intraoperative documentation, and postoperative care. Nevertheless, challenges such as data silos, poor interoperability, privacy concerns, and limited representativeness continue to hinder the development of multimodal surgical AI, highlighting the need for improved data-sharing mechanisms, federated learning, and multicenter collaborative frameworks.

2.3 Application modes of AI in surgery: decision support, recognition, and control

AI applications in surgery can be broadly categorized into three levels: decision support, recognition, and control, reflecting a progression from analysis to intervention. At the decision-support level, AI systems integrate multimodal perioperative data to provide predictions and recommendations for preoperative, intraoperative, and postoperative management without directly performing surgical actions. These systems have been used to predict postoperative complications, operative duration, intraoperative hypotension, resource utilization, and patient outcomes, thereby assisting clinical teams in optimizing surgical planning, assessing individual risks, and improving postoperative care (Varghese et al., 2024). In minimally invasive gynecologic surgery, such applications can support the evaluation of anatomical complexity, selection of optimal surgical approaches, and development of individualized treatment pathways, making them among the most readily translatable AI applications in clinical practice.

Recognition-based applications represent the most active and mature domain of surgical AI. These technologies, primarily based on deep learning and computer vision, enable real-time understanding of intraoperative conditions, including surgical phase segmentation, instrument identification, hand and instrument tracking, anatomical labeling, and risk zone detection (Knudsen et al., 2024; Yangi et al., 2025). Studies have demonstrated that some models achieve high sensitivity and specificity, often exceeding 0.95, in tasks such as phase recognition, instrument detection, and motion tracking (Paracchini et al., 2025). In gynecologic surgery, AI has shown the potential to identify key steps of hysterectomy, critical pelvic structures, and lesion regions, thereby providing real-time assistance in complex minimally invasive procedures and promoting standardization in quality control and training assessment.

Control-oriented applications represent the frontier of surgical AI, where systems move beyond recognition and recommendation toward active participation in surgical execution. Although current robotic systems remain surgeon-controlled, AI has begun to contribute to subtasks such as camera control, suturing trajectory planning, instrument positioning, tremor suppression, and partial automation of specific actions (Knudsen et al., 2024). In the future, semi-autonomous or partially autonomous control may be feasible in highly standardized tasks, such as specific incisions, localized hemostasis, or repetitive procedural steps (Guni et al., 2024; Leivaditis et al., 2025). However, control applications also carry the highest safety, ethical, and legal risks. Their implementation requires rigorous validation, clearly defined responsibility boundaries, and continuous surgeon oversight. Therefore, in minimally invasive gynecologic surgery, a pragmatic approach is to prioritize the development of decision-support and recognition applications, while cautiously advancing control technologies as evidence accumulates.

3 Current Status and Challenges of Minimally Invasive Gynecologic Surgery

3.1 Common surgical types and technical characteristics

Currently, minimally invasive gynecologic surgery (MIGS) encompasses a wide range of diagnostic and therapeutic applications for both benign and malignant gynecologic diseases. It primarily includes laparoscopic surgery, hysteroscopic surgery, and robotic-assisted surgery, and has further expanded to novel approaches such as single-port surgery, ultra-minimally invasive techniques, and natural orifice transluminal endoscopic surgery (Wu et al., 2025). Among these, laparoscopy remains the most mature and widely used platform, applicable to procedures such as myomectomy, ovarian cystectomy, tubal surgery, hysterectomy, and selected gynecologic oncologic staging procedures. Its core advantage lies in performing complex operations through small incisions, thereby reducing intraoperative blood loss, alleviating postoperative pain, and shortening hospital stay (Vazquez et al., 2025). Hysteroscopic surgery, on the other hand, is mainly used for intrauterine pathologies such as endometrial polyps, submucosal fibroids, and intrauterine adhesions, utilizing natural orifices and offering lower invasiveness with faster recovery. In gynecologic oncology, minimally invasive approaches have become the