Opinion Paper

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Towards the future of Endocrine Laboratory Medicine: defining the role of laboratory medicine specialists to strengthen the clinical–biological partnership – a joint opinion paper of EFLM-C:YS, IFCC TF-YS, and ESE-EYES

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Abstract: Clinical endocrinology relies critically on high-quality biochemical data for diagnosis, therapeutic decisions, and long-term patient monitoring. As endocrine diagnostics grow more complex due to expanding test menus, technological advances, and changing patient populations, the need for a strong, structured partnership between clinicians and Laboratory Medicine professionals has never been greater. This joint opinion paper, developed by young professionals from the EFLM Committee Young Scientists (EFLM-C:YS), the IFCC Task Force Young Scientists (IFCC TF-YS), and the European Young Endocrinologists and Scientists (ESE-EYES), explores clinicians' expectations of modern Endocrine Laboratory Medicine (ELM) and proposes actionable strategies to meet them. Using a clinician–laboratory question-and-answer framework, we address five key domains: procedural harmonization, analytical reliability, interpretability and contextualization of results, consultative partnership, and innovation in service delivery. We highlight the central role of laboratory medicine professionals throughout the total testing process, from test selection to post-analytical interpretation of laboratory results. Particular emphasis is placed on the harmonization of endocrine dynamic function tests, adoption of high-specificity analytical platforms such as liquid chromatography–tandem mass spectrometry, development of personalized reference intervals, and implementation of diagnostic management teams. Emerging challenges, including transgender care, endocrine disruptors, digital health technologies, and artificial intelligence, are discussed as opportunities for laboratories to assume leadership in precision and preventive endocrinology. We conclude that the future of endocrine diagnostics depends on transforming laboratory data from a technical endpoint into a strategic clinical partner, ensuring diagnostic excellence through continuous dialogue, shared accountability, and innovation.

Keywords: value-based laboratory medicine; clinical–biological dialogue; Endocrine Laboratory Medicine; clinician-laboratory relationship; clinical outcomes

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Defining the partnership for clinical excellence

Clinical endocrinology, among medical disciplines, is one of the most dependent on quantitative biochemical data. The diagnosis and follow-up of endocrine disorders require

laboratory results that are not only accurate but also clinically interpretable and harmonized across analytical methods and institutions [1, 2]. The stakes have increased in recent years: the expansion of point-of-care technologies, rapid adoption of digital health platforms, and increasing complexity of endocrine diagnostics have made analytical–clinical alignment more essential than ever. Endocrine Laboratory Medicine (ELM) is therefore particularly involved in clinical practice, but faces many challenges. Young Laboratory Medicine professionals may struggle to find their place in patient management because of the lack of clinical data and the great heterogeneity of hormonology demands and results, sometimes blurring the interpretation of laboratory results. How can clinicians in endocrinology and ELM specialists enhance their partnership with laboratory medicine professionals and use their strengths to bring together analytical relevance and clinical expertise?

Diagnostic excellence depends on integrating laboratory accuracy with clinical context. To achieve this, ELM must evolve from a technical service into a strategic partner in the clinical pathway, engaging across the total testing process (TTP): from pre-analytical standardization and laboratory tests ordering to post-analytical interpretation of the results. Young endocrinologists increasingly recognize that achieving "clinical excellence" requires shared accountability, continuous dialogue, and joint education between clinicians and laboratory professionals [2]. This opinion paper outlines clinicians' expectations and how laboratory medicine professionals can address them, following a question-and-answer dialogue illustrated by concrete example of clinically impactful actions that could serve as a model for future initiatives to improve the clinician-laboratory medicine professional "Brain-to-Brain loop" (Figure 1).

Adapting ELM practice to societal needs and evolutions

There have been several societal changes in the past few decades impacting the field of hormonology testing, with the appearance of new patient populations and clinical needs. For example, it is important to remind that the first *in vitro* fertilization baby was born less than 50 years ago, in 1978, whereas it is estimated that 10–13 million infants were born from assisted reproductive technology since then [4, 5]. This whole highly specialized network of health care implies several healthcare professionals, including hormonology testing with uncommon laboratory results to integrate (e.g., serum estradiol following ovarian stimulation).

More recently, the evolution in the management of transgender patients has brought new clinical needs and questions, such as laboratory monitoring gender-affirming hormone therapy, with reference ranges adapting to an individual's gender [6]. In addition, the general and hormonal pathophysiological long-term consequences of transitioning are yet to be described, as extensive longitudinal data in these patients are scarce. Thereby, there is a challenge in conducting observational clinical and biological studies to address this issue.

Besides, endocrine disruptors, such as perfluoroalkyl substances (PFAS) are at the centre of discussion in last several years, as an important public healthcare issue, notably impairing reproductive hormones [7]. Hopefully, exposome and large-scale ambitious research programs in this field are ongoing [8]. However, translation to clinical laboratories is lacking, both regarding the development of specific analytical methods and the clinical and biological definition of standard and over-exposition to these compounds, at the individual scale.

Finally, chronic metabolic diseases, such as diabetes or metabolic-associated fatty liver disease, are ever-growing worldwide, so there is a critical upcoming challenge for endocrinologists and ELM specialists to promote prevention, improve diagnosis and prognosis biomarker research, and enhance translational research for therapeutic development.

Clinical expectation 1 – Procedural consistency and harmonization

Reproducibility is central to clinical confidence. Yet across Europe, wide variability persists in pre-analytical handling, timing, and dynamic testing protocols [9]. Clinicians expect laboratory results to be interchangeable, regardless of where or when a test is performed [10].

Harmonization of endocrine dynamic function tests (EDFTs), including protocols for dexamethasone suppression, Adrenocorticotropic hormone (ACTH) stimulation, and Growth hormone (GH) suppression, should follow shared guidelines such as the EndoCompass initiative [9]. These efforts could reduce between-laboratories discrepancies and improve diagnostic comparability.

Implementation requires joint laboratory medicine professionals-clinician working groups to periodically review standard operating procedures and sample-handling protocols, ensuring that harmonization keeps pace with evolving guidelines and technologies.

