

Marriage and Gut (Microbiome) Feelings: Tracing Novel Dyadic Pathways to Accelerated Aging

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ABSTRACT

Within a couple, partners influence each other's mental and physical health. This review focuses on how couples' relationships, the partners' individual and joint vulnerabilities, and their health behaviors influence health through changes in the gut microbiota, metabolism, and immune function. Couples' shared stressors and emotions and their intertwined lifestyles and routines serve to promote common disease risks in part through parallel changes in their gut microbiotas. Marital discord, stress, and depression have strong bidirectional links, fueling one another. Chronic marital stress and depression can elevate the risk for obesity, metabolic syndrome, and cardiovascular disease by altering resting energy expenditure, insulin production, and triglyceride responses after unhealthy meals. During stressful times, health behaviors typically suffer—and sleep disturbances, poor diets, and sedentary behavior all influence these metabolic pathways while also promoting gut dysbiosis. Dysbiosis increases intestinal permeability (gut leakiness), providing a mechanistic pathway from marital distress and depression to heightened inflammation and accelerated aging. Age-related changes in the gut microbiota's composition and gut leakiness foster immunosenescence, as well as the progression of inflamm-aging; these age-related risks may be altered by stress and depression, diet, sleep, exercise habits, and developmental shifts in emotion regulation strategies. Consideration of the strong mutual influences that partners have on each other's mood and health behaviors, as well as the biological pathways that underlie these influences, provides a new way to view marriage's health implications.

Key words: gut dysbiosis, gut microbiota, health behaviors, immunosenescence, inflamm-aging, marriage.

INTRODUCTION

Couples influence each other's mental and physical health. Recent studies have demonstrated notable spousal concordance in gene expression patterns, cellular immune profiles, and inflammation (1–3). Furthermore, couples' intestinal microbial communities—or gut microbiotas—and health behaviors are also more similar to each other than those of unrelated partners, providing common pathways for shared disease risks (4,5).

Marital discord, stress, and depression have strong bidirectional links, and they alter health behaviors and biological pathways in ways that compromise health (6). Even in satisfying marriages, couples' interconnected health behaviors can be beneficial or harmful, because couples' diets, exercise habits, and sleep unite to influence the gut microbiota. In addition, developmental shifts in goals and emotion regulation strategies may shape couples' relationships and may interplay with age-related changes in the gut microbiota to extend couples' healthy years or hasten decline (Figure 1).

Spousal Similarities: Gene Expression, Immune Profiles, and the Gut Microbiota

Recent studies have provided mechanistic insights into spouses' shared disease risks. Gene expression, shaped by both genetic and environmental regulators, plays a fundamental role in determining biological function. In this context, it is significant that across a sizable number of genes, husbands' and wives' gene expression patterns exhibited noteworthy transcriptional similarity,

with much smaller variances in couples than random pairs (1). For example, a gene that has been associated with coronary artery disease and hypercholesterolemia was among those that showed the “couple effect” of transcription; spousal concordance has been demonstrated for coronary artery disease risk and cholesterol, among many others (5).

Another research team used a systems-level approach to determine cellular immune profiles for 670 healthy people (2). Cohabitation had the strongest influence: couples living together had 50% less variation in 54 different immune parameters than did unrelated pairs. This effect was independent of age and extended to stimulated cytokine production. The authors concluded that living together had a stronger relationship to immune system parameters than acute and untreated gastroenteritis.

