Exaggerated Facial Feedback from Temporomandibular Disorders May Contribute to the Pathophysiology of Clinical Depression

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Clinical depression, a highly prevalent and debilitating mental health challenge, has been widely studied, yet the pathophysiology is not fully understood. About eight percent of the U.S. population is clinically depressed at any time; among young adults, the rate is 17% (National Institute of Mental Health, 2022). Depression has the highest rate of global "lived with" disability (Lopez et al., 2006). Researchers studying the cause of depression often focus on either psychological or physiological factors. However, neither approach can explain how normal emotions, such as discouragement, transform into abnormal emotions, such as depression. Perhaps the pathophysiology of depression does not lie in psychological or physiological factors separately—but in their relationship. Exploring the physiological changes from psychological distress could help reveal the developmental path of many mental health disorders, including depression. Facial expressions are one of the first physical responses to emotional stimuli. The Facial Feedback Hypothesis (FFH), which has been thoroughly studied and is well-supported, proposes that neural "feedback" from facial expressions intensifies emotional experiences (Strack et al., 1988; Soussignan, 2002). It is possible that stressful experiences may initiate more frequent or intense facial expressions and amplify facial feedback responses. Additionally, strong facial expressions (or teeth clenching) during prolonged or extreme stress could result in the development of temporomandibular disorders (TMD)—involving injured facial muscles and joints (Li & Leung, 2021; Florjański & Orzeszek, 2021; Wieckiewicz et al., 2022). TMD may then alter facial feedback—magnifying physiological responses to emotional stimuli. Thus, exaggerated facial feedback resulting from TMD may contribute to the pathophysiology of clinical depression.

Physiological Changes from Facial Expressions

Facial expressions reveal psychological responses to various stimuli and can also modify autonomic responses. A study by Lerner et al. (2007) found that the strength of a person's facial expression during stress corresponded with cortisol and cardiovascular changes. Kraft and Pressman (2012) found that subjects' smile-like facial expressions significantly lowered heart rates during recovery from a stressful task. A follow-up study showed that both grimacing and smiling could reduce the perception of needle pain from an injection; however, only a full, genuine smile (with mouth and eyes) significantly lowered heart rate in the second study (Pressman et al., 2021). Subjects were blind to the purpose of both studies, and facial expressions were manipulated to the desired expression by how chopsticks were held in the subjects' mouths. Distraction is a possible explanation for reduced needle pain, and pain reduction could then reduce heart rate. However, facial feedback may also be involved, as facial expressions can also influence emotional responses (Ekman et al., 1983; Levenson et al., 1990).

Facial Feedback and Emotion

Facial Feedback can initiate or intensify emotions—such as increased cheerfulness from smiling or increased discouragement from frowning. This concept has been validated through multiple studies in the 20th century (Ekman et al., 1983; Strack et al., 1988; Levenson et al., 1990) and several in this century. For example, Soussignan (2002) found that a “smile” expression resulted in a more positive experience and autonomic response while subjects watched video clips. Larsen et al. (2003) found correlations between facial expression magnitude—both smiling and frowning—and self-reported affect from emotionally arousing stimuli. Michael Lewis (2012) had subjects raise their eyebrows, lower them, or keep them neutral while taking the Irritability-Depression-Anxiety (IDA) questionnaire. Lewis discovered that subjects that held their eyebrows down scored significantly higher on the IDA for depression and anxiety. These studies support the concept that facial expressions influence mood and autonomic responses. While some FFH studies included emotional stimulus, others relied solely on facial muscle manipulation—and still found mood alterations. Emotional reaction to facial expressions without emotional stimulus suggests that facial feedback may play an integral role in emotional responses. However, not all facial feedback studies have given a hearty endorsement.