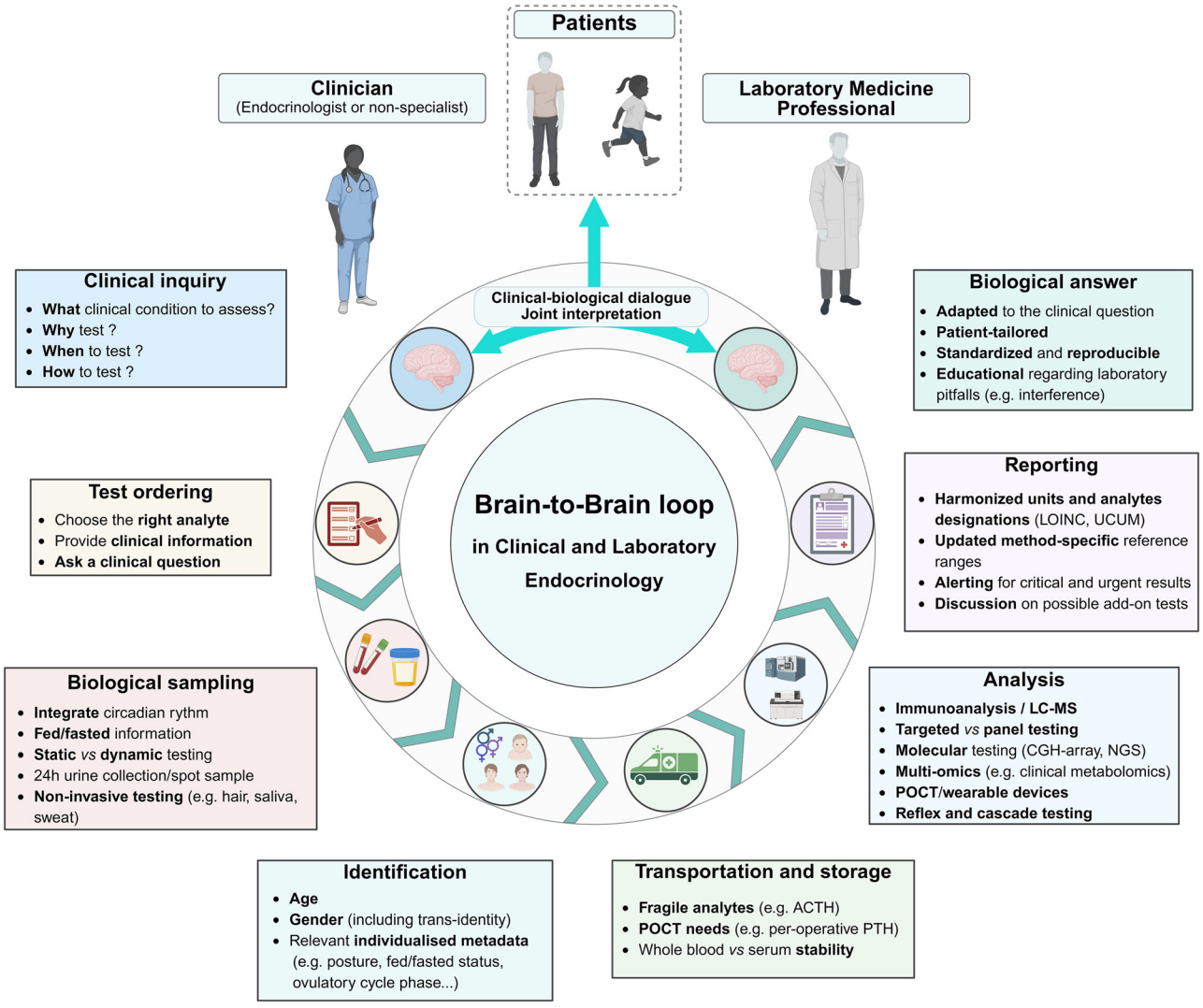

Figure 1: Adapted from Plebani et al. "The brain-to-brain loop concept for laboratory testing 40 years after its introduction" with modifications [3]. Representation of the brain-to-brain loop in Endocrine Laboratory Medicine, illustrating all steps of the total testing process that require collaboration between the endocrinologist and the laboratory medicine specialist to promote clinico-biological dialogue.

ELM answer 1 – Emphasizing the crucial role of pre-analytical phase in laboratory testing

The pre-analytical phase is the critical part of laboratory analyses, yielding from 70 to 98.4 % of the errors occurring in the clinical laboratory [11].

First and foremost, it is important to remind that the pre-analytical phase also involves the pre-pre-analytical phase of the TTP, including test ordering [12]. This part is especially critical in endocrinology, because although specialists are well aware of which test is the most appropriate to investigate their clinical hypothesis, errors are more frequent among general practitioners ordering hormone testing. For example, erroneous prescription of progesterone instead of 17-OH-progesterone in the diagnosis of adrenal congenital hyperplasia, or 1,25-Dihydroxyvitamin D3 instead of 25 OH vitamin D in vitamin D status assessment, are frequent and represent additional costs and delayed management. Measuring progesterone at the beginning of the menstrual cycle will reflect follicular phase rather than luteal progesterone secretion and is therefore not clinical informative [13]. With the spread of electronic prescription, laboratory medicine specialists can better accompany diagnosis and clinical decisions, by implementing reflex testing

or standardized comments, such as automatically added calcemia in primary care patients older than 45 years, without measurement in less than three years [14].

Pre-analytical phase is particularly important in ELM, given the large intra-individual variations observed for endocrinology parameters, due to the nycthemeral cycle (e.g. cortisol) [15, 16], postural conditions (e.g., lying or standing for renin and aldosterone) [17], or the fed/fasted status (e.g., insulin or free thyroxin) [18]. Such variations can be crucial for patient's treatment and impact clinical decisions by producing out-of-range results. Recently, the Association for Diagnostics and Laboratory Medicine (ADLM, formerly AACC) and the American Diabetes Association (ADA) published joint guidelines for laboratory analysis regarding the diagnosis and management of diabetes mellitus [19]. In this publication, authors emphasize the importance of the pre-analytical phase in blood glucose measurement, advocating for the use of: "*a tube containing a rapidly effective glycolytic inhibitor such as granulated citrate buffer*" to minimize glycolysis-induced glucose underestimation. However, depending on the sampling practices, and the choice and/or availability of glycolytic inhibitor-containing tubes, results can be slightly different [20, 21]. This can lead to misinterpretation in crucial diagnostic procedures such as the oral glucose tolerance test (OGTT) to screen for gestational diabetes mellitus [22]. Therefore, it is paramount for laboratory medicine professionals to collaborate with clinicians and phlebotomists to ensure the integration of all pre-analytical variables so results can be properly reported and interpreted.

