $p=0.005$).

Illgen *et al*⁴² assessed the results of a single surgeon series – conventional THAs in his early career (2000) vs 100 conventional THAs in his late career (2011) vs consecutive 100 robot-assisted THAs (2012). The acetabular component placement within Lewinnek safe zone was 30% early in his career, 45% in his late career and 77% in the robot-assisted group. The accuracy increased in robot-assisted THA by 71% in the first year of use. The dislocation rate was 5% with early THA, 3% in the late THA, and 0% in the robotic cohort within the first two years postoperatively.

Positioning of the acetabulum component affects dislocation rates, component impingement, bearing surface wear rates and need for revision surgery. Kamara *et al*⁴³ compared acetabular component placement using radiographs in three groups in a retrospective cohort study. The first 100 fluoroscopically guided direct anterior THAs (FA) vs first 100 robotic-assisted posterior THAs (RP) vs the last 100 manual posterior (MP) THAs done by each surgeon (200 THAs). Seventy-six per cent of MP THAs were within the surgeons' target zone (inclination, 30°–50°; anteversion, 10°–30°)

compared with 84% of FA THAs and 97% of RP THAs. Variances were lower for acetabulum inclination and anteversion in RP THAs (14.0 and 19.5) as compared to the MP (37.5 and 56.3) and FA (24.5 and 54.6) groups. These differences were statistically significant ($p<.01$). The study by Tsai *et al*⁴⁴ showed that robot-assisted THA has higher precision than manual THA and has the potential to restore native hip geometry. Similar results were achieved by Ellmallah *et al*,⁴⁵ 99% of their 224 patients achieved preoperatively determined radiographic targets for cup placements with robot assisted THAs. A matched-pair controlled study by Domb *et al*⁴⁶ 100% (50 hips) of the robotic group had acetabular component placed in the safe zone described by Lewinnek *et al*⁴⁷ compared to 80% of conventional THAs ($p=0.001$). Gupta *et al*⁴⁸ studied 105 patients with BMI (body mass index) <30 ($n=59$), BMI 30–35 ($n=34$) and BMI >35 ($n=12$) that had robotic THAs. There was no statistical difference between the groups in regards to the acetabular inclination ($p=0.43$) or version ($p=0.95$). They concluded that robotic THA is safe in obese patients and could provide accurate and reproducible placement of the acetabular cup within safe zones. Domb *et al*⁴⁹ assessed 175 patients for femoral version after robotic THA. All the patients had native femoral version corrected toward a target of 15°, irrespective of the approach or BMI.

A multicentre study reported a statistically significant improvement in femoral component fit and position ($p=0.02$, alignment; $p=0.01$, axial seating). The mean operating

time was >240 minutes to start with; however, this was later reduced to 90 minutes as a centre's experience increased.⁵⁰ The Limb length discrepancy and varus–valgus stem orientation were improved with robotic THA. Honl *et al*⁵¹ reported 18% conversion rate to conventional THA, significantly longer operating times and significantly higher complication rate with respect to dislocation, heterotopic ossification, rupture of the gluteus medius tendon and revision surgery. Schulz *et al* had a complication rate of 9.3% and stressed that technology required improvement before widespread use. Nishihara *et al*⁵² studied the clinical and radiographic results of uncemented THA using conventional hand-rasping vs robotic milling. The robotic group superior fit the implant with no intraoperative femoral fractures; however, the hand-rasping group suffered from undersizing of the stem, higher vertical seating and unexpected femoral anteversion. The robot-assisted group had significantly superior Merle d'Aubigné hip scores at two years. Nakamura *et al*⁵³ evaluated the benefits of robotic cementless femoral component implantation vs conventional implantation. At a minimum follow-up of five years the robot-assisted group had more precise implant position, less limb length discrepancy and less stress shielding in the proximal femur. The results did not change with short-stem implants (metaphyseal fit) – the robotic THAs had showed superior results in terms of stem alignment and leg-length equality than conventional THA.^{54,55} Studies in the English literature have consistently showed that the THA component position is improved with robotic-assisted THAs^{56–61} and the risks of systemic embolisation from

femur preparation is less with robotic femur preparation.⁶²

In a matched-pair controlled study, the acetabular cup size of robotic THAs are significantly smaller ($p < 0.02$) than the manual THAs.⁶³ Thus robotic THAs could preserve bone stock and could be of immense benefit in revision cases to preserve the remaining acetabulum.

