Purpose: To assess the contribution of secondary particles to pencil and passively scattered proton beams, in particular to determine the impact on linear energy transfer (LET), a central quantity in biological treatment planning.

Methods: Proton Monte Carlo simulations were performed directly in patient geometries considering all primary and secondary particles, including recoils stemming from inelastic nuclear interactions. Simulations were conducted for a prostate and a head&neck case to investigate the impact of different initial proton energies.

Results: Examination of the results reveals that secondary protons exhibit LET-values up to a factor 10 higher than those of the primary protons in the same region. This causes significant changes to the dose-averaged LET when including secondary protons, from 50% along the central axis of the beam to >200% in the penumbra. Furthermore the LET-maximum increases from 12 to 15 MeV/mm. The contribution of recoils (A>3) was observed to be 1.2% in the entrance region of the prostate case, increasing slightly compared to the same beam in a water phantom. The degree of biological damage inflicted by recoils remains hard to quantify, but can be discussed on account of detailed energy spectra of the preeminent particles.

Conclusions: These results indicate that secondary protons have a significant influence on LET and should therefore be incorporated into RBE calculations for proton therapy, as well as into radiobiological experiments. The contribution of heavier secondary particles is complex, yet may have an impact on precise measurements of the radiobiological effectiveness (RBE) of protons, especially in the plateau region of high-energy beams. In addition the LET distributions presented demonstrate the impact of inhomogeneities on the LET and the subtle changes between the LET distributions of passively scattered and actively scanned beams. The latter observation suggests higher RBE variations in active scanning than in passively scattered fields.

Funding Support, Disclosures, and Conflict of Interest:

The project was supported by the Federal Share of program income earned by Massachusetts General Hospital on C06 CA059267, Proton Therapy Research and Treatment Center.