Another crucial aspect of the pre-analytical phase involves dynamic testing. Endocrine dynamic function tests (EDFTs) are useful diagnostic tools as they allow to visualize pathological endocrine variation, exacerbated through exogenous triggering. However, there is a wide heterogeneity in EDFTs protocols. For instance, there are at least seven different types of dexamethasone suppression testing, which display different diagnostic performances [23]. This heterogeneity may be a strength, as sometimes it offers versatility and complementary data to refine diagnosis. In setting up diagnosis of pediatric GH deficiency, there are numerous stimulation tests, such as insulin tolerance test, glucagon stimulation test or GH-releasing peptide test, each of them having different cut-offs in laboratory report although all being focused on GH measurement [24]. In this context, performing two different EDFTs using different GH secretagogues may help to confirm GH deficiency [25]. Nevertheless, from one clinician or from one laboratory to another, differences in priming and EDFTs protocols may impair biological interpretation if pre-analytical conditions are not reported properly, so dialogue between clinicians and laboratory medicine professionals should be encouraged to allow laboratory identifying unnecessary or duplicate tests and cancel them, proposing reframed protocols, or adjusting testing method. As old habits die hard, the harmonization and unification of diagnostics pathways still have a long way to go. Nevertheless, this evolution will ultimately lead to clearer and more readable diagnostic patterns, enabling more robust hormone concentration decisional cut-offs to be defined in homogeneous populations and reducing unwarranted variability. In this perspective, close collaboration and co-design between clinicians and laboratory specialists are paramount.

Example 1 of concrete impactful action

Harmonized OGTT for GH suppression in diagnosing acromegaly should improve reproducibility of results between laboratories, facilitating multicenter research and consistent clinical decisions.

Clinical expectation 2 – Analytical reliability and specificity

Clinicians expect analytical results to be both sensitive and specific, free from cross-reactivity, and consistent over time [26–28]. Traditional immunoassays, while practical, are limited by variable specificity and matrix effects, particularly at low hormone concentrations [29, 30]. The adoption of liquid chromatography-tandem mass spectrometry (LC-MS/MS) as the analytical gold standard fulfills a major clinical expectation by offering high specificity, minimal interference, and the ability to quantify multiple analytes from small volume of sample by multiplexing [31, 32]. LC-MS/MS enables simultaneous steroid profiling enhancing the diagnostic accuracy of adrenal and gonadal disorders [33].

ELM answer 2 – Support technological advancements within the analytical phase

Nowadays, clinical endocrinology relies on laboratory results obtained through immunoassays, as these methods are highly specific and sensitive, allowing measurement of hormones present at very low concentrations [29]. Although

immunoassays have significantly evolved and become widespread since the first generations were developed, several analytical pitfalls remain. For example, falsely elevated prolactin concentrations due to macroprolactinemia, heterophile antibodies interfering and disrupting several hormone results, or cross-reactivity are quite frequent, and analytical errors impact 0.4–4 % of immunoassays [30]. Prolactin secretion is pulsatile and influenced by physiological and external factors such as sleep, stress and exercise. Therefore, measuring serum prolactin should be in the morning, after 15–30 min of rest to minimize stress-related effects. Clinicians and patients should be informed about this important pre-analytical consideration [34]. The type and magnitude of interference is highly depending on the reagents and analytical methods used by the laboratory. However, clinicians are often not fully aware of the specific techniques used by their laboratory. It is therefore essential that laboratory medicine professionals actively promote clinical-laboratory medicine communication whenever laboratory results are discrepant with clinical findings in order to discuss, investigate and solve potential analytical interference.

Beyond immunoassays, clinical hormonology has undergone significant changes in the analytical phase over the past few decades due to technological advancements. The development of cutting-edge technologies, such as LC-MS/MS, have completely changed the analytical phase (with consequences on the preanalytical phase too) in the endocrinology laboratory. Moving from radioimmunoanalysis (RIA) to LC-MS/MS has revolutionized the TTP by enhancing the medical service provided, improving the patient quality of life, and by implementing greener, sustainable practices, thanks to the withdrawal of radioactive elements. Additionally, environmental sustainability is promoted by reducing the number of blood collection tubes required. For example, whereas previously a separate tube was needed for each analyte in a steroid panel to explore steroidogenesis, a single sample is now sufficient to assess the whole steroid profile. This approach supports patient blood management and is particularly beneficial in neonates [35]. Furthermore, LC-MS/MS methods are typically set for multiplexing, meaning that all the molecules from one panel analysis are measured, even if only one was requested. It allows to screen and quantify a large number of compounds in a single run, with high sensitivity on a large dynamic range. Therefore, results are available on demand for the clinician in the need of a supplemental biological argument. These customisable methods will also enhance the development of diagnostic innovations through holistic panels. For example, the simultaneous measurement of 25-OH-vitamin D and 24,25-$(OH)_2$-dihydroxyvitamin D, constituting the Vitamin D metabolite ratio (VMR), offers a more dynamic approach of vitamin D metabolism, and is a more efficient biomarker of functional vitamin D deficiency [36].

Another key benefit of LC-MS/MS methods is their flexibility with different sample types. Unlike traditional methods focusing on urine or plasma, MS can also be used with alternative biological matrices like hair, oral fluid. Interestingly, the pre-treatment process performed for LC-MS/MS methods allows to explore unusual matrices that could be of interest. For example, cortisol and cortisone concentrations in hair samples are a valuable tool in assessing long-term glucocorticoids exposure and detect hypo- and hypercortisolism [37, 38], and salivary cortisol and cortisone are now widely spread biomarkers of Cushing's syndrome [39].

However, despite the numerous advantages outlined above, LC-MS/MS methods do not inherently guarantee analytical validity or superior performance compared with immunoassays, particularly when calibration and validation procedures are suboptimal. For instance, evidence from the Dutch external quality assurance program has shown that, although overall analytical bias is generally lower with LC-MS/MS, imprecision may remain comparable to that observed with immunoassays. This variability depends on both the analyte and whether the method is laboratory-developed or based on a commercial kit [40].

Another huge recent technological breakthrough is the development of genetic explorations through molecular biology. Array comparative genomic hybridization (CGH array), and Next Generation Sequencing (NGS), with whole exome/genome panels have deeply changed the way of managing syndromic patients, who are often referred to endocrinologists. Although these approaches provide valuable diagnostic insights, they generate large and complex amount of data that require joint interpretation by clinicians and laboratory medicine professionals.

Example 2 of concrete impactful action

Parathyroid hormone (PTH) measurement is highly discrepant depending on used assays. Recent standardization initiative performing PTH immunoassays recalibration based on a LC-MS/MS method made was a significant step towards PTH assessment standardization [41].

Clinical expectation 3 – Interpretability and clinical context

Endocrine interpretation of laboratory results cannot rely solely on reference intervals. Hormone concentrations fluctuate with age, sex, biological rhythm, and physiological or pathological state. Clinicians therefore expect personalized and contextually relevant interpretation rather than a binary "within/outside the reference range" approach.