Hip arthroscopy

Hip arthroscopy is a technically demanding procedure and is predominantly used for femoroacetabular impingement (FAI) or labral pathology. The use of robots for hip joint visualisation is still at an experimental stage,^{64–67} however, promising results are shown in dry bone models with accurate bone resection in Cam type FAI.⁶⁶ Park *et al* compared the freehand resection vs robotic resection of Cam type FAI in saw bones (8 in each group).⁶⁷ The predetermined desired arc of resection (117.7) was analysed with laser scanner. Freehand resection led to statistically significant ($p < 0.0001$) mean arc of resection error and over-resection with every specimen ($p < 0.01$). This study emphasised the need for robotic-assisted femoral osteochondroplasty when compared with the conventional freehand technique, which is used currently. The haptic three-armed da Vinci® standard surgical system (Intuitive Surgical, Sunnyvale, California) could overcome the technical concerns that are associated with this procedure. Kather *et al*⁶⁵ in his cadaveric study showed the technical feasibility of hip arthroscopy using existing laparoscopic instrumentation. In his study he viewed all parts of the joint, performed labral manip-

ulation and resected the limbus and plica in two cadavers.

Spine

The robots are extensively used in spine surgery for the placement of pedicle screws. There have been a couple of studies evaluating the role of robots in anterior and posterior surgical exposure of the vertebra.^{68,69} Two types of robots were used for spinal instrumentation and are SpineAssist robot (Mazor Surgical Technologies, Caesarea, Israel) and ROSA robot (Medtech). Two randomised controlled trials recently evaluated the safety, accuracy and precision of the pedicle screw instrumentation.^{70,71} Both demonstrated that the precision and accuracy of screw placements were better than the freehand technique. The study by Hyun *et al* showed that minimally invasive spinal fusions could be performed with less radiation exposure (3.5 vs 13.3 seconds per screw in robot vs freehand technique [$p < 0.001$]) and the average length of stay was 6.8 vs 9.4 days in robot compared with freehand technique ($p = 0.020$).⁷¹ Sukovich *et al*⁷² reported that 96% of pedicle screws were placed within 1mm of their planned trajectory, with instrumentation performed at thoracic, lumbar and sacral levels.

In a retrospective multicentre analysis of 3,271 robot-assisted pedicle screws, 3,204 were placed in a clinically acceptable position. Except for transient neurological deficit in four patients, there were no major complications.⁷³ Similar success stories were reported in various articles.^{74–83} In patients with spinal metastasis, pedicle screw placement in the thoracolumbar spine can be performed effectively and safely using robot-guided assistance.⁸⁴ In

patients with low-grade spondylolisthesis, robotic pedicle screw placement has a reduced rate of revision surgery compared with placing the screw using navigation or freehand technique.⁸⁵

Shoulder

Use of robotics in shoulder surgery is in its nascent stage. Robotic shoulder arthroscopy was performed using a four-armed da Vinci® surgical system in two cadavers in both beach chair and lateral decubitus position. Though there were limitations in instrumentation, the authors could access biceps, labrum, supraspinatus, infraspinatus, rotator interval, subscapularis, all glenohumeral ligaments and the coracoid process. The cadavers were dissected after the procedure to evaluate instrument placement, and demonstrated correct placement with no neurovascular injury.⁸⁶

Foot and ankle

Wiewiorski *et al*⁸⁷ evaluated the accuracy of CT-guided robotically (INNOMOTION robotic-assistance device [Innomedic, Herxheim, Germany]) assisted infiltration technique for diagnostic injections in foot and ankle orthopaedics. All injections in tibiotalar, talonavicular, tarsometatarsal, subtalar and calcaneocuboid joints were successful. This was confirmed by contrast visualisation and pain relief. Taking into account radiation exposure and the absence of a comparative group, the benefits of robot-guided foot and ankle injection when compared with radiologically guided injection are far from clear.

Trauma and general orthopaedics

A semi-automated telerobotic surgical system called Trauma Pod is in the experimental stage of development

to save the lives of critically injured patients on the battlefield.⁸⁸ The robot is supplied with autonomous robotic arms that can act as circulating and scrub nurses. The robot could automatically change tools and supply delivery is performed as fast as when performed manually by nurses. In addition, tracking and counting of the supplies is performed automatically. The authors demonstrated in a simulated patient that a surgeon could perform bowel anastomosis and shunt placement in major vessels via teleoperating, and that the process could support intraoperative CT scanning.

