potentially increasing the difficulty of procedures such as lymphadenectomy, parametrial dissection, and complex tumor cytoreduction (Kang et al., 2024). In single-port and ultra-minimally invasive techniques, challenges such as instrument crowding, limited maneuverability, reduced traction, and insufficient torque may prolong operative time and increase complication risk.

In addition to technical factors, patient characteristics and disease complexity significantly influence the safety and feasibility of MIGS. Conditions such as extensive pelvic adhesions, deep infiltrating endometriosis, prior multiple surgeries, severe obesity, cardiopulmonary comorbidities, or pregnancy-related factors may limit pneumoperitoneum tolerance, positioning adaptability, and surgical exposure, thereby increasing intraoperative risk and the likelihood of conversion to open surgery (Appelbaum, 2024). These limitations are particularly evident in gynecologic oncology. While MIGS is well established for early-stage endometrial cancer, findings from the LACC trial and subsequent studies have led to stricter indications for minimally invasive radical hysterectomy in cervical cancer. In ovarian cancer, concerns regarding tumor rupture, inadequate staging, and incomplete cytoreduction restrict the use of minimally invasive approaches to carefully selected patients in high-volume centers (Baba, 2024; Balafoutas and Vlahos, 2024).

System-level challenges are also significant. The high acquisition and maintenance costs of robotic systems, potential prolongation of operative time in certain cases, and variability in insurance coverage and resource allocation limit accessibility in resource-constrained settings and raise concerns regarding cost-effectiveness. Furthermore, the steep learning curve of minimally invasive techniques, lack of standardized training, and variability in surgeon experience contribute to heterogeneity in conversion rates, complication rates, and oncologic outcomes across institutions. These issues highlight that, although MIGS has been widely adopted, there is still considerable room for improvement in safety, consistency, reproducibility, and equitable access.

### 3.3 Clinical demand for precision and standardization

As MIGS evolves from simply being feasible to achieving high-quality outcomes, precision and standardization have become central clinical demands. Precision surgery emphasizes accurate lesion localization, boundary delineation, and optimal resection based on a comprehensive understanding of individual anatomical variations, disease extent, and functional preservation goals. For example, in deep infiltrating endometriosis, fertility-preserving myomectomy, and complex oncologic cytoreduction, surgeons must not only achieve maximal lesion removal but also precisely preserve critical structures such as the ureters, nerves, vessels, and reproductive tissues to minimize complications and optimize long-term functional and reproductive outcomes (D'Augè et al., 2025). In challenging patient populations, such as obese individuals, adolescents, patients with multiple prior surgeries, or those with complex comorbidities, the need for precision is even greater due to limited visualization, restricted operative space, and reduced tolerance to pneumoperitoneum (Appelbaum, 2024).

At the same time, standardization is essential for improving overall healthcare quality and reducing inter-institutional variability. Establishing uniform criteria for indications, standardized operative steps, and quality control metrics can reduce variability in surgical approaches, resection extent, and perioperative management, thereby enhancing consistency and reproducibility of outcomes (Vazquez et al., 2025; Wu et al., 2025). However, significant heterogeneity persists in current clinical practice, with substantial differences in technique selection, procedural pathways, and oncologic indications across regions and institutions. This is particularly evident in controversial areas such as cervical and ovarian cancer, where variations in patient selection and operative techniques can significantly influence outcomes (Balafoutas and Vlahos, 2024). Therefore, standardization should not equate to rigid protocols but rather represent individualized adjustments within an evidence-based framework.

In this context, the integration of intelligent assistive technologies is considered a key pathway to achieving both precision and standardization. By combining preoperative imaging, intraoperative video, perioperative parameters, and postoperative outcomes, data-driven surgical decision-support systems can be developed. Additionally, technologies based on real-time recognition, navigation, and quality assessment can provide continuous, objective, and quantifiable intraoperative guidance, reducing reliance on individual experience and improving consistency in