The laboratory medicine professionals' community must lead research on both population-based and personalized reference intervals (RIs), as well as clinical decision limits (CDLs). This effort should build on established initiatives such as the CALIPER project, which has defined age- and sex-specific pediatric RIs [42], and on emerging statistical approaches that integrate analytical variation with within-subject biological variation to derive individualized Ris at the patient level [43]. Partitioning RIs by ethnicity, Tanner stage, menstrual phase, and gender identity (in transgender care) represents the next frontier of laboratory and clinical endocrinology [44, 45].

A complementary expectation is harmonized reporting, including consistent measuring units, used analytical method, and traceability to reference materials. Use of Logical Observation Identifiers Names and Codes (LOINC) and Unified Code for Units of Measure (UCUM) allows data interoperability and facilitates integration into digital health systems and large research datasets [46].

In summary, clinicians require reports that are clear, personalized, and immediately applicable to clinical decision-making.

ELM answer 3 – Making ourselves understandable: challenges within the post-analytical phase

Although the expansion of chromatography methods has been a cornerstone in the improvement of ELM, results obtained by LC-MS/MS for a specific analyte are not always directly comparable with those previously generated by RIA or immunoassays. For example, the post-cosyntropin cutoff levels for cortisol and 17-hydroxyprogesterone in the diagnosis of adrenal insufficiency are lower when assessed by LC-MS/MS than with immunoassays [47]. It is therefore crucial that laboratory medicine specialists adapt the RIs and cut offs based on up-to-date literature, and that they inform and communicate closely with clinicians to avoid misinterpretation. In the field of clinical endocrinology, the pitfall of reasoning with a "reference intervals" approach is especially prevalent, due to the considerable inter- and intra-individual variability linked to age, gender, diurnal rhythm, pathological conditions, or medications. Thus, managing the post-analytical phase, including establishing the proper RIs, is a highly demanding task. Great efforts have been made to address this issue, such as the CALIPER database initiative, which provides pediatric reference intervals for numerous hormones [42], or the EFLM biological variation database, which provides key metadata on analytical, inter- and intra-individual variation [48]. These tailored patient-centred initiatives can lead to substantial advances. For example, several countries like Italy and France have proposed an age-adapted upper limit of thyroid-stimulating hormone (TSH) reference range, in order to acknowledge physiological changes and avoid unnecessary treatment of (subclinical) hypothyroidism [49].

Besides, a critical pitfall in the post-analytical phase lies in reporting analytes in appropriate terminology and measuring units. Hormones can be reported either according to their ponderal, molar or activity quantification, not necessarily being designated SI units, which may lead to misinterpretation [50]. Recently, a lot of work has been carried to harmonize laboratory reporting using tools such as LOINC system or UCUM [51]. In addition, international lean societies initiatives such as the EFLM working group on harmonization have highlighted the need for standardization in reporting data [46]. Interestingly, in a recent survey among European laboratories, the use of SI units for a panel of hormone reached from 70 to 90 % [46]. These advances are an important step in ensuring proper comprehension of ELM data, especially for clinicians, and providing large datasets that could be universally integrated in big data research, such as meta-analyses.

Another benefit of harmonizing analytes codes and units is the facilitation of data integration into cross-disciplinary clinical decision supports systems (CDSS), which link the Laboratory Information System with the electronic health record, including medication history. In laboratory medicine, CDSS are being progressively implemented to consolidate clinical and biological data to improve the use and interpretation of laboratory tests, and ultimately enhance diagnostic support and clinical management [52].

Example 3 of concrete impactful action

Inconsistent units for prolactin (mIU/L vs. ng/mL) once led to apparent hyperprolactinemia in a transferred patient;

harmonized SI reporting resolved the confusion. Moreover, hyperprolactinemia related to exposure to dopamine antagonists, such as antipsychotic medications, is a frequent cause of elevated prolactin concentrations. In this context, a CDSS integrating pharmacy records could automatically flag this likely drug-related explanation, thereby preventing unnecessary diagnostic investigations, unless a genuine clinical suspicion warrants further evaluation.

Clinical expectation 4 – Consultative partnership and diagnostic support

The most advanced expectation of clinicians is the transformation of the laboratory professional into a diagnostic consultant. Clinicians increasingly seek interpretive support, interference investigation, and guidance in test selection from laboratory medicine professionals [53].

Diagnostic management teams (DMTs) formalize this collaboration: multidisciplinary case conferences where clinical endocrinologists and laboratory medicine professionals jointly interpret complex or discordant patients' findings. Beyond reactive consultation, laboratory medicine professionals must proactively educate clinicians about assay limitations, pre-analytical variables, and appropriate test use (*linking with test ordering management, see answer 1*). Regular feedback sessions and joint continuing medical education activities enhance analytical literacy across disciplines and reduce diagnostic error [2, 53].

ELM answer 4 – Embracing a synergistic patient-centred approach

The final part of the post-analytical phase lies in interpreting laboratory results in relation to clinical data. Diagnostic errors are common in the area of endocrinology, particularly among general practitioners, either due to diagnosis misidentification, or to a lack of knowledge regarding a specific condition [54]. As highly trained specialists, laboratory medicine professionals should promote multidisciplinary case reviewing and joint interpretation, especially with clinicians in different fields to reduce diagnosis errors.

Example 4 of concrete impactful action

In cases of discordance between abnormal thyroid function tests showing low TSH and elevated T4, and normal clinical presentation, the laboratory may identify biotin interference as the underlying cause and alert clinicians, thereby preventing unnecessary pituitary imaging [55].

Clinical expectation 5 – Innovation and future service delivery

Clinicians increasingly expect laboratories to lead in innovation, delivering faster, less invasive, and more integrated diagnostic services.

Non-invasive sampling (e.g. salivary or hair cortisol) offers valuable alternatives for Cushing's evaluation [56], while intraoperative point-of-care testing (POCT) of PTH provides fast results that optimize surgical outcomes [57].

Meanwhile, the rise in digital health technologies, including continuous glucose monitoring (CGM) requires laboratory oversight to ensure analytical validity and safe data integration [58]. The laboratory medicine professional becomes a data quality gatekeeper, ensuring device metrics are traceable and interoperable through standardized coding (LOINC/UCUM).