The bacteria and viruses that inhabit the gut help educate the immune system, and thus, it is no surprise that an analysis of cohabiting couples' stool samples revealed that they also share similar gut microbiotas (4). Physical interaction promotes microbial sharing, and couples' intimate behaviors—touching, kissing, and sex—ensure microbial transfers (7). Importantly, factors including diet, drugs, and body measurements account for more than 20% of between-person gut microbiota variability—a large sphere of

CRP = C-reactive protein, **LBP** = LPS-binding protein, **LPS** = lipopolysaccharide

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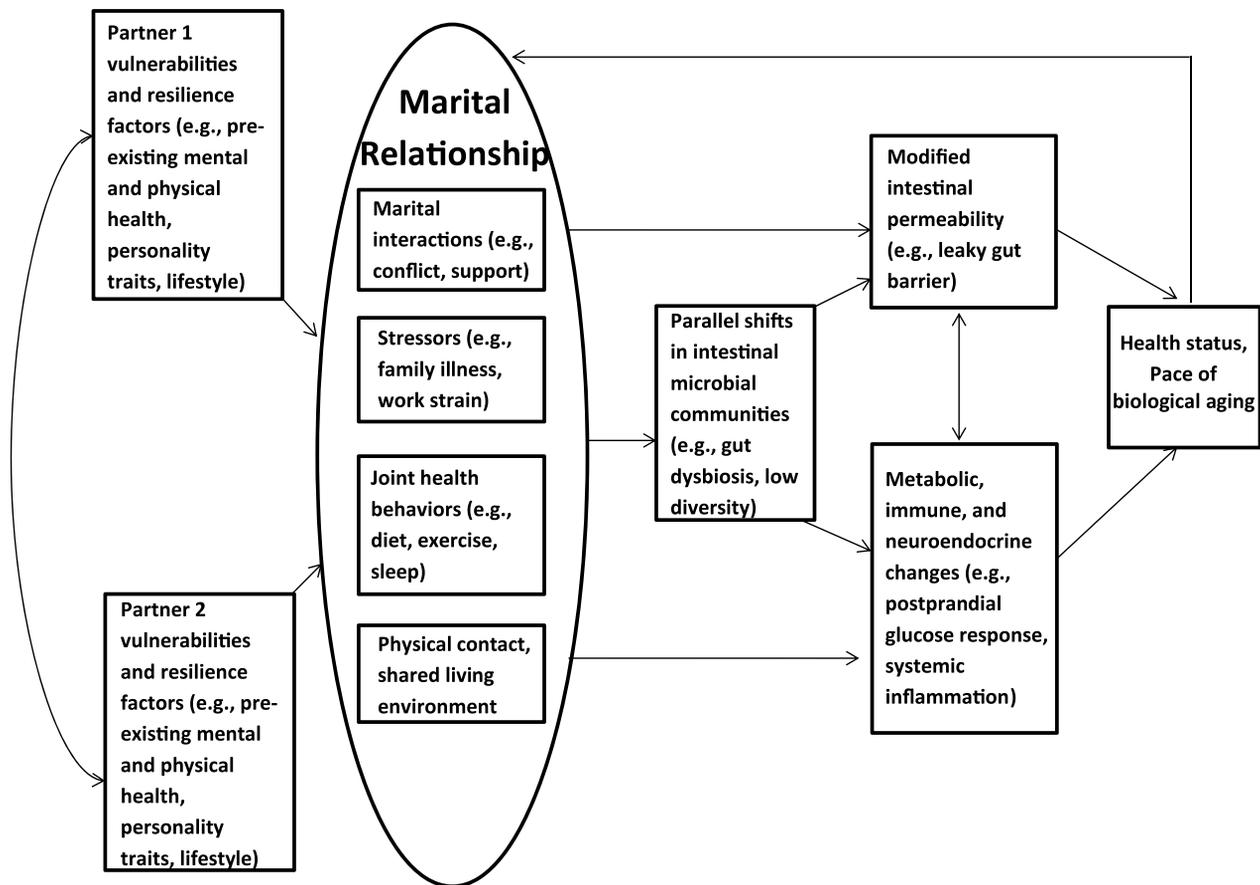


FIGURE 1. Conceptual model summarizing the paths by which the marital relationship may influence health and aging via the gut. Often interrelated, both partners' characteristics—e.g., their own prior mental and physical health, personality traits, and lifestyles—affect the relationship. In turn, partners' marital interactions, the stressors they face together and individually, their health behaviors, as well as their physical contact and living environment have physiological consequences. Namely, they may augment intestinal permeability, as well as metabolic, immune, and neuroendocrine function directly or indirectly in part through changes in intestinal microbial communities. Thereafter, these mutually reinforcing physiological cascades shape partners' health status and set the pace of aging. Ultimately, changes in health and biological aging feed back to affect life with one's partner.

influence for couples' shared living space and life-style patterns; in contrast, genetics have only a minor influence, less than 2% (4).

