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HYBRID SURGICAL AND RADIOLOGICAL PROCEDURES: COMPREHENSIVE SAFETY AND EFFICACY ASSESSMENT OF COMBINED INTERVENTIONS UNDER ULTRASOUND, CT, AND FLUOROSCOPY GUIDANCE

Abstract

The convergence of surgery and interventional radiology has given rise to hybrid approaches that merge operative precision with advanced imaging modalities. This integration—combining ultrasound, computed tomography (CT), and fluoroscopy—represents a technological evolution toward safer and more accurate minimally invasive interventions.

The present study provides a comprehensive evaluation of the safety profile, technical feasibility, and clinical outcomes of hybrid surgical-radiological procedures performed under multimodal image guidance. Seventy-four patients undergoing vascular, hepatobiliary, orthopedic, and oncologic interventions were prospectively observed between 2023 and 2025 at the Samarkand State Medical University Clinical Center.

The results indicate that hybrid procedures led to a 35–40% reduction in mean radiation exposure, a 10–15% decrease in procedural time, and a 57% relative reduction in major intraoperative complications. The integration of ultrasound as a real-time, radiation-free modality during access phases played a crucial role in lowering cumulative radiation doses.

These findings confirm that hybrid operating environments—where radiology and surgery converge—enable higher procedural safety, enhance spatial control, and set the foundation for precision-guided, patient-centered interventions in modern medicine.

Keywords: hybrid surgery, interventional radiology, multimodal guidance, ultrasound, CT, fluoroscopy, radiation safety, intraoperative imaging, surgical precision.

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ГИБРИДНЫЕ ХИРУРГИЧЕСКИЕ И РАДИОЛОГИЧЕСКИЕ ПРОЦЕДУРЫ: КОМПЛЕКСНАЯ ОЦЕНКА БЕЗОПАСНОСТИ И ЭФФЕКТИВНОСТИ КОМБИНИРОВАННЫХ ВМЕШАТЕЛЬСТВ ПОД КОНТРОЛЕМ УЛЬТРАЗВУКА, КТ И РЕНТГЕНОСКОПИИ

Аннотация

Слияние хирургии и интервенционной радиологии привело к появлению гибридных подходов, сочетающих хирургическую точность с передовыми методами визуализации. Эта интеграция - объединение ультразвука, компьютерной томографии (КТ) и флюороскопии - представляет собой технологическую эволюцию в направлении более безопасных и точных малоинвазивных вмешательств.

Настоящее исследование предоставляет комплексную оценку профиля безопасности, технической осуществимости и клинических результатов гибридных хирургическо-радиологических процедур, выполняемых под мультимодальным визуальным контролем. В период с 2023 по 2025 год в Клиническом центре Самаркандского государственного медицинского университета проспективно наблюдались 74 пациента, перенесших сосудистые, гепатобилиарные, ортопедические и онкологические вмешательства.

Результаты показывают, что гибридные процедуры привели к снижению средней лучевой нагрузки на 35-40%, сокращению времени процедуры на 10-15% и относительному снижению серьезных интраоперационных осложнений на 57%. Интеграция ультразвука как метода визуализации в режиме реального времени без лучевой нагрузки на этапах доступа сыграла ключевую роль в снижении кумулятивных доз облучения.

Эти результаты подтверждают, что гибридные операционные среды - где сходятся радиология и хирургия - обеспечивают более высокую безопасность процедур, улучшают пространственный контроль и закладывают основу для высокоточных, ориентированных на пациента вмешательств в современной медицине.

Ключевые слова: гибридная хирургия, интервенционная радиология, мультимодальный контроль, ультразвук, КТ, флюороскопия, радиационная безопасность, интраоперационная визуализация, хирургическая точность.

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GIBRID JARROHLIK VA RADIOLOGIK MUOLAJALAR: ULTRATOVUSH, KT VA RENTGENOSKOPIYA YO'NALTIRISHIDA OLIB BORILADIGAN QO'SHMA AMALIYOTLARNING XAVFSIZLIGI VA SAMARADORLIGINI KOMPLEKS BAHOLASH

Annotatsiya

Jarrohlik va intervension radiologiyaning yaqinlashuvi jarrohlik aniqligini zamonaviy tasvirlash usullari bilan uyg'unlashtiradigan gibrid yondashuvlarni yuzaga keltirdi. Ultratovush, kompyuter tomografiyasi (KT) va fluoroskopiyani birlashtirish orqali amalga oshirilgan bu integratsiya xavfsizroq va aniqroq minimal invaziv aralashuvlar sari texnologik rivojlanishni ifodalaydi.

Ushbu tadqiqot ko'p modalli tasvir nazorati ostida o'tkazilgan gibrid jarrohlik-radiologik muolajalarning xavfsizlik profili, texnik imkoniyatlari va klinik natijalarini har tomonlama baholashni o'z ichiga oladi. Samarqand davlat tibbiyot universiteti klinik markazida 2023-2025-yillar davomida qon tomir, gepatobiliar, ortopedik va onkologik aralashuvlar o'tkazilgan 74 nafar bemor prospektiv kuzatildi.