ELM answer 5 – Leading innovation in biomarker research and translate into clinical impact

The field of clinical chemistry and laboratory medicine is experiencing rapid development and innovation. The emerging use of LC-MS/MS technology offers high sensitivity and comprehensive multiplexing of several analytes while overcoming the cross-reactivity issue of immunoassays. The LC-MS/MS technology is already being integrated into automated analyzers, such as the Cobas® i 601 analyzer (Roche Diagnostics, Switzerland), which offers a number of available analytes, including steroids, vitamin D, drugs of abuse, and therapeutic drug monitoring. Another field based on LC-MS/MS has also emerged: metabolomics, which focuses on the relative or absolute quantification of a wide array of small molecules, also known as metabolites. Metabolomics can provide clinically compliant analysis of over a hundred

metabolites in a single assay. The metabolome shows promise for novel biomarker discovery, unravelling disease pathophysiology, and advancing integrated and personalized laboratory medicine. Several applications of metabolomics are already pioneering in the field of endocrinology, such as in obesity or endometriosis [59]. These examples show how finding new biomarkers combined with highly multiplexed LC-MS/MS analyses is paving the way for more personalized laboratory medicine.

Another revolution in the field of laboratory medicine is occurring in sample collection itself. One aspect is reducing the sample volume needed for analysis, a process known as microsampling [60]. Furthermore, there is a current focus on non-invasive methods and alternative biological materials, such as sweat, saliva, and tears [61]. Patient-friendly microsampling enables individuals to collect small volumes of blood or plasma at home, which can be mailed to the laboratory as stabilized dried samples, thereby eliminating the need for hospital visits. This reduces the risk of infection for immunosuppressed patients and reduces the burden on personnel and time for sample collection. Minimally invasive microsampling and home sampling are key trends that will probably shape the future of the field of laboratory medicine.

Technical advancements concern not only the core laboratory, but also all the out-of-the-lab technologies, such as point-of-care-testing, continuous glycemic control, smartwatch and connected devices following metabolic status, etc. These are new resources in the diagnostic arsenal that can significantly improve patient management. For example, the use of intraoperative PTH during minimally invasive parathyroidectomy has been associated to higher cure rates in patients presenting with primary hyperparathyroidism [62]. However, there are technical pitfalls and limitations that should be acknowledged. First, the classical core laboratory turnaround time (TAT), due to centrifugation and immunoanalysis delays may hinder the clinical value of this test if results are not available promptly. Furthermore, during such surgeries, PTH fragments that interfere with second-generation PTH assays may be released and mask the expected rapid decrease [63]. It is important that the joint clinical-biological team be thoroughly familiar with their PTH assay and optimize workflows to prevent these potential caveats. Recent innovation, such as the development of a 'in theatre' point-of-care analysis method for PTH has allowed to reduce TAT to 5 min [64], with reliable analytical performances, thus improving laboratory medical value. However, there are still few publications evaluating this practice and unfortunately only a single manufacturer currently provides this technology. Therefore, caution is warranted, and further validation of its analytical and clinical performance is required before it can be widely implemented.

Illustration of out-of-the-lab competence of laboratory medicine professionals is the continuous glucose monitoring (CGM). There was an exponential development since early 2010's in the spread of CGM as a key player of diabetes mellitus follow-up among glucose meters, improving concentrations of HbA_{1c} and time-in-range while reducing time-above-range [65]. Although these analyses are not actually performed in the laboratory, laboratory medicine specialists have to integrate these practices in the global patient-centred TTP. However, despite these technological advancements being promising for monitoring patients at risk of developing metabolic conditions (e.g., wearable devices capable of measuring blood glucose, cholesterol or cortisol) [66] and thus potentially representing a breakthrough in preventive medicine, caution is still warranted, as numerous non-FDA-authorized wearable devices fail to provide accurate measurements and could be harmful if not properly supervised [66].

Lastly, artificial intelligence is becoming increasingly prevalent in laboratory medicine. While current large language models (LLMs) can interpret laboratory findings with a satisfactory degree of accuracy [67], expert evaluation and approval remain irreplaceable [67]. However, models trained on medical data, such as Med-PaLM 2, show promise in adapting LLMs to interpret clinical data and laboratory findings and aid professionals in the diagnostic process [68]. It is essential to follow laboratory-aware considerations when developing and using artificial intelligence in laboratory medicine to ensure that it is scientifically rigorous, robust, and reproducible in routine practice [69].

Example 5 of concrete impactful action

Laboratory validation of smartwatch-based glucose trend data against capillary and venous glucose confirmed clinical usability and informed structured CGM protocols.

The future of endocrine diagnostics depends on laboratories embracing their role as leaders in digital, translational, and precision medicine.

Meeting the expectations: practical joint actions and collaborative models

The transition from expectation to clinical practice requires structured collaboration, harmonized protocols,

Table 1: Reflexion on joint clinician-laboratory medicine professionals' actionable strategies to promote collaboration and enhance patient management.

Clinician expectation	Joint clinician-laboratory medicine professional strategies	Concrete clinical illustration
Procedural consistency and harmonization	Work on the pre-pre and pre-analytical phases aiming at harmonization of laboratory results	**Actionable strategy** – Implement test ordering management for specialized analyses to reduce misuse of laboratory resources – Expert advising endocrinologists about clinical inquiries to help choosing the right test for clinical question – Unify pre-analytical protocols for endocrinology testing (posture, fed/fasted, type of priming, etc.), especially in endocrine dynamic function tests The (pre)-preanalytical phase is the most critical part of the total testing process. Efforts made within this phase will undoubtedly benefit to clinical practice. **Clinical example** Inappropriate ordering mistaking progesterone for 17-OH-progesterone is frequent and may jeopardize diagnosis (e.g. congenital adrenal hyperplasia). A better test ordering management helps preventing this type of mistake.
	Implement joint and harmonized interpretation	**Actionable strategy** – Develop co-signed interpretation templates for key endocrine conditions (Cushing's, acromegaly, adrenal insufficiency). – Use standardized comment libraries linking analytical findings to clinical context. – Review and update annually through clinician-laboratory medicine steering groups. These measures provide clinicians with context-anchored, method-specific interpretation while embedding laboratory transparency within routine reporting. **Clinical example** In suspected Cushing's syndrome, cortisol results following low-dose dexamethasone suppression may appear borderline due to of cross-reactivity with prednisolone. A joint interpretation algorithm that accounts for assay generation can prevent unnecessary imaging and false-positive conclusions.
Analytical reliability and specificity	Implement validated reference methods & pursue global harmonization	**Actionable strategy** – Work on immunoassays interference and cross-reactivity comprehension to alert clinicians on potential pitfalls – Enhance LC-MS development to serve as reference method for standardization – Promote integrative multiparametric panel testing – Define method and population-specific cut-offs and reference ranges and clinical decision limits
Interpretability and clinical context	Safety, critical values, and multidisciplinary engagement	**Actionable strategy** – Jointly define endocrine-specific critical analytes and values lists with agreed escalation protocols. – Establish reflex and cascade testing pathways, e.g., elevated total calcium automatically triggering PTH measurement. – Implement 24-h on-call notification pathways with clear handover documentation. – Involve laboratory experts in multidisciplinary meetings for complex cases (e.g., multiple pituitary hormone deficiency, assay interference investigations). Structured multidisciplinary engagement, through Diagnostic Management Teams (DMTs), ensures analytical expertise directly informs patient care, reducing misinterpretation and improving safety.