Researchers seeking to confirm the FFH through a study replication found mixed results; however, their methodology may have been to blame. Wagenmaker et al. (2016) replicated a study by Strack et al. (1988) that had previously found that subjects with pen-facilitated smiles rated cartoons more amusing compared to ratings by those without smiles. Only nine of Wagenmaker et al.'s 17 replication trials showed the facial feedback effect. Noah et al. (2018) criticized the replication because they had altered Strack et al.'s protocol by filming the participants. Noah et al. conducted a revised replication and compared subjects' responses with and without being filmed. They found that filmed subjects were less amused by cartoons than those not filmed—suggesting filming participants can alter study outcomes. However, Soussignan (2002) replicated Strack's study with a few alterations, including filming participants, and still showed the facial feedback effect. A closer look at Wagenmaker et al.'s successful and failed trials might discover why some showed the facial feedback effect—and others did not.

Another semi-criticism of facial feedback came from a meta-analysis of the effect sizes of 138 facial feedback studies (Coles et al., 2019a). The researchers concluded that the combined effect sizes were relatively minimal (d = .20). However, they also indicated that the effect size varied based on the stimulus. While picture, film, and social context facial feedback studies had low effect sizes—larger facial feedback effect sizes were found for manipulated facial muscle studies (d = .32), emotional stories (d = .41), emotional audio, (d = .72), and imagined scenarios (d = 1.28). The sizeable facial feedback response for imagined scenarios is noteworthy as many people struggling with depression tend to "imagine" their problems as very dire. Cognitive Behavioral Therapy (CBT) is based on this premise and teaches patients to reframe their maladaptive interpretations of adverse life events to reduce depression (Fenn & Byrne, 2013). Without reframing, negatively biased cognitions could lead to stronger negative facial expressions and exaggerated facial feedback—resulting in painful emotional responses. This cycle from thoughts to facial expressions to emotion suggests that a neural network in involved. Facial muscles, tissues, and nerves may relay messages back to the brain for emotion amplification or reduction—depending on the facial expression.

Facial Feedback and Neural Activity

The brain is a unique and complicated organ that scientists are learning to understand through relatively new tools, such as functional magnetic resonance imaging (fMRI). Neuroscience research on facial feedback often examines amygdala responses—as the amygdala is a critical component in the brain involved with interpreting emotional stimuli and processing negative emotions such as fear, anger, and sadness. (Ledoux, 2000). Hennenlotter et al. (2008) found bilateral (left and right side) amygdala activation in fMRI images while subjects imitated angry and sad facial expressions. A significant linear correlation was also found between brow-lowering intensity and amygdala activation during angry facial expressions. In another study by Heller et al. (2014), the strength of the subjects' frowns while viewing negative pictures correlated with the amygdala activity magnitude in fMRI images. Additionally, increased amygdala and frown activity correlated with decreased ventromedial prefrontal cortex activity—

where executive, logical thinking occurs. Both studies show evidence of neural connections between facial expressions and amygdala activation. The Hennenlotter et al. study (2008) also shows that facial expressions alone can activate neural activity, as the subjects were not sad or angry but merely mimicked emotional facial expressions. These neural findings support the facial feedback hypothesis that facial muscles, tissues, and nerves are involved in normal emotional responses—and suggest they likely play a role in abnormal responses. However, the connection between facial feedback and mental health is still unclear.

Facial Feedback and Depression

So how do normal negative emotions, such as discouragement, sometimes progress to clinical levels and become depression? Some researchers have examined this question and also how to reverse depressive changes by studying the impact of botulinum toxins (BTX) treatment on emotional responses. Cosmetic BTX treatments immobilize frown muscles which, in theory, should also reduce negative-emotional facial feedback and depression. In a survey on cosmetic BTX satisfaction, 30% of patients reported improved emotional states (Sommer et al., 2003). This emotional improvement could be due to enhanced self-esteem; however, several studies followed Sommer et al.'s by examining the impact of BTX on depression. Wollmer et al.'s (2012) randomized, double-blind trial of BTX injections for depression treatment showed significant depression reduction six weeks after injection. Finzi & Rosenthal (2014) found a 50% depression reduction in a BTX-frown-line treated group compared to a 15% reduction in a saline-injection-placebo group six weeks after treatment. A study by Michael Lewis (2018) showed a significant decrease in a negative mood for those with BTX frown-line treatment, while those who were also treated for crow's feet did not experience an improved mood. Lewis suggested that "genuine" smiles—which include eyes—initiate the most significant benefit from facial feedback; therefore, crow's feet BTX, which immobilizes eye muscles, nullifies mood improvement from frown-line BTX treatment. The success of these BTX studies in reducing depression suggests that facial expressions influence negative moods. However, additional scientific research might clarify who might best benefit from BTX treatment and how it compares to other FDA-approved depression therapies.

