



Emerging Stroke Biomarkers: Advancing Precision Diagnosis from Innovation to Clinical Translation

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DESCRIPTION

Stroke remains one of the most time-sensitive neurological emergencies, in which rapid recognition and appropriate treatment can substantially influence survival and long-term recovery. Conventional diagnostic approaches, including neurological assessment and brain imaging, have transformed acute stroke management, but important clinical uncertainties can remain, particularly during the earliest stages. Next-generation biomarkers are attracting attention because they may provide additional biological information about tissue injury, vascular dysfunction, inflammation, blood-brain barrier disruption and recovery. Their development represents an important step toward more individualized approaches to stroke diagnosis, classification, treatment selection and prognosis. A biomarker is a measurable biological characteristic that can provide information about a physiological or pathological process. In stroke, potentially useful biomarkers may be detected in blood, cerebrospinal fluid, urine or other biological materials. Advances in molecular biology, proteomics, metabolomics, lipidomics, extracellular vesicle analysis and nucleic-acid profiling have expanded the range of molecules that can be investigated.

Proteins released after neuronal injury, inflammatory mediators, circulating micro Ribonucleic Acid (RNA), vesicles contents and metabolic signatures are among the candidates being evaluated for their ability to distinguish different forms and stages of cerebrovascular injury. One major goal is to improve the distinction between ischemic and haemorrhagic stroke. Although neuroimaging remains essential for determining the type and location of stroke, molecular indicators could eventually provide complementary information when immediate imaging is delayed or when clinical presentation is ambiguous. Biomarker combinations may be more informative than individual molecules because stroke involves multiple interconnected biological pathways. A panel incorporating

markers of neuronal damage, inflammation, vascular injury and coagulation could potentially provide a broader biological profile than any single measurement.

The timing of biomarker release is equally important. Biological molecules do not appear in circulation at identical stages after vascular injury. Some may rise rapidly during the initial event, whereas others become detectable as inflammation, tissue destruction or repair progresses. Consequently, interpreting a biomarker without considering the time elapsed since symptom onset can reduce its clinical value. Future diagnostic platforms will need to account for these temporal patterns and provide results that can be interpreted alongside neurological findings and imaging. Another promising direction involves biomarkers capable of predicting functional outcomes. Stroke recovery varies considerably between individuals even when the initial neurological deficit appears similar. Molecular indicators associated with neuronal injury, inflammation, vascular remodelling and neuroplasticity could potentially help identify patients at greater risk of severe disability or complications. Such information might support more individualized rehabilitation strategies and closer clinical monitoring. Biomarkers may also assist in identifying biological responses associated with recovery, providing an additional dimension to conventional functional assessments.

Despite rapid technological progress, translating promising biomarkers into routine clinical practice remains challenging. A candidate must demonstrate reliable analytical performance, reproducible measurement, clinically meaningful accuracy and practical usefulness. Biological variation between individuals can complicate interpretation, while factors such as age, kidney function, medications, infections and other medical conditions may influence circulating biomarker concentrations. Differences in sample collection, processing, storage and laboratory platforms can further affect results. Standardization is therefore essential if measurements are to be compared across hospitals and patient populations. Artificial intelligence may strengthen the clinical

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value of next-generation biomarkers by integrating molecular measurements with imaging, electronic health records, neurological scores and demographic information. Rather than relying on a single laboratory value, computational models could generate multidimensional profiles that reflect the complexity of stroke. However, sophisticated algorithms require appropriate validation and transparent performance assessment.

Another important consideration is accessibility. A biomarker that requires expensive equipment, highly specialized personnel or prolonged processing may have limited usefulness in emergency settings. Point-of-care technologies could address this

challenge by enabling rapid measurement close to the patient. Portable platforms capable of detecting multiple molecular targets from small blood samples may eventually complement conventional imaging and neurological evaluation, particularly in locations where advanced diagnostic resources are limited. Next-generation biomarkers have the potential to move stroke care toward a more precise and biologically informed model. Their greatest value may emerge through combination with established diagnostic methods rather than through replacement of imaging or clinical assessment.