

Table 1. Key biomarkers of biological aging and frailty: mechanisms and clinical relevance in older adults.

Biomarker	Main mechanism / biological rationale	Clinical relevance in older adults / frailty	Representative references
IL-6	Pro-inflammatory cytokine involved in chronic low-grade inflammation (“inflammaging”)	Associated with frailty, reduced physiological reserve, disability, and adverse outcomes	Franceschi et al., 2018 [3] Soysal et al., 2016 [5] Leng et al., 2007 [11]
CRP	Acute-phase reactant reflecting systemic inflammation	Elevated in frail older adults; non-specific marker of chronic inflammatory burden	Ferrucci & Fabbri, 2018; [4] Walston et al., 2002 [12] Hubbard et al., 2009 [13]
TNF-α	Pro-inflammatory cytokine linked to catabolism and immune dysregulation	Associated with frailty biology and adverse outcomes	Franceschi et al., 2018; [3] Soysal et al., 2016 [5]
Albumin	Reflects nutritional status, inflammation, and disease burden	Low levels associated with frailty, poor functional status, and worse prognosis	Cabrerizoetal., 2015 [15]
Vitamin D	Regulates muscle function and metabolism	Low levels linked to sarcopenia and frailty	Visseretal., 2003 [16]
IGF-1	Marker of anabolic/endocrine function	Reduced levels associated with frailty and impaired performance	Cappolaetal., 2003 [17]
Totalcholesterol / LDL-C	Reflect metabolic reserve; low levels may indicate catabolism	Lower levels associated with frailty and vulnerability	Volpatoetal., 2001 [18]
Non-HDL cholesterol	Marker of atherogenic lipid burden	U-shaped association with frailty risk	Panetal., 2025 [19]
NT-proBNP	Reflects myocardial stress and cardiac dysfunction	Useful in cardiovascular risk assessment in elderly	Januzzi et al., 2018; [21] Hildebrandt et al., 2010 [22]
D-dimer	Marker of coagulationactivation	Useful for thrombotic risk; requires age-adjusted interpretation	Righini et al., 2014 [23] A Penalzoaet al., 2012 [24]