Depression treatments vary from therapies addressing psychological causes to treatments for physiological symptoms. BTX treatments may treat both if the subjects' moods are lifted from their improved physical appearance and reduced negative facial feedback. To assess the mood improvement from BTX more thoroughly, Coles et al. (2019b) conducted another meta-analysis—this time of seven BTX depression treatment studies. They found very significant effect sizes (d = 1.28), which were much larger than the most effective antidepressants (d =.42). These findings created concern for their validity. The authors examined the studies more carefully, found errors in many study protocols, and discovered that 96% of the researchers had a conflict of interest. Additional research is needed to confirm the actual effect size of BTX treatment for depression. However, the initial success of these studies suggests the potential role facial feedback may play in abnormal emotions, such as depression. It also suggests that alterations to facial muscles and tissues could alter typical responses.

Development of Temporomandibular Disorders

Temporomandibular disorders (TMD) are a group of common orofacial conditions of the masticatory system—the muscles and tissues for eating and speaking—and are estimated to impact 5 to 15% of adults (Li & Leung, 2021), with a higher percentage represented in the female population (Namvar et al., 2021; Sójka et al., 2019; Wieckiewicz et al., 2022; Diracoglu et al., 2016). There are approximately a dozen symptom variations of TMD that include pain and dysfunction in 1) the temporalis and masseter muscles, 2) the temporomandibular joint (TMJ) and disc, or 3) both muscles and joint. These disorders are complicated, as the etiology, diagnosis, pain levels, treatments, prognosis, and actual outcomes vary significantly across TMD variations and between individuals (Li & Leung, 2021). Pain—and the impact of pain—is a central feature of TMD; however, the mechanisms are not fully understood. For instance, it is uncertain whether the functional impairment in the temporomandibular joint results from pain or is the cause of the pain (Ohrbach & Dworkin, 2019). TMD can be acute or chronic, lasting for only a few months or many years. Treatments can be conservative, minimally invasive, or surgical (Li & Leung, 2021). However, minimally invasive procedures and surgeries are not as common because conservative options are usually quite effective (Auerbach et al., 2001). One factor is understood—TMD usually results from stress (Namvar et al., 2021). Fillingim et al. (2013) suggested that TMD patients may have altered physiological functioning. Putting this together, we can assume that stress-related facial expressions may cause altered physiological functioning. These alterations may cause challenges beyond painful muscles and joints.

Temporomandibular Disorders and Facial Malfunction

Chronic painful TMD is often associated with alterations in psychosocial, neurosensory, autonomic, and physiological functions (Ohrbach & Dworkin, 2019). Al-Khotani et al. (2021) suggested that facial muscle tension in TMD is likely due to increased cortisol levels from stress. Auerbach et al. (2001) found that temporomandibular muscle hyperactivity correlated with high levels of stress-induced emotion in muscular-based-TMD patients. Cognitive therapy instructs that depressed and anxious symptoms stem from negatively biased (e.g., discouraged, worried, or catastrophic) thinking (Fenn & Byrne, 2013). These negatively biased cognitions would also instigate correlating facial reactions—perhaps including frequent or intense facial expressions.

Kindler et al. (2012) suggested that depression and anxiety symptoms could result in hyperactive musculature in the temporalis or masseter muscles, which might alter their normal mechanisms. Unfortunately, altered facial muscle activity may become enduring once TMD has developed.