The role of robots in percutaneous reduction of fractures has been extensively investigated.^{89–91} Experiments in cadavers showed promising results, with fracture reduction accuracy of about 1mm and 1.5°. The surgeon reduced the fracture in a 3D virtual environment and the robot manipulator reduced the fragments accurately. The surgeon took 95 seconds on an average to reduce 80 fractures virtually using the navigation system and the robotic arms took an average of about 75 seconds to physically reduce the fracture. The entire reduction procedure was accomplished in about 3 minutes.⁹⁰ In a similar study a robot-assisted fracture surgery (RAFS) system was tested on 9 cadaver specimens and was able to reduce 7 out of 9 distal femur fractures (T- and Y-shape 33-C1) with acceptable accuracy ($\approx 1\text{mm}$, $\approx 5^\circ$).⁹¹ This technology could help develop minimally invasive fracture surgeries. Robots have been used to identify the entry point of intramedullary nailing and apply distal locking bolts in cadavers.^{92,93}

The da Vinci® system has been used to safely identify, dissect and repair nerves in Brachial plexus injuries.^{94,95} Mantovani *et al*⁹⁴ through an endoscopic approach in two fresh human cadavers, successfully dissected brachial plexuses and performed nerve graft with minimal dissection. Garcia *et al*⁹⁵ performed brachial plexus surgery in three patients and the authors concluded that the robotic surgery will help with tremor filtration, motion-scaling and ergonomics.

Wang *et al*⁹⁶ randomised 30 patients requiring posterior pelvic ring stabilisation to either freehand or robot-assisted (TiRobot™ [TINAVI Medical Technologies Co, Ltd, Beijing, China]). Of the 45 sacro-iliac joint (S1 and S2) screws, 22 were done freehand and 23 robot-assisted. There was no significant difference between the operation time; however, the robot-assisted group had less radiation exposure. The accuracy of screw placement was graded as excellent and good in 100% of robot-assisted group and 95% in the freehand group.

Discussion

Innovative robotic surgical applications and techniques are being developed and reported every day in trauma and orthopaedics. Increased use will eventually fuel the discovery of newer applications of robotic systems. The surgical outcome in trauma and orthopaedics is directionally proportionate to the precision and accuracy of the surgery, and robot-assisted systems has huge potential in helping surgeons achieve this. Although there were plenty of prospective randomised controlled trials published in the literature to support the use of

robots in trauma and orthopaedics (Table 2), numerous factors have to be taken into consideration before widespread implementation and use.

The costs associated with the use are a major issue, especially in this economic climate of financial pressures in the NHS. The costs of a robotic system ranges from USD 400,000 (GBP 290,000) for a NAVIO orthopaedic system, USD 700,000 (GBP 502,000) for a MAKO Rio system and for advanced da Vinci® systems the costs could be around USD 2.8 million (2 million GBP). In addition, for each procedure the costs for consumables could be around USD 2,000 (GBP 1,400) and the annual maintenance fees for robots could cost GBP 140,000^{97,98}. Studies based on the North American healthcare system have shown that using this system would lead to breaking even in two years.⁹⁹ A more detailed Markov Decision Analysis to evaluate the costs, outcomes, and incremental cost-effectiveness has shown that the robot-assisted UKA is cost-effective if the centres perform more than 94 cases a year.¹⁰⁰ Low- and medium-volume centres should continue with the conventional technique, unless there is enough evidence in the literature to prove that robots reduce revision rates by better component placement and soft-tissue balancing.

The costs are bound to reduce with widespread use and more healthcare industries providing these services. Trehan *et al*⁹⁸ revealed that some of these companies operate with a profit margin of 40.3%, which is remarkably high when compared with other industries in the sector. Patented technologies, a high barrier to entry,

and bigger companies buying the competitors make the competition unhealthy. The UK (unlike US) has a universal healthcare system in the form of the NHS, which places us in a better position to negotiate with the companies to reduce the costs.

Serious complications were reported in earlier studies in knee replacements¹⁰¹ (patellar tendon rupture, fracture or dislocation of the patella, supracondylar fracture and peroneal nerve injury) and hip replacements⁵⁸ (increased blood loss, dislocation, revision rate and heterotopic ossification). Any new technique introduced will have a steep learning curve and studies have shown that the operation time, blood loss, and complication rates were more in the early stages of a surgeon's learning curve. However, with the increase in use of the procedures and training opportunities, the recent RCTs have demonstrated that the robotic-assisted surgeries were as safe as – sometimes better than – the conventional procedures. In spine procedures, robots have shown that soft-tissue dissection and radiation exposure could be reduced in deformed spines.¹⁰² As the use of robots could be fraught with issues related to hardware/software, surgeons performing robotic surgery should be competent enough to proceed with conventional surgery.^{50,75}

From the patients' perspective, the majority think that robotic arthroplasty is more accurate, technically easier to perform, and involves less operating time than conventional surgery.¹⁰³ The acceptance rate was high in one group of 100 patients in an arthroplasty clinic – although only 12% knew about the system, 80% were happy to have

robotic surgery. This review has highlighted the fact that the current problems are to do with economic viability, training and good-quality data rather than safety issues. As suggested in an earlier review,¹⁰⁴ a national registry to record these procedures and guidelines, which provides adequate training to the future orthopaedic surgeons is the need of the hour.