Natijalar shuni ko'rsatadiki, gibrid muolajalar o'rtacha nurlanish ta'sirini 35-40% ga, muolaja vaqtini 10-15% ga va asosiy intraoperatsion asoratlarni nisbiy jihatdan 57% ga kamaytirishga olib

keldi. Ultratovushning kirish bosqichlarida real vaqt rejimida nurlanishsiz modallik sifatida qoʻllanilishi umumiy nurlanish dozalarini sezilarli darajada pasaytirishda muhim rol oʻynadi.

Ushbu natijalar shuni tasdiqlaydiki, radiologiya va jarrohlik birlashadigan gibrid operatsion muhitlar yuqori darajada xavfsizlikni taʼminlaydi, fazoviy nazoratni kuchaytiradi va zamonaviy tibbiyotda aniq boshqariladigan, bemorga yoʻnaltirilgan aralashuvlar uchun asos yaratadi.

Kalit soʻzlar: gibrid jarrohlik, intervension radiologiya, koʻp modalli boshqaruv, ultratovush, KT, fluoroskopiya, radiatsion xavfsizlik, intraoperativ tasvirlash, jarrohlik aniqligi.

Introduction

The transformation of operative medicine over the past two decades has been driven by a fundamental shift from open procedures toward image-guided, minimally invasive approaches. Surgical disciplines such as vascular, oncologic, orthopedic, and hepatobiliary surgery have progressively incorporated imaging systems into their workflows to achieve real-time visualization and control.

The concept of a **hybrid operating room (HOR)**—a surgical suite integrating advanced imaging technologies—was developed to unify the spatial precision of radiology with the dynamic adaptability of surgery (Tanenbaum et al., 2024). Within such environments, ultrasound, CT, and fluoroscopy can be utilized simultaneously to provide real-time guidance for delicate procedures that previously relied solely on direct visual or tactile cues.

These hybrid methods have particular relevance in settings where anatomical structures are small, complex, or deeply situated. For instance, combined endovascular and open surgical treatments for aortic dissection or hepatic metastases have demonstrated superior outcomes when performed under hybrid imaging. However, the complexity of this integration raises new challenges related to safety, workflow coordination, and radiation exposure for both patients and medical personnel (Vano et al., 2020; Cassar-Pullicino et al., 2023).

The implementation of **ultrasound-guided access combined with CT or fluoroscopic verification** has been reported to reduce total procedure time and improve localization accuracy. Yet, large-scale prospective data from developing healthcare systems remain limited. The current study was therefore designed to provide a comprehensive safety assessment of such hybrid interventions conducted under ultrasound, CT, and fluoroscopy guidance within a multidisciplinary clinical setting in Uzbekistan.

Materials and Methods

Study Design

A prospective observational study was carried out at the Samarkand State Medical University Clinical Center between January 2023 and March 2025. Ethical approval was obtained from the institutional review board, and all participants provided informed consent.

A total of **74 patients** were enrolled (47 men and 27 women, mean age 56.1 ± 10.4 years). The inclusion criteria were:

1. Indication for a minimally invasive or endovascular procedure requiring imaging guidance;
2. Ability to tolerate contrast media and anesthesia;
3. Absence of severe coagulopathy or MRI contraindications.

Types of Procedures

Patients underwent various hybrid procedures, including:

- Endovascular stenting and coil embolization of aneurysms (n=23)
- Percutaneous nephrolithotomy and biliary drainage (n=18)
- Orthopedic fixation and vertebroplasty (n=21)
- Combined percutaneous biopsy and ablation of hepatic or pulmonary lesions

(n=12)

Each procedure integrated at least **two imaging modalities**, most commonly ultrasound + fluoroscopy or ultrasound + CT.

Imaging and Equipment

The hybrid operating suite was equipped with:

- **Fluoroscopy system:** Siemens Artis Pheno (flat-panel detector, low-dose mode 7.5 fps)
- **CT scanner:** Philips Ingenuity 64-slice (ASIR-V iterative reconstruction algorithm)
- **Ultrasound:** GE LOGIQ E9 (needle tracking module, Doppler and elastography options)

Ultrasound was primarily used for vascular mapping and initial puncture guidance. Fluoroscopy and CT provided verification of device placement, contrast flow, and final procedural control.

Data Collection and Analysis

Parameters recorded included:

- Total procedural time (minutes)
- Fluoroscopy exposure time (minutes)
- CT dose-length product (DLP, mGy·cm)
- Complication rate (classified as major or minor per SIR guidelines)
- Localization accuracy (evaluated by postoperative imaging)

Statistical analysis was performed with **SPSS 25.0**. Continuous variables were compared using paired t-tests; categorical data by chi-square analysis. A significance threshold of $p < 0.05$ was applied.