Patients with TMD may have specific facial-muscular alterations and malfunctions. Studies using electromyography (EMG) to measure facial muscle activity have found altered temporalis and masseter muscle recruitment in TMD subjects (compared to people without TMD) during clenching and gum chewing (Tartaglia et al., 2011; Di Giacomo et al., 2020). Some facial-muscular alterations may influence emotional states. Stocka et al. (2018) found that subjects' increased masseter muscle activity while clenching correlated with increased depression scores. This correlation is noteworthy, as facial-muscle alterations may be the basis of depression and anxiety symptoms often associated with TMD. Specific facial-muscular alterations may impact mood and instigate emotional dysfunction.

Temporomandibular Disorders and Mental Health

TMD is frequently associated with mental health challenges. Li & Leung (2021) noted that TMJ and muscular TMD patients experience significantly higher levels of depression and somatization than non-TMD patients. Wieckiewicz et al. (2022) assessed the relationship between pain intensity, disability, depression, anxiety, and stress in TMD patients using self-report questionnaires and found significant scores for each domain. Depression was twice as likely in patients with muscular TMD than without TMD. Several other studies found that depression levels in TMD patients ranged from 39% - 62% (Yap et al., 2003; Plesh et al., 2005; Reißmann et al., 2008; Manfredini et al., 2011). A review of 22 TMD and mental health studies by Florjański and Orzeszek (2021) found significant differences between TMD patients and those without TMD in levels of depression. In addition, differences were found between TMD categories. Chronic TMD patients experienced significantly higher depression rates than acute TMD patients, and patients with painful TMD experienced higher depression and anxiety rates than patients with non-painful TMD. Auerbach et al. (2001) found significantly higher depression scores in muscular based TMD than in TMJ disorder patients. The high comorbidity of TMD and mental health challenges may indicate a critical connection between them. Assessing risk factors for TMD and comorbid mental health disorders may help those with either condition.

Life events, social support, and even gender may contribute to stress levels resulting in TMD and depression. Diracoglu et al. (2016) found the highest rates of TMD in females or people with insufficient social support. Posttraumatic Stress Disorder (PTSD) is an unfortunate challenge many war veterans experience and may have correlations with TMD; war veterans have significantly elevated rates of comorbid TMD and mental health challenges (Mottaghi et al., 2014; Fenton et al., 2018). The impact of traumatic stress may be even more difficult for females. Fenton et al. (2018) found that female veterans with TMD experience more than double the depression rates of male veterans. Students in rigorous university studies often experience elevated stress contributing to TMD and depression. Undergraduate university health science students in Brazil were randomly surveyed, and 71.9% had TMD symptoms. This study also assessed psychosocial symptoms such as insomnia, irritability, and fatigue—and found a moderate correlation (r = 0.46) between TMD and psychosocial symptoms (Augusto et al., 2016). A study by Sójka et al. (2019) discovered that 33% of Polish medical students experienced TMD symptoms and felt more physical symptoms of distress, anxiety, and depression than students without TMD symptoms. Namvar et al. (2021) found that 40% of Iranian dental students with TMD were depressed—compared to 23.33% without TMD. Stress appears to be a key player in developing TMD and mental health disorders. However, these results may or may not be localized to specific countries and cultures.

Higher rates of TMD and depression are not universal in all student populations. A Swedish study of dental students with TMD did not find significant differences in depression rates between those with and without TMD (Lövgren et al., 2018). However, the various student studies examining TMD and mental health were not identical. All three examined medical and dental student studies used different mental health assessments and were located in different countries. The assessments may have different sensitivities, and the various universities may have different educational rigor, medical care, and mental health support. In addition, the subjects in the Swedish study were third-year dental students with a good understanding of TMD diagnosis and treatment. The Swedish students with TMD may have previously been self-diagnosed, which could alter study outcomes. Future research should determine the differences between diagnosed-TMD medical students with and without depression. The findings may prove helpful in improving the mental health of stressed students and others at risk.

