

A Proposed Mechanism for the Induction of Bone Loss as a Function of Chronic Envy

William W. Sabol, MS

ABSTRACT

The dorsal anterior cingulate cortex (dACC) has been shown to be uniquely activated when people engage in envy. Similarly, dACC is the major component of a proposed adversity processing circuit that predicts risks to prevent destructive behaviors and inhibit release of dopamine and serotonin, which play a significant role in skeletal health. A causal relationship may therefore exist between chronic envy and the induction of lowered bone mineral density (BMD) as a result of dACC activation.

A significant body of research shows that depression may induce bone loss, which has resulted in calls for it to be recognized as a contributing factor for lowered bone mineral density (BMD) and even the more advanced condition of osteoporosis. For example, rodents subjected to chronic mild stress with an experimentally established model of depression led researchers to conclude that depression induces bone loss through stimulation of the sympathetic nervous system, associated with increases in skeletal norepinephrine and serum corticosterone levels (1).

This raises the intriguing question of whether other mood states may have a similar effect. Statistically reliable assessment instruments – Dispositional Envy Scale, Beck Depression Inventory, and Center for Epidemiological Studies Depression Scale – consistently showed a significant correlation between measures of envy and depression, $p < .001$ (2). Can envy play a role in the induction of bone loss as well? The dorsal anterior cingulate cortex (dACC) has been shown to be uniquely activated when humans exhibit envy (3). This “envy center” is also the warning generating component of a proposed adversity processing circuit that evaluates and predicts risks to stop us from making destructive choices. This circuit, along with dACC directly, may activate the lateral habenula (LHb) (4), where afferent projections to the midbrain and brainstem inhibit, rather than excite, release of dopamine and serotonin.

Dopamine's role in bone health is largely unknown, but it may enhance bone regeneration by affecting osteogenic gene expression (5), and it may have a role in calcium and phosphorous metabolism. And serotonin increases, via brain-derived serotonin (BDS), bone mass accrual while limiting bone resorption through the inhibition of sympathetic activity (6). This is significant because with age the resorption rate exceeds the rate of replacement with new bone growth which may lead to osteoporosis.

There is no serotonergic innervation of bone, although osteocytes and osteoblastic cells can synthesize serotonin and regulate its uptake in a functional serotonergic system (7). Disruption of the gene that encodes the serotonin transporter protein (5-HTT or SERT) may cause osteopenia, just as deletion of the dopamine transporter gene (DAT) caused impairment of skeletal mass, strength and structural integrity in rodents (8). These neurotransmitter transporters rapidly return the substances to

presynaptic terminals, so their disruption or deletion can result in hyperserotonergia or hyperdopaminergia. Bones do not appear to tolerate excessive or insufficient amounts of neurotransmitter activity well.

Researchers have recently found evidence for lowered BMD and decreased serotonergic synthesis in the dorsal raphe nucleus in htau mice in a tauopathy model of Alzheimer's disease (9). This very serotonin-producing site is inhibited by LHb in the adversity processing aspect of the Vadovicova model.

Persons exhibiting chronic, debilitating envy may well be tempted to engage in risky and destructive behaviors. The dACC would be activated by envy while stimulating the adversity processing center and LHb into action, resulting in inhibition of serotonin and dopamine release and an indirectly causal relation between envy and reduced bone mass. Irrespective of the merits or shortcomings of the model proposed here, the role of envy and possibly other affective states in influencing skeletal health warrants further investigation.

REFERENCES

1. Yirmiya R, Goshen I, Bajayo A, Kreisel T, Feldman S, Tam J, Trembovier V, Csernus V, Shohami E, Bab I. Depression induces bone loss through stimulation of the sympathetic nervous system. *PNAS*. 2006;103:16876-16881.
2. Smith RH, Parrott WG, Diener EF, Hoyle RH, Kim SH. Dispositional envy. *Personality and Social Psychology Bulletin*. 1999;25:1007-1020.
3. Takahashi H, Kato M, Matsuura M, Moobs D, Suhara T, Okubo Y. When your gain is my pain and your pain is my gain: neural correlates of envy and Schadenfreude. *Science*. 2009;323:937-939.
4. Vadovicova K, Gasparotti R. Reward and adversity processing circuits, their competition and interactions with dopamine and serotonin signaling. 2014;arXiv:1304.4201.
5. Lee DJ, Tseng HC, Wong SW, Wang Z, Deng M, Ko C-C. Dopaminergic effects on *in vitro* osteogenesis. *Bone Research*. 2015;3:15020; doi:10.1038/boneres.2015.20.
6. Ducy P, Karsenty G. The two faces of serotonin in bone biology. *The Journal of Cell Biology*. 2010;191:7-13.
7. Bliziotis M, Eshleman A, Burt-Pichat B, Zhang X.-W., Hashimoto J, Wiren K, Chenu C. Serotonin transporter and receptor expression in osteocytic MLO-Y4 cells. *Bone*. 2006;39:1313-1321.
8. Bliziotis M, Gunness M, Eshleman A, Wiren K. The role of dopamine and serotonin in regulating bone mass and strength: Studies on dopamine and serotonin transporter null mice. *Journal of Musculoskeletal and Neuronal Interactions*. 2002;2:291-295.
9. Dangler-Crish CM, Smith MA, Wilson GM. Early evidence of low bone density and decreased serotonergic synthesis in the dorsal raphe of a tauopathy model of Alzheimer's disease. *Journal of Alzheimer's Disease*. 2017;55:1605-1619.