CURRENT TRENDS IN THE MINIMALLY INVASIVE TREATMENT OF ADRENAL PATHOLOGY

ABSTRACT

INTRODUCTION

With technological progress, there has been a significant improvement in the diagnosis of incidentally discovered adrenal lesions—known as adrenal incidentalomas—due to the increasingly widespread use of high-performance imaging techniques. This reality has required the adaptation of clinical guidelines, both from an endocrinological and surgical perspective, in order to establish the optimal therapeutic strategy for each individual patient. Consequently, the timing of surgical intervention, patient selection, and the choice of the optimal surgical approach have become subjects of intensive investigation in contemporary medical literature.

This thesis aligns with the growing trend toward precision and personalized medicine, aiming to provide a comprehensive and rigorous evaluation of minimally invasive techniques used in the treatment of adrenal tumors. The primary objective of the thesis is to compare the three major laparoscopic approaches—transperitoneal, lateral retroperitoneal, and posterior retroperitoneal—in terms of efficiency, safety, operative time, blood loss, length of hospital stay, and postoperative complications. In doing so, the study offers an up-to-date foundation for selecting the optimal surgical technique based on both patient- and tumor-specific characteristics.

Additionally, the thesis addresses the integrative role of modern technologies—ranging from HD/4K/3D visualization systems to artificial intelligence and augmented reality—in optimizing surgical decision-making, guiding precise

dissection, and enhancing the training of the modern surgeon. In an era in which surgery is no longer merely a technical act but a digitally assisted, data-informed process, adaptation to these new paradigms is essential to ensure safe and effective medical care.

In conclusion, this work aims to make a significant contribution to the understanding, application, and refinement of minimally invasive techniques in adrenal gland surgery by leveraging the synergy between clinical expertise, emerging technologies, and the principles of personalized medicine. Through this approach, the thesis seeks to serve as a valuable tool for informed medical decision-making, clinical research, and the advancement of modern surgical practice.

PART I

CHAPTER 1. GENERAL DATA, DIAGNOSTIC ASPECTS, AND CLINICAL-THERAPEUTIC CONTEXT OF ADRENAL GLAND PATHOLOGY

With the development of advanced imaging techniques such as CT and MRI, the number of detected adrenal tumors has increased significantly [6]. Differential diagnosis between benign and malignant lesions requires a complex approach combining hormonal and imaging investigations [7].

Adrenal pathology represents a major challenge in medical practice, with significant clinical, diagnostic, and therapeutic implications. The development of minimally invasive methods and new technologies has contributed substantially to

improving patient prognosis and quality of life, making this field one of considerable interest in current medical research [9].

Although relatively rare, adrenal gland disorders have a significant impact on health due to their essential role in regulating hormonal and metabolic functions [10].

The incidence of these disorders continues to rise as a result of the widespread use of advanced imaging techniques. Epidemiologically, these conditions vary according to etiology, hormonal profile, and population characteristics, and can be broadly categorized into syndromes of hormonal hypersecretion and hyposecretion [11].

New perspectives in the treatment of adrenal disorders focus on synthetic hormone therapy and steroids, which are still under investigation to provide safer, more effective treatment options with fewer side effects. Currently, there is increasing emphasis on personalized medicine, particularly individualized treatments based on genetic data that predict patient-specific responses. Immunological therapies and targeted biological treatments addressing the immunological causes of adrenal disorders are also under development [28].

Over the years, the diagnosis and treatment of adrenal gland disorders have improved significantly, evolving from empirical therapies and unclear approaches to individualized, patient-centered treatment plans. This ongoing evolution has contributed to improved patient prognosis and enhanced quality of life.

The evolution of adrenal gland surgery has benefited from major technological advances, which have improved operative techniques, safety, and surgical efficiency. While traditional invasive surgery was associated with high risks and

complication rates, contemporary approaches are based on precise minimally invasive techniques that offer lower risk and rapid recovery.

The adrenal gland is a paired endocrine organ, triangular in shape, located above each kidney, and composed of the adrenal cortex and medulla [34]. It plays a crucial role in hormone secretion and regulation, influencing the body's response to stress, metabolic balance, blood pressure regulation, and electrolyte homeostasis. The gland consists of two main functional components, each responsible for the secretion of different hormones [36].

Adrenal tumors may be benign, slow-growing, and non-invasive, or malignant, and may be functional (hormone-secreting) or non-functional, the latter often being incidentally discovered. Secondary adrenal tumors originate from primary malignancies such as lung, renal, breast cancers, and malignant melanoma.