Because the number of bacterial cells closely mirrors the number of human cells in the human body, microbiota variability has real-world implications (8). Even after controlling for age, sex, diet, and host genetics, microbiota data accounted for substantial variability in body mass index (25%), fasting glucose (22%), high-density lipoprotein (36%), waist circumference (29%), waist-hip ratio (24%), and lactose consumption (36%) (4). For example, even when people eat identical foods, their blood glucose responses are highly variable, and largely pathogenic bacteria phyla positively correlate with glucose responses—demonstrating the microbiota's influence on metabolism (9). Thus, between-person microbiota variability may help explain metabolic differences.

This within-couple microbiota similarity (4) parallels some of the spousal linkages reported for major coronary risk factors (diastolic blood pressure, triglycerides, total and low-density lipoprotein cholesterol, body mass index, and waist-to-hip ratio), as well as health conditions (diabetes, metabolic syndrome, hypertension, arthritis, cancer, asthma, peptic ulcer disease, and physician-diagnosed hay fever) (5). The spousal ties are sizable: people

whose partners have asthma or peptic ulcer disease have a 70% or more increased risk themselves for these conditions, even after controlling for partners' age, smoking, and obesity (10), whereas a spouse's hypertension increases the partner's risk two-fold (11), and a partner's arthritis almost triples the odds (12). New analyses from the UK Understanding Society panel showed spousal concordance for adiposity measures, blood pressure, heart rate, and two inflammatory markers, C-reactive protein (CRP) and fibrinogen (3).

Dyadic Pathways: Couples' Shared Stressors, Emotions, and Health Behaviors

Beyond the effects of a common living environment and physical touch, couples' shared stressors may help drive biological convergence and compound health risks (Figure 1). Whether they encounter a stressful event together, e.g., when a child is sick, or bring home their work strain, partners tend to feel similarly stressed (13). According to ecological momentary studies, bad moods are particularly contagious in close proximity—i.e., when couples are physically together or have experienced the same stressor and work jointly on the problem (14,15).

Happy and unhappy marriages can both transmit stress via mood contagion, perhaps through distinct routes. In the daily diaries of people with chronic pain and their spouses, happier wives reported greater emotional distress on days when their spouse was suffering more compared to days with lower suffering (16). On the other hand, marital discord can fuel negative affect reciprocity, as unhappier spouses' negative moods and cortisol patterns tracked more closely together than those of happier couples (17).

Stress can drain marital resources. Among dual-earner couples, spouses were less responsive to each other after more demanding workdays compared with less stressful days (14). The relationship faces greatest risks when both partners are stressed and among couples who lack strong conflict resolution skills (13). Marital discord carries its own health consequences, promoting additional stress and depression (5). In turn, having a depressed partner doubles the risk of becoming depressed (10).

The stress that accompanies a troubled marriage promotes adverse health behaviors. However, couples' convergence or interdependence can also prove problematic in untroubled marriages if their shared behaviors are unhealthy. Couples' diet, sleep, exercise, smoking, and alcohol consumption show significant associations (5), and each of these behaviors influences the microbiota (18).

