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# COMPOSITE RISK INDEX AND EARLY DETECTION ALGORITHM FOR STRESS AND LOW-ENERGY INJURIES AMONG MILITARY PERSONNEL

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**Abstract.** Based on an examination of 220 military personnel aged 18–45 years, a composite risk index for stress and low-energy injuries was developed, incorporating 10 clinical, physical load-related, and bone metabolic indicators. The index demonstrated good discriminative performance, with an area under the receiver operating characteristic curve (AUC) of 0.825 (95% CI 0.763–0.887), a sensitivity of 68.4%, and a specificity of 81.2%. Injury rates in the low-, moderate-, and high-risk groups were 7.1%, 23.5%, and 65.8%, respectively ($p<0.001$). A two-stage early detection algorithm was developed, comprising initial screening at the military unit medical facility followed by comprehensive assessment at a military hospital. The first-stage screening achieved a sensitivity of 94.7%, enabling the identification of military personnel at increased risk of injury before the onset of pronounced clinical manifestations.

**Keywords:** military personnel, stress fractures, low-energy injuries, composite risk index, ROC analysis, early detection, screening, bone metabolism.

# ИНТЕГРАЛЬНЫЙ ИНДЕКС РИСКА И АЛГОРИТМ РАННЕГО ВЫЯВЛЕНИЯ СТРЕССОВЫХ И НИЗКОЭНЕРГЕТИЧЕСКИХ ПОВРЕЖДЕНИЙ У ВОЕННОСЛУЖАЩИХ

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**Аннотация.** На основании обследования 220 военнослужащих в возрасте 18–45 лет разработан интегральный индекс риска стрессовых и низкоэнергетических повреждений, включающий 10 клинических, нагрузочных и костно-метаболических показателей. Диагностическая точность индекса составила AUC=0,825 (95% ДИ 0,763–0,887), чувствительность — 68,4%, специфичность — 81,2%. При низком, умеренном и высоком риске частота повреждений составляла соответственно 7,1%, 23,5% и 65,8% ($p<0,001$). Разработан двухуровневый алгоритм раннего выявления, предусматривающий первичный скрининг в медицинском пункте воинской части и углублённое обследование в госпитале. Чувствительность первого этапа достигала 94,7%, что обеспечивало выявление военнослужащих с повышенным риском повреждений до появления выраженных клинических проявлений.

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**Ключевые слова:** военнослужащие, стрессовые переломы, низкоэнергетические повреждения, индекс риска, ROC-анализ, ранняя диагностика, скрининг, костный метаболизм.

**Relevance.** Existing fracture risk assessment tools are unsuitable for military personnel aged 18–45 years. The FRAX calculator is designed for individuals aged 40 years and older and does not account for physical training loads, while injury risk assessment scales used by foreign armed forces do not incorporate bone metabolic parameters and have not been developed for military personnel with prolonged service histories. Magnetic resonance imaging and bone densitometry are generally unavailable at the military unit level, leaving unit medical officers without a standardized screening tool to guide referral decisions.

**Objective.** To develop a composite risk index for stress and low-energy injuries, evaluate its diagnostic accuracy, and establish an early detection algorithm applicable at military unit medical facilities and military hospitals.

**Materials and Methods.** The risk index was developed using examination data from 220 contract military personnel aged 18–45 years, including 76 individuals with a history of injury and 144 without previous injury. Points were assigned to ten predictors in proportion to the coefficients obtained from multivariable logistic regression. A bone mineral density Z-score of −2.0 or lower was assigned 3 points. Extreme body mass index values, C-terminal telopeptide of type I collagen (CTX) above 0.70 ng/mL, and a rapid increase in physical training load were assigned 2 points each. Vitamin D deficiency, a history of injury, dietary calcium intake below 600 mg/day, smoking, military service exceeding 10 years, and assignment to a military branch characterized by high-impact physical loading were each assigned 1 point. The total score ranged from 0 to 15 points. Diagnostic performance was assessed using receiver operating characteristic (ROC) curve analysis, with cross-validation based on a 2:1 split of the study sample.

**Results.** The mean risk index was 7.89±0.33 points among personnel with a history of injury, 5.84±0.23 points in the at-risk group, and 2.79±0.18 points among healthy personnel ($p<0.001$). The area under the ROC curve (AUC) was 0.825 (95% CI 0.763–0.887), compared with 0.607–0.691 for individual predictors. At the optimal cutoff of 7 points, determined by maximizing the Youden index, sensitivity was 68.4%, specificity was 81.2%, positive predictive value was 65.8%, and negative predictive value was 83.0%. The AUC in the validation subset was 0.775.

Three risk categories were identified: low risk (0–3 points), moderate risk (4–6 points), and high risk (≥7 points). The corresponding injury rates were 7.1%, 23.5%, and 65.8%, respectively ($p<0.001$), representing an approximately threefold increase between successive risk categories.

Seven of the ten predictors could be assessed at military unit medical facilities without specialized equipment, providing the basis for a two-stage early detection algorithm. At the first stage, a preliminary risk score was calculated using seven readily available predictors, followed by four clinical provocation tests. A preliminary score of ≥3 points or a positive provocation test constituted an indication for referral to a military hospital. At the second stage, serum vitamin D and CTX levels and bone

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mineral density Z-scores were determined, allowing calculation of the complete risk index.

The first-stage screening algorithm achieved a sensitivity of 94.7%, while approximately half of the screened personnel required referral for second-stage assessment. Within the occupational risk group, provocation testing identified a subgroup comprising 32.4% of military personnel whose bone mineral density Z-scores, vitamin D levels, and CTX concentrations did not differ significantly from those observed among personnel with previous injuries (p=0.13–0.63).

**Conclusions.** The ten-parameter composite risk index demonstrated superior discriminatory performance compared with individual predictors, maintained its performance during cross-validation, and classified military personnel into three risk categories characterized by approximately threefold differences in injury rates between successive categories. The two-stage algorithm enabled initial risk stratification at military unit medical facilities, followed by comprehensive diagnostic assessment at military hospitals. This approach facilitated the identification of possible preclinical bone stress injuries in approximately one-third of personnel classified as being at occupational risk.

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