The diagnostic approach to adrenal disorders requires a comprehensive evaluation combining biochemical tests and imaging investigations to assess hormonal imbalances, electrolyte disturbances, and gland morphology. Biochemical diagnosis is based on hormone measurements tailored to the suspected clinical syndrome.

CHAPTER 2. SURGICAL TECHNIQUES, THE ROLE OF MODERN TECHNOLOGIES, FUTURE DIRECTIONS IN MINIMALLY INVASIVE TREATMENT, AND COMPARATIVE OUTCOMES

Surgical treatment of adrenal gland disorders has undergone significant transformation over recent decades, reflecting technological progress and the adoption of minimally invasive surgical principles. From early open adrenalectomies performed through large incisions with substantial postoperative morbidity, current

practice has evolved toward laparoscopic and robotic techniques that offer faster recovery and improved patient comfort [55, 56].

Laparoscopic adrenal surgery is currently considered the gold standard for the treatment of most benign, functional, and tumoral adrenal lesions. This technique has gradually replaced open surgery due to its superior advantages in postoperative recovery, reduced morbidity, and improved cosmetic outcomes [75, 76].

Robotic surgery represents an emerging extension of laparoscopy, offering enhanced three-dimensional visualization, articulated instruments, and improved ergonomic conditions for the surgeon. While particularly useful in complex cases, its accessibility remains limited due to high costs [102,103].

Intraoperative imaging provides real-time visualization of vascular structures and anatomical landmarks, allowing precise dissection and complete tumor resection. It is particularly valuable in cases involving large tumors, reoperations for recurrent disease, or lesions with atypical localization [123].

PART II. PERSONAL CONTRIBUTIONS

Objectives and Hypothesis of the Thesis

This work aims to address several key questions raised by adrenal pathology:

- diagnostic and therapeutic algorithms,
- indications for laparoscopic adrenalectomy,
- the most appropriate adrenalectomy technique,
- complications associated with transperitoneal and retroperitoneal laparoscopic adrenalectomy and their prevention and management,
- postoperative evaluation of patients' quality of life.

CHAPTER 3. LAPAROSCOPIC ADRENALECTOMY: ADAPTING APPROACHES FOR OPTIMAL TUMOR RESECTION

Adrenal tumors encompass a broad spectrum of pathological entities, ranging from benign, non-secreting adrenocortical adenomas to hyperfunctional malignancies such as adrenocortical carcinoma and hormone-secreting medullary tumors such as pheochromocytoma [194].

In a retrospective analysis, we examined 82 patients with adrenal tumors who underwent laparoscopic adrenalectomy via retroperitoneal or transperitoneal approaches at the Urology Department of the Sibiu County Clinical Hospital over the past eight years. All procedures were performed by the same surgical team.

The retroperitoneal approach was predominantly used, accounting for 55 cases. Specifically, the posterior retroperitoneal approach was applied in 24 patients (35.8%), the lateral retroperitoneal approach in 31 patients (46.2%), and the transperitoneal approach in 12 patients (18%).

Patients undergoing retroperitoneal approaches experienced complications such as wound infections. These findings contrast with some literature reports that do not identify significant safety differences between the two surgical approaches [225]. In cases involving small tumors, there is broad consensus that the transperitoneal approach should be avoided or approached with particular caution [226].

CHAPTER 4. ULTRASOUND-GUIDED LAPAROSCOPIC ADRENAL SURGERY: REAL-TIME IMAGING FOR SAFE AND PRECISE RESECTION

Intraoperative ultrasound, first introduced by Sigel in 1979 and later adapted for laparoscopic surgery, has demonstrated an exceptional ability to “palpate by sight” tissues in the absence of direct tactile feedback [253,254]. Rapid technological advancements have led to dedicated high-frequency laparoscopic probes with color and power Doppler modes, eliminating skin-related artifacts and providing high-resolution images even within the confined spaces of the abdominal or retroperitoneal cavities [255].

In this study, we present our experience using intraoperative ultrasound in 58 laparoscopic adrenalectomies. We describe the dedicated imaging technique and highlight its impact on surgical planning and execution, complication rates, and long-term outcomes. A total of 58 patients were included, all undergoing IOUS-guided laparoscopic adrenalectomy: 28 via the retroperitoneal approach and 30 via the transperitoneal approach.

The transition from open to laparoscopic and now robotic adrenalectomy has revolutionized patient care, offering shorter hospital stays, reduced discomfort, and faster return to normal activity. Among laparoscopic techniques, the retroperitoneal approach frequently outperforms the transperitoneal approach in perioperative metrics, although both are safe in experienced hands. IOUS has become a vital adjunct, reducing blood loss, shortening hospitalization, and minimizing complications.