In particular, apart from the sleep-disrupting effects of marital conflict, sharing a bed or a sleep routine may be sufficient to spread health risks between partners. Indeed, couples share remarkable similarity in their sleep patterns: when partners' minute-by-minute night actigraphy was compared, more than half the time, when a person was awake during the night, the partner was too (19). Although partners with more similar bedtimes and higher minute-to-minute sleep concordance report greater relationship satisfaction and fewer mood symptoms (19,20), actigraphy assessments reveal that sleep is more restless with a bed partner than alone (21). Accordingly, people whose partners report chronic sleep problems have higher inflammation (22) as well as poorer self-rated health and higher levels of depressive symptoms than those with well-rested partners (21,23).

The Gut Microbiota: Inflammation and Health

A healthy gut microbiota is diverse—a term that captures both the number of distinct bacterial species (i.e., richness) and the relative abundance, or evenness, of the species. The goal is homeostatic equilibrium, with pathogenic populations counterbalanced by commensal, i.e., beneficial, populations. A greater number of species as well as an even distribution prevents the overgrowth or dominance of a particular species and supports healthy metabolic and immune function. People with low bacterial richness have greater adiposity, insulin resistance, and dyslipidemia, as well as a more pronounced inflammatory phenotype compared to those with high bacterial richness; in addition, among those with lower richness, obese individuals also gain more weight over time (24). Low diversity in the bacterial community structure makes the host more vulnerable when challenged or perturbed (Figure 1).

Some evidence suggests that depressed patients' microbiotas are less diverse than those of controls (25). The microbiota composition may promote depression; transferring fecal matter from people with a major depression diagnosis to microbiota-deficient rats induced depressive-like behavior in the rats (25). This link is

relevant for marriage: both syndromal depression and depressive symptoms are strongly associated with marital distress (26). Troubled marriages provide fertile soil for depression, and depression promotes poorer marital quality, both pathways that can impact the microbiota (26).

The bidirectional communication between the gut and brain—the gut-brain axis—involves multiple depression- and stress-responsive pathways including the sympathetic nervous system, the hypothalamic-pituitary-adrenal axis, the vagus nerve, and the immune system. Through these diverse pathways, depression and stress can provoke gut dysbiosis (adverse changes in gut microbiota profiles). Microbes fortify the gut barrier, ensuring that food particles, toxins, and pathogens do not enter the bloodstream, but gut dysbiosis can disrupt barrier integrity, producing intestinal permeability (27). Translocation of bacterial endotoxin (lipopolysaccharide, LPS) from the gut microbiota to blood circulation—the result of a “leaky gut”—stimulates systemic inflammatory responses (28,29).

Long-term diets have major effects on the microbiota (7). Typical Western-style diets (high intake of red meat, refined sugars, and saturated fat) generate lower overall microbial diversity than plant-based diets such as the Mediterranean diet (18). The Western diet can increase microbial populations that are more efficient in harvesting energy from food, facilitating weight gain. Furthermore, high saturated fat diets induce gut dysbiosis, and promote gut permeability (18). Couples are highly concordant on diet, particularly total fat (30), providing one prime pathway to shared risk. Stress has been associated with poorer diets, e.g., greater reliance on high-fat, high-sugar comfort foods, and couples in troubled marriages have poorer diets (31).

To investigate increased gut permeability as one potential mechanistic pathway from marital distress to heightened inflammation, we examined LPS-binding protein (LBP), a surrogate marker of microbial translocation, in healthy married couples. The couples discussed a marital disagreement during two separate sessions; behavioral coding of these interactions provided data on hostile marital behaviors, a hallmark of marital distress. Participants with more hostile marital interactions had less healthy diets as well as higher LBP than those who were less hostile. Higher LBP was associated with greater CRP production; for example, compared with low LBP participants (25th percentile), those in the 75th percentile had 79% higher CRP (31).