Conclusion

Robotic surgery is here to stay and will occupy a key place in the future of trauma and orthopaedics. Significant progression has been made in the use of robots in the past few years. Current literature suggests that the robotics are safe and as effective as conventional surgery in UKA, TKA, THA and pedicle screw insertion in the spine. Although some studies show that the robots are better than the conventional technique in achieving limb alignment, reduce operation time and blood loss, more good-quality research is needed from independent centres to confirm the same. The role of robots in other orthopaedic subspecialties is still in its nascent stage. Training future surgeons on cadaveric or simulation systems could reduce the complications rate and steepness of the learning curve. The costs associated with the implant used could be lowered by negotiation, encouraging more commercial ventures and increased use in high-volume centres. Establishment of a national registry is essential to monitor revision rate, complications and patient satisfaction.

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Table 2 Prospective Randomised control trials. C= Conventional R= Robotic

Study/year/ Procedure	Robot used	Sample size/mean follow-up	Results	Major complications
Cobb <i>et al</i> ³ , 2006 UKA	Acrobot System (The Acrobot Co Ltd, London, UK)	C-14; R-13 18 weeks	Radiological alignment is better than conventional technique; Functional outcome is similar in both groups	None
Bell <i>et al</i> ⁶ , 2016 UKA	MAKO Robotic Interactive Orthopedic (RIO) Arm (Stryker, Mahwah, NJ, USA)	C-58; R-62	Radiological alignment is better than conventional technique;	None
Liow <i>et al</i> ⁹ 2017 TKA	ROBODOC system (Integrated Surgical Systems, Sacramento, CA)	C-29; R-31	Subtle improvement in quality-of-life scores in robotic group	None
Park <i>et al</i> ¹⁰ , 2007 TKA	ROBODOC system (Integrated Surgical Systems, Sacramento, CA)	C-30; R-32 44–52 months	Radiological alignment is better than conventional technique Functional outcome is similar in both groups	1 each of patellar tendon rupture, dislocation of the patella, postoperative supracondylar fracture, patellar fracture, and peroneal injury in early cases where robots were used. None in conventional.
Song <i>et al</i> ⁰ , 2011 TKA	ROBODOC system (Integrated Surgical Systems, Sacramento, CA)	C-30; R-30 Minimum 12 months	Simultaneous bilateral surgery Radiological alignment is better than conventional technique Functional outcome is similar in both groups	None
Bargar <i>et al</i> ⁰ THA USA – Prospective, randomised controlled trial Germany – Case series	ROBODOC; Integrated Surgical Systems, Davis, CA	C-65; R-69 24 months Germany R-900	Radiological alignment is better than conventional technique Functional outcome is similar in both groups Germany Improvement in both radiological and functional outcome	No difference between the groups
Bargar <i>et al</i> ⁰ , 2017 THA	ROBODOC; Integrated Surgical Systems, Davis, CA	14 years follow-up of Bargar <i>et al</i> ⁰	Functional outcome and radiological alignment is better in Robot group	None
Lim <i>et al</i> ⁵ , 2016 THA (Short stem)	ROBODOC; Integrated Surgical Systems, Davis, CA	C-27; R-27 24 months	Radiological alignment is better than conventional technique Functional outcome is similar in both groups	2 fractures in Manual rasping group
Nishihara <i>et al</i> ⁹ Prospective, RCT	ROBODOC; Integrated Surgical Systems, Davis, CA	C-78; R-78 2.3 years	Functional and radiological outcome is better in robotic group	Intraoperative femoral fractures C5; R0
Kim <i>et al</i> ⁰ , 2017 Pedicle screw–spine	SpineAssist (Mazor Surgical Technologies Ltd, Caesarea, Israel)	C-41; R-41	Similar accuracy (99.4%)	13 (15.9%) violations with the freehand technique, none with robots
Hyun <i>et al</i> ¹ , 2017 Pedicle screw–spine	SpineAssist (Mazor Surgical Technologies Ltd, Caesarea, Israel)	C-30; R-30	Accuracy R -100% C -98.6%	None
Ringel <i>et al</i> ⁴ , 2012 Pedicle screw–spine	SpineAssist (Mazor Surgical Technologies Ltd, Caesarea, Israel)	C-30; R-30	Accuracy R -85% C -93%	Ten robotic screws require intraoperative conversion to the free hand application. One freehand screw needed a secondary revision.
Wang <i>et al</i> ⁶ , 2017 Pelvis	TiRobot™ (TINAVI Medical Technologies Co, Ltd, Beijing, China)	C-22; R-23	Accuracy R -100% C -95%	None

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