Table 1: (continued)

Clinician expectation	Joint clinician-laboratory medicine professional strategies	Concrete clinical illustration
		Clinical example Rapid laboratory notification of serum calcium >3.5 mmol/L with reflex testing of parathormone enables urgent evaluation for parathyroid carcinoma.
	Communication and transparency on laboratory data	**Actionable strategy** – Integrate automatic alerts within Laboratory Information Systems (LIS) and Electronic Health Records (EHRs) to notify users of assay updates. – Apply a discontinuity in the patient's result history to exclude data obtained with earlier analytical methods and prevent interpretation mistake on variations – Ensure metadata capture (sampling time, fasting status, posture, medications) through digital order forms, enabling precise interpretation. Reflex algorithms and systematic alerts reduce diagnostic delay, prevent unnecessary retesting, and enhance clinical confidence in trending results **Clinical example** After a thyroid assay platform change, abrupt shifts in TSH and fT4 triggered unnecessary medication adjustments until the laboratory clarified the method update
Consultative partnership and diagnostic support	Bridging between clinical and laboratory practice	**Actionable strategy** – Schedule regularly joint review meetings focusing on analytical-clinical discrepancies. – Incorporate case-based learning into Continuing Medical Education programs for endocrinology and laboratory trainees. – Use anonymized case summaries to highlight the impact of assay harmonization and communication failures on patient outcomes, and promote continuous improvement Embedding education within quality cycles turns every discrepancy into a shared learning opportunity **Clinical example** Review of falsely low testosterone results revealed SHBG interference. Subsequent discussion led to a standardized interpretive comment in all testosterone reports.
Innovation and future service delivery	Innovation and patient-centred practice	**Actionable strategy** – Evaluate alternative matrices (saliva, dried blood, hair) for validated LC-MS/MS analytes. – Co-design digital scheduling systems for timed dynamic tests. – Evaluate and integrate Point-of-Care Testing (POCT) and wearable devices data streams under laboratory medicine professional's supervision to maintain analytical governance. Patient-centred innovation not only increases efficiency but also fosters trust by aligning laboratory development with clinical workflow realities. **Clinical example** Dried blood spot sampling for morning cortisol monitoring allowed patients to collect samples at home, improving compliance and reducing pre-analytical error.
	Shaping the practice of tomorrow	**Actionable strategy** – Support translational research with cutting-edge multi-omics development – Translate metabolomics from research into clinical impact – Embrace and supervise advancements linked to artificial intelligence **Clinical example** Metabolomic-based scoring systems will refine diagnosis in endocrine diagnosis.

and consistent communication between clinical endocrinologists and laboratory medicine professionals. Table 1 presents the reflexion and propositions of concrete actionable strategies co-developed by young endocrinologists and laboratory medicine specialists to achieve excellence in endocrine diagnosis.

Outlook – Establishing strategic partnership between the ELM specialist and the clinician

The future of Endocrine Laboratory Medicine lies in strategic partnership.

Clinicians expect data that are reliable, standardized, and clinically interpretable, while laboratories seek insight into patient context to refine testing and reporting.

This reciprocal relationship, rooted in analytical excellence, transparent communication, and continuous innovation, forms the foundation of precision endocrinology.

By integrating harmonization efforts, interpretive collaboration, and translational research, young clinical endocrinologists and laboratory medicine specialists together can redefine diagnostic practice, transforming the laboratory from a technical endpoint into a guardian of diagnostic quality and an engine of patient-centred innovation.

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References

1. Baum HBA. Clinical excellence in endocrinology. J Clin Endocrinol Metab 2018;103:2430–5.
2. Lubin IM, Astles JR, Shahangian S, Madison B, Parry R, Schmidt RL, et al. Bringing the clinical laboratory into the strategy to advance diagnostic excellence. Diagnosis 2021;8:281–94.
3. Plebani M, Laposata M, Lundberg GD. The brain-to-brain loop concept for laboratory testing 40 years after its introduction. Am J Clin Pathol 2011;136:829–33.
4. Fishel S. First in vitro fertilization baby – this is how it happened. Fertil Steril 2018;110:5–11.
5. Adamson GD, Creighton P, de Mouzon J, Zegers-Hochschild F, Dyer S, Chambers GM. How many infants have been born with the help of assisted reproductive technology? Fertil Steril 2025;124:40–50.
6. Nolan BJ, Cheung AS. Laboratory monitoring in transgender and gender-diverse individuals. Clin Chem 2025;71:358–77.
7. Li L, Guo Y, Ma S, Wen H, Li Y, Qiao J. Association between exposure to per- and perfluoroalkyl substances (PFAS) and reproductive hormones in human: a systematic review and meta-analysis. Environ Res 2024; 241:117553.
8. Lee J, Jang H, Pearce EN, Shin H-M. Exposome-wide association study of thyroid function using U.S. National Health and Nutrition Examination Survey data. Environ Res 2025;269:120884.
9. Heijboer AC, Hillebrand JJ, Keevil B, Ladang A, Davies E, Mertens J, et al. EndoCompass project: endocrine laboratory medicine. Eur J Endocrinol 2025;193:ii161–9.
10. Plebani M. Harmonization in laboratory medicine: requests, samples, measurements and reports. Crit Rev Clin Lab Sci 2016;53:184–96.
11. Lin Y, Spies NC, Zohner K, McCoy D, Zaydman MA, Farnsworth CW. Pre-analytical phase errors constitute the vast majority of errors in clinical laboratory testing. Clin Chem Lab Med 2025;63:1709–15.
12. Plebani M, Sciacovelli L, Aita A, Pelloso M, Chiozza ML. Performance criteria and quality indicators for the pre-analytical phase. Clin Chem Lab Med 2015;53:943–8.
13. Häggström M. Reference ranges for estradiol, progesterone, luteinizing hormone and follicle-stimulating hormone during the menstrual cycle. Wiki J Med 2014;1. https://doi.org/10.15347/wjm/2014.001.
14. Salinas M, López-Garrigós M, Flores E, Martín E, Leiva-Salinas C. The clinical laboratory: a decision maker hub. Clin Chem Lab Med 2021;59: 1634–41.
15. Zhong J, Wang D, Xie S, Li M, Yin Y, Yu J, et al. Pre-analytical stability and physiological fluctuations affect plasma steroid hormone outcomes: a real-world study. J Steroid Biochem Mol Biol 2024;244:106596.
16. Kim BH, Joo Y, Kim M-S, Choe HK, Tong Q, Kwon O. Effects of intermittent fasting on the circulating levels and circadian rhythms of hormones. Endocrinol Metab 2021;36:745–56.
17. Cheng JYK, Lo WSC, Tsui TKC, Chow WKE, Cheung KKT, Ma RCW, et al. Oral salt loading combined with postural stimulation tests for confirming and subtyping primary aldosteronism. Clin Chem Lab Med 2025;63:2485–93.
18. Basolo A, Begaye B, Hollstein T, Vinales KL, Walter M, Santini F, et al. Effects of short-term fasting and different overfeeding diets on thyroid hormones in healthy humans. Thyroid 2019;29:1209–19.
19. Sacks DB, Arnold M, Bakris GL, Bruns DE, Horvath AR, Lernmark Å, et al. Guidelines and recommendations for laboratory analysis in the diagnosis and management of diabetes mellitus. Clin Chem 2023;69: 808–68.
20. Norman M, Jones I. The shift from fluoride/oxalate to acid citrate/ fluoride blood collection tubes for glucose testing – the impact upon patient results. Clin Biochem 2014;47:683–5.
21. Islam MN, Lyons C, Griffin TP, Hamon S, Dunne FP, O'Shea PM. Maintaining glucose integrity ex-vivo: impact of preanalytical specimen handling. Ann Clin Biochem 2024;61:133–42.