The gut microbiota can also impact energy balance, glucose metabolism, and obesity-related inflammation, in part through gut leakiness (32). Recent work from our laboratory has shown that stress and a mood disorder history alter metabolic responses to high-fat meals (33–35). In one study, couples ate a high-fat meal and then discussed a marital disagreement during each of two visits (34). When combined with a mood disorder history, men and women who had more hostile marital interactions had lower postmeal energy expenditure, and this disparity was clinically meaningful: 128 kcal, a difference that could add approximately 7.7 lb/yr. Furthermore, higher levels of hostile behaviors among those who had a mood disorder history were also associated with higher postmeal insulin compared with other participants. Higher insulin levels stimulate food intake and visceral fat accumulation (36) and thus would act in tandem with lower energy expenditure to promote obesity.

In addition to unhealthy diets, marital discord, stress, and depression, disturbed sleep, and sedentary lifestyles influence the gut microbiota and promote intestinal permeability and thus

enhance inflammation. During stressful times, health behaviors often suffer; therefore, sleep disturbances, poor diets, and sedentary behavior may interact with marital discord and depression to further exacerbate gut dysbiosis and bacterial translocation (18).

Sleep and Its Links to Metabolism and the Gut Microbiota

Sleep problems elevate risks for diabetes, cardiovascular disease, cancer, and premature death (e.g., (37)), perhaps in part through their effects on metabolism and weight (38). Both sleep restriction and circadian disruption—sleep's misalignment with the body's internal clock—alter appetite hormones in a way that makes people hungrier and eat more (38). The gut microbiota may mediate this effect, because gut microbes also affect production of leptin, an appetite-stimulating hormone (7). After a night of poor sleep, people also tend to eat more food high in saturated fat and simple carbohydrates, exacerbating the effects of circadian misalignment and sleep loss (39).

Even overweight people on a calorie-restricted diet who slept poorly lost less fat than those on the same diet who slept well, suggesting that sleep disruption slows fat metabolism regardless of calorie intake (38). Moreover, healthy people who were restricted to 4 hours of sleep for six nights showed a 40% decrease in glucose clearance, comparable with diabetic levels (38); conversely, extending the sleep of chronically short sleepers enhanced glucose metabolism (38).

Likewise, circadian misalignment decreases insulin sensitivity, apart from and compounded by the effects of sleep loss (38). Glucose metabolism does not seem to habituate to sleep disruptions (38), suggesting that the risks accumulate over time. As described earlier, microbiota data account for 22% of the variability in fasting glucose (4).

A theoretical review conceptualized sleep loss and acute circadian disruption as physiological stressors, noting that periods of shorter or no sleep often lead to increases in afternoon and early evening cortisol levels, which promote visceral fat storage and elevate circulating glucose (39). Insofar as sleep dysregulation triggers a stress response, this review also proposed that alterations in the gut microbiota may help explain sleep-related risks for obesity and metabolic diseases. As discussed, gut microbes help maintain metabolism, nutrient absorption, and the intestinal barrier, and stress and high-fat diets induce gut dysbiosis (18). The sleep-dysbiosis link has support in rodent models: within 5 days of sleep deprivation, intestinal bacteria appeared in rats' mesenteric lymph nodes, outside the intestine, implying rapid bacterial translocation (39). Mice with genetically induced circadian disruption also had lower gut microbiota diversity compared with wild types (40). Unhealthy diet may further exacerbate these effects: in mice fed a high-fat diet, gut microbes themselves showed altered circadian rhythms, which in turn were associated with changes in the mice's own circadian clock gene expression and weight gain (39,41).

Taken together, when marital hostility disrupts sleep, it likely triggers maladaptive gut microbiota responses and metabolic cascades as well. In turn, sleep loss can interfere with partners' ability to read each other's emotions and fuel hostility (22,42), forming a risky cycle. Furthermore, a few nights of shorter sleep prime larger inflammatory responses to marital conflict (22), suggesting that the physiological stress of sleep restriction may interact with marital stress to heighten health risks.