Children and adolescents often experience significant stress and complex life events and can develop TMD and mental health disorders. Restrepo et al. (2021) evaluated the association between depression, anxiety, and somatization and the incidence of TMD in randomly selected Columbian adolescent students and found that 40% had TMD. Of those, 54.42% also had depression, and 45.47% had anxiety. Another study found TMD with pain in 41% of randomly selected students 10 to 18 years of age. This group had a slightly higher rate (1.4x) of Anxiety/Depression than those without TMD pain. However, adolescents in this study aged 14 to 18 years with TMD pain had approximately three times the rate of Anxiety/Depression compared to others their age without TMD pain (Al-Khotani et al., 2021). Interestingly, the youth diagnosed with TMD in both these studies were randomly selected and did not volunteer because of symptoms. The high incidence of TMD diagnosis in randomly selected subjects—many with comorbid mental health challenges—suggests that many people with these disorders may go undiagnosed. In addition, none of the studies that found comorbid disorders indicated which occurred first.

TMD and mental health challenges may be bidirectional. Depression is frequently identified as a risk factor for TMD, yet at other times it is thought to be the consequence of TMD pain. For instance, Auerbach et al. (2001) found that psychological factors play a critical role in the development of muscular TMD—and that muscular TMD patients had higher depression, stress, and pain disability than TMJ patients. A five-year study by Kindler et al. (2012) found that depressed subjects were more than twice as likely as non-depressed people to develop TMJ pain. An evaluation of 18 years of data in the national patient registry (NPR) in Sweden by Fredricson et al. (2022) found that approximately 21% of patients diagnosed with TMD had previously been diagnosed with depression. Ohrbach and Dworkin (2019) state that chronic pain from TMD may instigate psychological challenges, including depression, anxiety, and fear avoidance. However, they also mention that risk factors for TMD include psychological influences such as depression, stress reactivity, pain catastrophizing, and personality disorders. It appears that TMD or depression could occur first and instigate the other. It is also possible that they can become cyclical—each sustaining the other. Successful treatments for co-morbid disorders need to address both physical and psychological symptoms.

Psychological Treatment for TMD

Mental health treatment for TMD patients may not only reduce depression but can also be beneficial for healing TMD itself. Li and Leung (2021) recognized psychological counseling and therapy as effective conservative treatments for TMD. Auerbach et al. (2001) stated that biofeedback and stress management are helpful TMD treatments. A study by Turk et al. (1996) showed that adding cognitive therapy to other traditional conservative TMD treatments (e.g., anti-inflammatory drugs, antidepressants, and occlusal appliances) significantly reduced pain, depression, and medication use compared to traditional conservative treatment alone. As mentioned previously, cognitive therapy helps patients reassess their negative reactions to stress and life adversities, reducing stress and depression. It is important to note that more positive thoughts will also result in more relaxed and positive facial expressions. Therefore, bidirectional treatment of TMD and comorbid depression may result in the bidirectional healing of both disorders—the best outcome.