22. Jamieson EL, Dimeski G, Flatman R, Hickman PE, Ross Dallas Jones G, V MJ, et al. Oral glucose tolerance test to diagnose gestational diabetes mellitus: impact of variations in specimen handling. Clin Biochem 2023; 115:33–48.
23. Babic N, Yeo K-TJ, Hannoush ZC, Weiss RE. Endocrine testing protocols: hypothalamic pituitary adrenal axis. South Dartmouth (MA): Endotext [Internet], MDText.com, Inc.; 2000.PMID: 25905177.
24. Yuen KCJ, Johannsson G, Ho KKY, Miller BS, Bergada I, Rogol AD. Diagnosis and testing for growth hormone deficiency across the ages: a global view of the accuracy, caveats, and cut-offs for diagnosis. Endocr Connect 2023;12:e220504.
25. Diagnosis of GH insufficiency requires two GH stimulation tests. Nat Rev Endocrinol 2007;3:500.
26. Saah AJ, Hoover DR. "Sensitivity" and "specificity" reconsidered: the meaning of these terms in analytical and diagnostic settings. Ann Intern Med 1997;126:91–4.
27. Sturgeon CM, Viljoen A. Analytical error and interference in immunoassay: minimizing risk. Ann Clin Biochem 2011;48:418–32.
28. Klein G, Junge W. Creation of the necessary analytical quality for generating and using reference intervals. Clin Chem Lab Med 2004;42: 851–7.
29. Ghazal K, Brabant S, Prie D, Piketty M-L. Hormone immunoassay interference: a 2021 update. Ann Lab Med 2022;42:3–23.
30. Wauthier L, Plebani M, Favresse J. Interferences in immunoassays: review and practical algorithm. Clin Chem Lab Med 2022;60: 808–20.
31. Holmes DT. A brief update on mass spectrometry applications to routine clinical endocrinology. Clin Mass Spectrom 2019;13:18–20.
32. Renda LD, Costantino F, Canu G, Cristina DSM, Roli L, Trenti T, et al. Liquid chromatography-tandem mass spectrometry (LC-MS/MS) reliability compared to immunometric assay (IA) for testosterone (T) assay in a clinical laboratory setting for male hypogonadism management. Endocr Abstr 2025;110. https://doi.org/10.1530/endoabs.110.P990.
33. Travers S, Martinerie L, Bouvattier C, Boileau P, Lombès M, Pussard E. Multiplexed steroid profiling of gluco- and mineralocorticoids pathways using a liquid chromatography tandem mass spectrometry method. J Steroid Biochem Mol Biol 2017;165:202–11.
34. Das M, Gogoi C. Pool vs single sample determination of serum prolactin to explore venipuncture associated stress induced variation. Sci Rep 2023;13:113.
35. Lopriore E. The total volume of blood in an extremely preterm neonate is about the size of a double espresso. Acta Paediatr 2023;112:2458–9.
36. Ladang A, Gendebien A-S, Kovacs S, Demonceau C, Beaudart C, Peeters S, et al. Investigation of the vitamin D metabolite ratio (VMR) as a marker of functional vitamin D deficiency: findings from the SarcoPhAge cohort. Nutrients 2024;16:3224.
37. Mirzaian M, Zundert SKMvan, Schilleman WF, Mohseni M, Kuckuck S, Rossum EFCvan, et al. Determination of cortisone and cortisol in human scalp hair using an improved LC-MS/MS-based method. Clin Chem Lab Med 2024;62:118–27.
38. Brossaud J, Charret L, De Angeli D, Haissaguerre M, Ferriere A, Puerto M, et al. Hair cortisol and cortisone measurements for the diagnosis of overt and mild Cushing's syndrome. Eur J Endocrinol 2021; 184:445–54.
39. Bäcklund N, Brattsand G, Lundstedt S, Aardal E, Bartuseviciene I, Berinder K, et al. Salivary cortisol and cortisone in diagnosis of Cushing's syndrome – a comparison of six different analytical methods. Clin Chem Lab Med 2023;61:1780–91.
40. Lentjes EGWM, Bui HN, Ruhaak LR, Kema IP, Coene KLM, Van Den Ouweland JMW. LC-MS/MS in clinical chemistry: did it live up to its promise? Clin Chim Acta 2023;546:117391.
41. Cavalier E, Farré-Segura J, Lukas P, Gendebien A-S, Peeters S, Massonnet P, et al. Unveiling a new era with liquid chromatography coupled with mass spectrometry to enhance parathyroid hormone measurement in patients with chronic kidney disease. Kidney Int 2024; 105:338–46.
42. Adeli K, Higgins V, Trajcevski K, White-Al Habeeb N. The Canadian laboratory initiative on pediatric reference intervals: a CALIPER white paper. Crit Rev Clin Lab Sci 2017;54:358–413.
43. Coskun A, Sandberg S, Unsal I, Yavuz FG, Cavusoglu C, Serteser M, et al. Personalized reference intervals – statistical approaches and considerations. Clin Chem Lab Med 2022;60:629–35.
44. Diaz-Thomas AM, Golden SH, Dabelea DM, Grimberg A, Magge SN, Safer JD, et al. Endocrine health and health care disparities in the pediatric and sexual and gender minority populations: an endocrine society scientific statement. J Clin Endocrinol Metab 2023;108:1533–84.
45. Lyle AN, Pokuah F, Dietzen DJ, Wong ECC, Pyle-Eilola AL, Fuqua JS, et al. Current state of pediatric reference intervals and the importance of correctly describing the biochemistry of child development: a review. JAMA Pediatr 2022;176:699–714.
46. Zaninotto M, Agnello L, Dukic L, Akhvlediani L. Assessing post-analytical phase harmonization in European laboratories: a survey promoted by the EFLM Working Group on Harmonization. Clin Chem Lab Med 2024; 62:1966–74.
47. Ueland GÅ, Methlie P, Øksnes M, Thordarson HB, Sagen J, Kellmann R, et al. The short cosyntropin test revisited: new normal reference range using LC-MS/MS. J Clin Endocrinol Metabol 2018;103:1696–703.
48. Aarsand A, Fernandez-Calle P, Webster C, Coskun A, Gonzales-Lao E, Diaz-Garzon J, et al. The EFLM biological variation database. n.d. https://biologicalvariation.eu/ [Accessed 10 Jan 2024].
49. Benamour M, Burlacu M-C, Petrossians P, Unuane D, Bruel AVden, Poorten VV, et al. Urgent need to adopt age-specific TSH upper reference limit for the elderly – a position statement of the Belgian thyroid club. Clin Chem Lab Med 2025;63:e36–8.
50. Flatman R. Terminology, units and reporting – how harmonized do we need to be? Clin Chem Lab Med 2019;57:1–11.
51. Zayed AM, Sarikakis I, Delvaux N. Automated standardization and harmonization of laboratory units in large-scale clinical data using open-source R functions. Int J Med Inf 2026;205:106131.
52. Flores E, Martínez-Racaj L, Torreblanca R, Blasco A, Lopez-Garrigós M, Gutiérrez I, et al. Clinical decision support system in laboratory medicine. Clin Chem Lab Med 2024;62:1277–82.
53. Dabla PK, Sethi HK. Enhancing clinical collaboration: interface linking between laboratories and clinics for translational healthcare. J Diabetes Clin Res 2025;7:19–21.
54. Frey J, Braun LT, Handgriff L, Kendziora B, Fischer MR, Reincke M, et al. Insights into diagnostic errors in endocrinology: a prospective, case-based, international study. BMC Med Educ 2023;23:934.
55. Favresse J, Burlacu M-C, Maiter D, Gruson D. Interferences with thyroid function immunoassays: clinical implications and detection algorithm. Endocr Rev 2018;39:830–50.
56. Raff H. Utility of salivary cortisol measurements in Cushing's syndrome and adrenal insufficiency. J Clin Endocrinol Metab 2009;94:3647–55.
57. Mohan Kumar R, Pannu A, Metcalfe E, Senbeto M, Balasubramanian SP. Findings of pilot study following the implementation of point of care intraoperative PTH assay using whole blood during surgery for primary hyperparathyroidism. Front Endocrinol 2023;14:1198894.