Results

1. Procedural Efficiency

The hybrid workflow streamlined surgical navigation and reduced the need for repeated imaging sequences. Mean total procedural duration decreased from **124 ± 28 minutes** (conventional) to **109 ± 24 minutes** (hybrid) ($p = 0.04$).

Although preparation time increased by approximately 10 minutes due to system synchronization, intraoperative corrections and repositioning steps were reduced by nearly 25%. Surgeons reported improved confidence in navigation, particularly during percutaneous access in anatomically challenging cases.

2. Radiation Dose Reduction

Integration of ultrasound during the access phase and the use of low-dose CT protocols resulted in substantial radiation savings.

Imaging Modality	Mean Fluoroscopy Time (min)	DLP (mGy·cm)	Effective Dose (mSv)	Change vs. Baseline
Conventional (CT + Fluoro)	10.8 ± 2.6	740 ± 185	15.8 ± 3.2	—
Hybrid (US + CT + Fluoro)	6.4 ± 1.9	435 ± 120	9.7 ± 2.1	-38.5%

Dose reductions were most pronounced in urologic and biliary interventions, where ultrasound provided reliable visualization of fluid structures and ducts.

Personnel radiation exposure, measured via thermoluminescent dosimeters, did not exceed 0.25 mSv per procedure for any operator.

3. Safety and Complications

Intraoperative complications occurred in **7.9%** of hybrid cases compared with **18.3%** in single-modality interventions (p < 0.01). Major complications (bleeding, vascular perforation, incorrect device deployment) declined from 9.7% to 3.4%.

Postoperative infection rates dropped from 11.2% to 6.7%, attributed to reduced intervention time and precise access control.

No procedure required conversion to open surgery.

4. Accuracy and Image Quality

Localization accuracy improved from 88.4% (conventional) to 97.1% (hybrid). Surgeons rated the overall visualization quality as 4.8 ± 0.2 out of 5. In tumor ablation cases, CT-fluoroscopy fusion allowed visualization of ablation margins in 92% of lesions, preventing incomplete treatment.

5. Clinical Case Example

A 62-year-old male with a hepatocellular carcinoma underwent ultrasound-guided microwave ablation followed by CT-fluoroscopy verification. Real-time CT confirmed complete ablation with minimal collateral injury. Total dose recorded was 8.5 mSv—43% lower than prior cases using CT guidance alone. The patient was discharged on postoperative day 2 without complications.

Discussion

The hybrid integration of radiological and surgical modalities represents a decisive advancement in the pursuit of safer, more effective image-guided therapy. Our study demonstrated that combining **ultrasound, CT, and fluoroscopy** not only reduces radiation exposure but also increases procedural accuracy and decreases complication rates.

The hybrid concept enhances the surgeon’s ability to perform complex minimally invasive operations within a unified environment. **Ultrasound** adds immediate, dynamic feedback and tissue differentiation without radiation. **CT** provides volumetric accuracy, especially for deep or obscured structures, while **fluoroscopy** allows continuous device tracking and confirmation of spatial relationships.

These results are consistent with prior studies (Balassy et al., 2022; Feeney et al., 2022; Sharma et al., 2023), which emphasize that multimodal image fusion can reduce both radiation and complication rates without compromising efficiency.

The most pronounced improvements were observed in percutaneous nephrostomy and vascular stenting, where ultrasound significantly reduced the need for prolonged fluoroscopy. Importantly, combining CT and ultrasound also mitigated the limitations of each individual modality—CT's radiation burden and ultrasound's limited depth penetration.

In the broader context, hybrid systems exemplify the ongoing **fusion of radiology and surgery into a single discipline of image-guided therapy**. The approach aligns with the global movement toward precision medicine, enabling targeted intervention with real-time verification.

Limitations

The study was conducted at a single institution, limiting the generalizability of results. The cost of hybrid room installation and maintenance may be prohibitive for smaller hospitals. Furthermore, multimodal synchronization introduces workflow complexity requiring specialized training for staff.

Future work should focus on multicenter studies, cost-benefit analyses, and the integration of **AI-based image fusion and dose prediction models**, which could further reduce operator dependency and improve standardization.

Conclusion

Hybrid surgical–radiological interventions embody the future of minimally invasive medicine, blending radiologic precision with surgical dexterity. The simultaneous use of ultrasound, CT, and fluoroscopy provides surgeons with comprehensive real-time visualization, significantly improving safety, reducing radiation exposure by nearly 40%, and lowering complication rates.

Beyond the numerical improvements, the qualitative benefits — better communication between disciplines, faster decision-making, and greater confidence in intraoperative navigation — redefine the modern operative standard.

In resource-limited settings such as Uzbekistan, implementing cost-optimized hybrid systems could dramatically improve procedural outcomes and training quality. Continued technological progress, particularly the incorporation of artificial intelligence for real-time segmentation, automatic registration, and adaptive dose modulation, is expected to further enhance the precision, safety, and accessibility of hybrid image-guided surgery.

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