Editorial

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The future of robotic thoracic surgery education: experience, challenges, and opportunities

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The global adoption of Robotic Thoracic Surgery (RTS) has grown exponentially in recent years, offering substantial advantages in precision, visualization, and patient outcomes. However, mastering this highly sophisticated technology demands the development of complex cognitive, psychomotor, and behavioral skills that exceed those required in traditional surgical techniques. As such, dedicated education and structured training frameworks are essential for safe and effective dissemination of robotic thoracic surgery worldwide.

At the *Hospital Israelita Albert Einstein* in São Paulo, Brazil, we have established a comprehensive International Postgraduate Program in Robotic Thoracic Surgery. This program, which has trained over 150 thoracic surgeons to date, combines simulation-based training, dry-lab and wet-lab practice, high-fidelity crisis simulation, crisis resource management, direct observation, and over 150 hours of interactive lectures. This modular and competency-based approach allows trainees to progress from basic console operation to complex intraoperative decision-making and non-technical crisis management.

Persistent challenges in robotic thoracic surgery training

Despite these advances, several challenges remain in the education of robotic thoracic surgery, which are particularly pronounced in emerging economies.

Lack of standardized curricula

Currently, robotic thoracic surgery lacks universally accepted training standards. Several models have been proposed, including the Fundamentals of Robotic Surgery (FRS), Global Evaluative Assessment of Robotic Skills (GEARS), and Robotic Objective Structured Assessment of Technical Skills (R-OSATS), all aiming to standardize the assessment of robotic surgical proficiency

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through objective performance metrics. Modular stepwise approaches combining simulation, laboratory training, and mentored clinical practice have been widely advocated to promote safe and progressive skill acquisition.[1-3]

Extended learning curve

The robotic learning curve remains longer and steeper than that of conventional minimally invasive surgery. International series suggest that proficiency for robotic lobectomy may require at least 20-60 cases depending on prior surgical experience and training structure.[4-6] In our own experience, conducted in an emerging country, we observed that substantial proficiency may be reached after 15-20 cases, with full operative autonomy often requiring extended clinical exposure and continuous mentorship.[7]

Barriers in emerging countries

The high costs of robotic platforms, limited availability of experienced proctors, and insufficient case volumes pose particular obstacles to the widespread implementation of robotic thoracic surgery in low- and middle-income countries. Our own institutional experience demonstrated that these barriers can be overcome through carefully structured training programs, multidisciplinary team engagement, and institutional commitment.[8,9]

The essential role of non-technical skills

Beyond technical proficiency, non-technical skills (NTS) are increasingly recognized as critical for safe robotic surgery. These include situational awareness, decision-making under stress, communication, leadership, and teamwork–domains particularly relevant in complex robotic environments with limited tactile feedback and complex equipment interfaces.

Our postgraduate program incorporates NTS training through dedicated crisis resource management modules, high-fidelity simulation of intraoperative emergencies, and team-based debriefing sessions. This mirrors international experience, notably the work by Baste et al., who have highlighted the importance of cognitive training, standardized checklists, and team dynamics in robotic thoracic surgery education.[10-12] Their studies demonstrate that structured NTS training improves intraoperative safety, enhances team performance, and reduces cognitive overload for both junior and senior surgeons.

Despite their importance, NTS training remains underrepresented in many curricula. As robotic technology evolves toward more autonomous and complex platforms, human factors and behavioral skills will become even more central to surgical education and credentialing.

Scientific contributions from the Brazilian experience

Over the past decade, our group has actively contributed to the scientific literature on robotic thoracic surgery education, learning curves, and implementation. The BRAVO trial, a Brazilian randomized study comparing robotic-assisted versus video-assisted lobectomy, demonstrated equivalent perioperative outcomes after structured training, underscoring the safety of robotic adoption when training is properly standardized.[13]

We have also published guidelines on how to teach robotic lobectomy, emphasizing a modular, mentored approach to gradually build complexity while ensuring patient safety.[14] In addition, our institutional experience in building one of the largest robotic thoracic surgery programs in Latin America serves as a model for implementation in emerging countries, where resource limitations and training gaps are significant.[8,9]

Emerging technologies shaping the future of robotic education

Looking ahead, several emerging technologies are poised to further revolutionize robotic surgical education:

- Artificial intelligence and automated metrics: machine learning algorithms can analyze instrument kinematics, motion economy, and technical precision to provide

objective, real-time feedback for performance evaluation and credentialing.[15,16]

- Virtual and augmented reality: immersive simulation technologies offer the opportunity for patient-specific rehearsal, enhancing anatomical recognition, surgical planning, and decision-making skills in a safe environment.[17,18]
- Telementoring and remote proctoring: digital platforms facilitate expert supervision across geographic boundaries, addressing local shortages of experienced mentors in low-resource settings.[19]
- Crisis resource management simulation: highfidelity scenarios simulating catastrophic intraoperative events allow trainees to practice leadership, cognitive adaptability, and team coordination under stress.[10,11,20]

As we gather for the 4th International Congress on Robotic Thoracic Surgery at *Hospital Israelita Albert Einstein*, the abstracts presented here reflect both the scientific evolution and educational maturation of our field. Moving forward, a global commitment to structured education, validated assessment, and the integration of emerging technologies will be essential to ensure safe, equitable, and universal access to robotic thoracic surgery – not only for patients but also for the next generation of surgeons worldwide.

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