CHAPTER 5. INTRAOPERATIVE ULTRASOUND GUIDANCE IN LAPAROSCOPIC ADRENALECTOMY: A RETROSPECTIVE ANALYSIS OF PERIOPERATIVE OUTCOMES

Ultrasonography is a fundamental tool in both diagnosis and therapy, providing essential support in the evaluation of internal organs and superficial tissues [288]. Technological advances have expanded its applications through three-dimensional (3D) and four-dimensional (4D) imaging, which may become standard in the near future [289, 290].

Advances in IOUS technology have extended its use across multiple surgical specialties, including endocrine, cardiac, neurological, vascular, digestive, and breast surgery.

This retrospective study analyzed 128 patients with adrenal tumors who underwent laparoscopic adrenalectomy, comparing those who received IOUS guidance with those who did not. A total of 128 patients were divided into four groups based on surgical approach: IOUS-guided retroperitoneal (21.9%, n=28), non-IOUS retroperitoneal (39.1%, n=50), IOUS-guided transperitoneal (23.4%, n=30), and non-IOUS transperitoneal (15.6%, n=20).

In laparoscopic adrenalectomy, intraoperative ultrasound plays a crucial role by significantly enhancing procedural precision and safety. The findings highlight significant differences between surgical approaches, with the retroperitoneal approach demonstrating superior outcomes, including shorter hospital stays and faster resumption of oral intake.

CHAPTER 6. THERAPEUTIC OPTIONS IN THREE-DIMENSIONAL LAPAROSCOPIC SURGERY FOR ADRENAL TUMORS: A RETROSPECTIVE ANALYSIS OF THREE APPROACHES

Adrenal tumors represent a diverse clinical category, including benign lesions such as adenomas and malignant or hypersecretory neoplasms such as pheochromocytoma and Cushing syndrome [329]. Minimally invasive surgery, particularly 3D laparoscopic adrenalectomy, has transformed the management of these conditions by offering significant advantages over traditional open surgery.

This retrospective study included 84 patients diagnosed with adrenal tumors who underwent 3D laparoscopic surgery at the Sibiu County Emergency Clinical Hospital between 2019 and 2025. The surgical plan also divided the retroperitoneal technique into lateral and posterior approaches, adapted to tumor location and surgical team preference. All adrenalectomies were performed laparoscopically in 3D.

Our study confirms the advantages of the retroperitoneal approach, particularly for small tumors and patients with a history of abdominal surgery. Benefits included shorter operative time, minimal blood loss, faster return to oral feeding and mobilization, and reduced hospital stay [269,335].

The results suggest that 3D laparoscopic adrenalectomy—whether performed via the retroperitoneal or transperitoneal approach—is a safe and effective technique. The choice of approach should be based on comprehensive patient evaluation, considering tumor size and location, surgical history, BMI, hormonal assessment, and procedural risks.

SYNTHETIC DISCUSSION OF STUDY RESULTS

The collected data allowed a detailed evaluation of operative time, blood loss, hospital stay, time to oral intake and mobilization, and complication rates.

Laparoscopic surgery, particularly the retroperitoneal approach, has become the gold standard for the treatment of benign and functional adrenal tumors. Compared to open surgery, it offers shorter operative times, minimal blood loss, faster recovery, and improved postoperative quality of life.

The study also evaluated the role of intraoperative ultrasound as a surgical guidance tool. IOUS proved essential for tumor localization, vascular assessment, and dissection guidance, particularly in obese patients or those with complex anatomy. The study statistically demonstrated reductions in bleeding and complications with IOUS use.

Overall, the findings confirm that minimally invasive surgery—especially the retroperitoneal approach—is effective, safe, and well tolerated. The integration of modern technologies enhances surgical precision and may redefine therapeutic standards in adrenal pathology. The data support the adoption of a personalized treatment algorithm tailored to each patient, tumor type, and available resources.

There is no single optimal surgical approach. The choice must be individualized based on tumor size, functionality, patient comorbidities, prior abdominal surgery, and surgical team experience.

FUTURE PERSPECTIVES

One of the most promising areas is the development of AI-assisted navigation platforms that enable not only preoperative planning based on three-dimensional anatomical reconstruction but also real-time adjustment of the surgical trajectory in response to intraoperative anatomical changes. These tools may significantly reduce operative risks, particularly in complex cases or altered anatomy.

Scarless surgery techniques, such as NOTES (Natural Orifice Translumenal Endoscopic Surgery), and the miniaturization of surgical instruments represent the next step in minimizing operative impact. Future clinical studies are required to validate the feasibility and safety of these techniques in adrenal surgery.