Up-regulation of tubulin genes and growth phenotype of tubulin mutants in *Arabidopsis* under hypergravity conditions

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Plants resist the gravitational force by constructing a tough body via an increase in cell wall rigidity and modifications of growth anisotropy. The analysis of the changes in gene expression by hypergravity treatment in *Arabidopsis* hypocotyls by the differential display method has shown that a gene encoding alpha-tubulin is up-regulated by hypergravity [Yoshioka et al. (2003) Adv. Space Res. 31: 2187], suggesting the involvement of microtubules in gravity resistance in plants. In the present study, we examined this possibility by analyzing the expression levels of each member of alpha- and beta- tubulin genes and growth behavior of tubulin mutants in *Arabidopsis* under hypergravity conditions produced by centrifugation. Most of alpha- and beta-tubulin genes were up-regulated by hypergravity at 300 g. Isolated amino acid substitution mutants (*tua3*(D205N), *tua4*(S178), *tua6*(A281T), *tua6*(S277F)) showed left-handed or right-handed helical growth, derived from disordered organization of cortical microtubules, in hypocotyls even under 1 g conditions. Such a phenotype was intensified under hypergravity conditions, especially in *tua3* and *tua4* mutants. Tubulin mutants had thicker and shorter hypocotyls than wild-type under 1 g conditions. Their thickening was stimulated and elongation was suppressed by hypergravity treatment, although to a lesser extent than wild-type. The cell wall rigidity of wild-type hypocotyls was increased under hypergravity conditions, whereas such an increase is unclear in mutant hypocotyls, especially in *tua3* and *tua4*. These results support the hypothesis that cortical microtubules play an important role in gravity resistance in plants.