Integration of Overall Findings

Exaggerated facial feedback from altered facial muscles and connective tissue due to TMD may be a "missing link" in understanding the pathophysiology of depression—connecting psychological challenges to abnormal and enduring physiological responses. Mental health challenges may begin when stressful life events initiate negatively-biased cognitions (Fenn & Byrne, 2013), also triggering stressful facial expressions. Multiple studies show that facial expressions initiate or intensify emotions (Strack et al., 1988; Soussignan, 2002; Larsen et al., 2003; Lewis, 2012). We have seen that neural processes of sad and angry facial expressions, even without emotional stimuli, activate the amygdala—where negative emotions are processed (Hennenlotter et al., 2008; LeDoux, 2000). The strength of facial expressions seems to make a difference in emotional outcomes, as it correlates with cortisol levels and cardiovascular responses (Lerner, 2007; Kraft & Pressman, 2012; Pressman et al., 2021) as well as the magnitude of amygdala activation (Heller et al., 2014). Researchers indicate that TMD facial injuries could alter normal autonomic responses through hyperactivity in the temporalis and masseter muscles and joints (Auerbach et al., 2001), which would then exaggerate facial feedback and increase emotional responses. Stress-induced TMD alterations could occur during prolonged or intense psychological distress (Namvar, 2021), such as during university studies or during battle. They might also occur from trauma, childhood neglect, or abuse—known risk factors for depression (Lippard & Nemeroff, 2020). Many people with TMD and depression may likely go undiagnosed, as randomly selected subjects were diagnosed with both conditions (Restrepo et al., 2021; Al-Khotani et al., 2021). TMD and mental health disorders are frequently comorbid and likely bidirectional. The adverse effects of either could initiate the other, making them cyclical. Understanding the connection between TMD and depression may help in healing both disorders. The early success of BTX treatment for depression suggests that facial feedback contributes to depression—and immobilizing facial muscles may assist in recovery. Psychological treatments have proven effective in treating TMD (Turk et al., 1996; Auerbach, 2001; Li & Leung, 2021). Correspondingly, diagnosing and treating TMD in depressed patients may also speed recovery from depression. However, no studies have yet confirmed this assumption.

There are several limitations to this literature review on TMD and depression. No studies assessed the bidirectionality of TMD and mental health disorders. In addition, none of the examined studies discussed any involvement between TMD and facial feedback. There have been limited facial feedback studies in the last few decades, and the only mental health studies regarding facial feedback have focused on BTX as a depression treatment. Other limitations include studies that did not support facial feedback or correlations between TMD and mental health disorders, such as Wagenmaker et al.'s (2016) failed facial feedback trials and Lövgren et al.'s (2018) study without elevated depression in TMD patients. Noah et al. (2018) determined that filming participants altered Wagenmaker et al.'s outcomes, although Soussignan's (2002) study also filmed participants and still found the facial feedback effect. Why some trials did not show the facial feedback effect or correlations between TMD and mental health disorders is unknown. A careful examination of the studies' methodology or additional studies may explain the differences.

Future studies should examine correlations between facial feedback, neural processes, mental health, and the involvement of TMD. Even without the exaggerated effects of TMD, facial feedback deserves renewed attention from researchers, as it may contribute to non-clinical psychological disturbances—which may progress to clinical depression. Studies could examine the emotional influence of facial expressions during arguments, frustrating tasks, or grief recovery. The therapeutic effects of relaxing facial muscles or facial movement during positive emotions—such as excitement, determination, and courage—should also be examined. Replicating previous facial feedback studies with an added TMD group would be instructive. Data studies could assess the question of bidirectionality and if there is a typical developmental order to TMD and depression. Other studies could examine how cognitions affect the temporalis and masseter muscles and joints. Comparing facial muscle activity with EMG and neural responses with fMRI in TMD and control subjects during cognitive tasks could also be enlightening. Additional depression treatment research should include TMD therapies and clarify BTX effectiveness. These various studies could provide a wealth of information about facial feedback's and TMD's influence on mental health, which could be a turning point in understanding the pathophysiology of depression.

Conclusion

Understanding the correlations between TMD and mental health may help in the development of effective therapies and improve treatment outcomes for both disorders. The cognitive model of mental illness suggests that depression results from negatively-biased psychological reactions to life events (Fenn & Byrne, 2013); however, the strength and enduring properties of the somatic symptoms suggest that physiological alterations contribute to depression development. Based on multiple studies confirming the impact of facial expressions on mood, autonomic responses, and neural activity, as well as studies revealing the frequent mental health challenges of TMD patients, it is likely that malfunctions in the facial feedback system from TMD contribute to mental health challenges, such as depression. Future research should clarify this connection, investigate specific TMD injuries and correlated mental health disorders, and determine the most effective physiological and psychological treatments for each.

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