Exercise and the Gut Microbiota

Physical activity benefits the microbiota in multiple ways (43). Exercise increases gut motility, and faster colonic transit times increase microbiota diversity. Regular physical activity changes the microbial community's composition and also modulates bacterial metabolism via production of beneficial short-chain fatty acids, which helps prevent gut barrier dysfunction and limits the resulting systemic inflammation (43,44).

Spouses tend to engage in activities with similar frequency (5). Furthermore, partners who had been living together for 2 or more years were twice as likely to both be physically inactive and sedentary (45).

Marriage, Aging, and Gut Microbiota

Marriage, Emotions, and Aging

The microbiota-mediated health consequences of marriage may compound over time and with age. Because middle-aged and older adults prune their more distant social ties (46), the marital relationship assumes an increasingly central role in coloring the emotions of daily life. With biological aging, physiological responsiveness to stressors becomes dysregulated (47), further exacerbating the health risks of marital stress. Indeed, in two separate marital disagreement studies, the effect sizes of healthy older couples' immune reactivity to conflict were medium to large (48), whereas effects in healthy younger couples were small to medium (49). Associations between postconflict appraisals and wound healing emerged only among middle-aged and older partners, not younger couples (50).

Longitudinal data reveal consonant patterns: older adults in strained marriages had steeper declines in self-rated health for 8 years compared with younger and happily married counterparts (51). In a 20-year prospective study, couples' greater anger and stonewalling (i.e., discussion-blocking) predicted steeper increases in self-reported physical symptoms over time but were unrelated to initial symptoms, suggesting that the scars of a chronically stressed marriage may appear years later (52).

According to social-emotional aging theories, as people perceive less time to live, they focus on maximizing emotional well-being and meaningful experiences with loved ones (46). To serve this goal, during adulthood, people increasingly shift away from confrontation, to avoiding and reframing potential stressors (47). Consistent with theory, older couples tend to feel closer and more satisfied in their marriages than younger couples (53). Older couples' positive affect is less disrupted by marital disagreement compared with their younger counterparts', and older adults rate their spouses' behavior as more positive than independent raters judge them to be (50,54). On the other hand, corresponding patterns in conflict behaviors and autonomic reactivity to marital disagreement have produced equivocal results (55–58).

Beyond this, the closeness that might emerge from years of life together can also confer health risks. Although older adults report fewer stressors on average (53), the increasing intertwining of partners' goals and routines with older age may boost *shared* stress and draw them closer to partners' suffering. Even the most comforting relationships may promote poor health when partners bond around unhealthy behaviors such as smoking, drinking excessively, or dining on high-fat, sugary foods. A longer history of these behaviors could pile on the risks, particularly in aging

bodies. Thus, it is unclear whether social-emotional advantages and the joy and support of a close marriage in older age may offset the magnified health risks of marital strain or closeness. The unique contributions of older age and a longer marriage also remain unknown.

Stress, Depression, and the Microbiota: A Marital Path to Accelerated Aging

When marital stress or depression disrupts the homeostatic relationship between the microbiota and the host, exaggerated inflammation can occur (59). Mouse studies have documented multiple adverse effects of stress on the gut microbiota, including alterations in bacterial composition, decreased diversity, increased gut leakiness, and heightened inflammation (29). Similarly, compared with controls, the gut microbiotas of depressed patients differed in composition, with less diversity and greater leakiness (25,60). Paralleling these stress- and depression-related patterns, aging is accompanied by less diversity in the gut microbiota's bacterial composition, as well as increased gut bacteria translocation, and these changes promote the persistent age-associated low-grade inflammation, termed "inflamm-aging," that contributes to age-associated frailty, morbidity, and mortality (28,61).

Indeed, the decline in microbiota diversity may be a stronger factor in age-related frailty than chronological age (62,63). For example, among 728 female twins (mean = 63 years old), frailty— independent of chronological age—predicted distinctive genera in the microbiota community and was also associated with lower diversity (64). The microbiota's composition may impact the rate of aging (Figure 1), in tandem with age-linked changes in lifestyle, nutrition, frailty, and inflammation (62,63). Higher levels of LBP, reflecting greater gut leakiness, have been associated with poorer physical function and higher levels of inflammation, even among healthy older adults (61).