58. Klonoff DC, Gabbay M, Moon SJ, Wilmot EG. Importance of FDA-integrated continuous glucose monitors to ensure accuracy of continuous glucose monitoring. J Diabetes Sci Technol 2025;19:1392–9.
59. Tokarz J, Haid M, Cecil A, Prehn C, Artati A, Möller G, et al. Endocrinology meets metabolomics: achievements, pitfalls, and challenges. Trends Endocrinol Metabol 2017;28:705–21.
60. Protti M, Milandri E, Di Lecce R, Mercolini L, Mandrioli R. New trends in bioanalysis sampling and pretreatment: how modern microsampling is revolutionising the field. Adv Sample Prep 2025;13:100161.
61. Bordin DM, McCauley JI, de Campos EG, Bishop DP, De Martinis BS. Sweat as a diagnostic biofluid: analytical advances and future directions. J Pharm Anal 2025:101473. https://doi.org/10.1016/j.jpha.2025.101473.
62. Quinn AJ, Ryan ÉJ, Garry S, James DL, Boland MR, Young O, et al. Use of intraoperative parathyroid hormone in minimally invasive parathyroidectomy for primary hyperparathyroidism: a systematic review and meta-analysis. JAMA Otolaryngol Head Neck Surg 2021;147:135.
63. Cavalier E, Schleck M-L, Souberbielle J-C. Spurious intraoperative PTH results observed with 2nd, but not with 3rd generation PTH assays. Clin Chim Acta 2018;477:72–3.
64. Kurzawinski TR, Zielke A, Busch M, Wagner J, Soromani C, Abdelsalam A, et al. Ultrafast intraoperative parathyroid hormone monitoring system: prospective, multicentre, clinical validity study. Br J Surg 2024;111:znae101.
65. Tan YY, Suan E, Koh GCH, Suhairi SB, Tyagi S. Effectiveness of continuous glucose monitoring in patient management of Type 2 diabetes mellitus: an umbrella review of systematic reviews from 2011 to 2024. Arch Public Health 2024;82:231.
66. Lyzwinski L, Elgendi M, Shokurov AV, Cuthbert TJ, Ahmadizadeh C, Menon C. Opportunities and challenges for sweat-based monitoring of metabolic syndrome via wearable technologies. Commun Eng 2023;2:48.
67. Pighi L, Negrini D, Lippi G. Evaluation of freely available artificial intelligence (AI) tools for diagnostic support in a complex clinical and laboratory presentations: a pilot study. Advances in Laboratory Medicine / Avances En Medicina de Laboratorio n.d.. https://doi.org/10.1515/almed-2025-0157. https://www.degruyterbrill.com/document/doi/10.1515/almed-2025-0157/html.
68. Singhal K, Tu T, Gottweis J, Sayres R, Wulczyn E, Amin M, et al. Toward expert-level medical question answering with large language models. Nat Med 2025;31:943–50.
69. Carobene A, Cadamuro J, Frans G, Goldshmidt H, Debeljak Z, Bruyne SD, et al. EFLM checklist for the assessment of AI/ML studies in laboratory medicine: enhancing general medical AI frameworks for laboratory-specific applications. Clin Chem Lab Med 2026;64:27–40.