The independent and joint functionality of the host and the microbiota influence health status via an inflammatory phenotype and thus help set the pace of biological aging by speeding or impeding inflamm-aging (62). Importantly, unlike chronological age, functional status—of both the host and microbes—may be modified via health behaviors (diet, sleep, and exercise), as well as stress and depression. After a disturbance, the gut microbiota community typically returns to the predisturbance "core" composition. However, severe or repetitive insults may produce long-term—perhaps permanent—changes in the core composition, leading to problematic alterations in the commensal gut microbiota that regulate local and systemic inflammation and immunity and maintain gut barrier function. As described earlier, greater marital hostility predicted heightened gut leakiness (31). Thus, persistent marital strain may create long-term maladaptive changes in the microbiota.

CONCLUSIONS

Troubled marriages set the stage for poorer mental and physical health. However, we have also described how happy marriages can increase risk through couples' shared health habits. Indeed, the new evidence showing couples' concordance on gene expression, cellular immune profiles, and microbiotas highlights key pathways that influence spousal similarities in disease risk. As noted, these are interconnected pathways; the immune system serves as a major communication path between the brain and the

gut (65), and the gut microbiota seems to play a central mediational role while influencing both. Factors that negatively impact the microbiota's composition and diversity can also induce dysregulated immune responses, accelerate inflamm-aging, and thus promote the development of inflammatory diseases (66). In addition, the immune system has a role in limiting bacterial translocation and the associated inflammation. This interplay between the immune system and the gut microbiota is important for homeostasis; dysbiosis promotes systemic inflammation (66). In this intricate web, inflammation can fuel depression, and, in turn, marital stress and depression boost inflammation (67).

The bidirectional gut-immune-brain paths have been well-documented in rodent models, but the corresponding human behavioral data are scant; human studies have been primarily cross-sectional and observational. Future work using prospective longitudinal studies and experimental designs is needed to understand how these interconnected cascades unfold in couples, and future research should carefully consider the role of selection effects. For example, a history of depression increases stress responsiveness and heightens risk for marital discord as well as gut dysbiosis (31,68,69). Furthermore, whereas this review has focused primarily on presence, absence, and abundance of gut microorganisms, their genome (termed microbiome) and functionality (studied with metabolomics) are also critical targets for future research and intervention.

Although we have emphasized risk-related pathways, couples' concordance also may be leveraged for both partners' benefit. For example, addressing one person's sleep problems may promote both partners' sleep health: treating a person's sleep apnea improved the partner's sleep and the co-sleeping partner bolstered treatment adherence (21,70,71). In addition, positive changes in one spouse's behavior can prompt change in their partner. Data from the English Longitudinal Study of Ageing, a population-based study of middle-aged and older adults, showed that a person was more likely to stop smoking, increase physical activity, and lose 5% or more of their weight if their partner made the same positive change (72).

Moreover, one spouse can benefit from an intervention delivered to their partner, a "ripple effect" (73). For example, in a trial that evaluated how intentional weight loss affected cardiovascular outcomes in overweight people with type 2 diabetes, spouses of intervention group participants lost more weight than the partners of usual care condition participants, and the spouses' weight loss was significantly correlated (73). Similarly, husbands of women in the low-fat intervention arm of the Women's Health Trial reduced their body fat and weight more than the husbands of control arm women (74).

Within a couple, partners clearly influence each other's mental and physical health. New studies have revealed the deep roots of biological concordance that span gene expression patterns, cellular immune profiles, inflammation, and the gut microbiota. Couples' emotions, their relationship satisfaction, and their interconnected health behaviors all interplay with age-related biological changes. Through these pathways, a couple's partnership shapes their shared journey toward healthy or unhealthy aging.

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