Intervertebral Disc Degeneration: Functional Analysis of Bite Force and Masseter and Temporal Muscles Thickness

Nicole Barbosa Bettiol[1], Simone Cecilio Hallak Regalo[1,2], Flávia Argentato Cecilio[1], Ligia Maria Napolitano Gonçalves[1], Paulo Batista de Vasconcelos[1], Claire Genoveze Gauch Lopes[1], Lilian Mendes Andrade[1], Isabela Hallak Regalo[1], Selma Siéssere[1,2], Marcelo Palinkas[1,2]

[1]Department of Basic and Oral Biology, School of Dentistry of Ribeirão Preto, University of São Paulo, São Paulo, Brazil;
[2]Department of Neuroscience and Behavioral Sciences, Faculty of Medicine of Ribeirão Preto, University of São Paulo; National Institute and Technology – Translational Medicine (INCT.TM), São Paulo, Brazil

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Abstract: Intervertebral disc degeneration is a pathological condition associated with the intervertebral disc and is related to functional alterations in the human body. This study aimed to evaluate the maximum molar bite force and masseter and temporal muscles thickness in individuals with intervertebral disc degeneration. Thirty-two individuals were divided into two groups: those with degeneration of intervertebral discs (n=16) and those without degeneration (n=16). The maximum molar bite force (on the right and left sides) was measured using a dynamometer. Masseter and temporal muscle thickness during mandibular task rest and dental clenching in maximum voluntary contraction were analysed using ultrasound. Significant differences in the left molar bite force ($p=0.04$) were observed between the groups (Student's *t*-test, $p<0.05$). The intervertebral disc degeneration group

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Mailing Address: Prof. Marcelo Palinkas, PhD., School of Dentistry of Ribeirão Preto, University of São Paulo, Avenida do Café s/n, Bairro Monte Alegre CEP 14040-904, Ribeirão Preto, São Paulo, Brazil; e-mail: palinkas@usp.br

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had a lower maximum molar bite force. No significant differences in muscle thickness were observed between the masseter and temporal muscles in either group. However, based on clinical observations, the group with intervertebral disc degeneration presented less masseter muscle thickness and greater temporal muscle thickness in both mandibular tasks. Degenerative disease of the intervertebral discs promoted morphofunctional changes in the stomatognathic system, especially in maximum molar bite force and masticatory muscle thickness. This study provides insight into the interaction between spinal pathology and the stomatognathic system, which is important for healthcare professionals who treat patients with functional degeneration.

Introduction

Intervertebral discs are anatomical structures that form part of the vertebral column and are composed of the fibrous ring, nucleus pulposus, and cartilaginous end plates. They are indispensable in the union of adjacent vertebrae that allow flexion, extension, and rotation movements, without sacrificing a large amount of force, thus providing shock absorption within the spine (Prescher, 1998; Zvicer and Obradovic, 2018).

With aging, the spine, regardless of the region (cervical, thoracic, lumbar, or sacral), may face functional changes resulting from degeneration of the intervertebral discs, promoting postural imbalance with painful symptoms (Truszczyńska et al., 2016; Ji et al., 2020).

Degenerative disease of the intervertebral discs, considered progressive and chronic, is characterized by dehydration of the discs and alterations in the load distribution in the spine, promoting structural degradation of the healthy matrix that promotes the appearance of muscle dysfunction (Rustenburg et al., 2019; Cannata et al., 2020).

The etiopathogenesis is multifactorial and is mainly associated with genetic factors, smoking, aging, sedentary lifestyle, and obesity (Russo et al., 2017), affecting about 60 to 85% of adults at some stage of life, making them disabled with a negative impact on the quality of life, with great socioeconomic impact on the population (Cheung and Luk, 2019), and represents an important cause of morbidity and mortality in daily clinical practice (Kos et al., 2019).

Intervertebral disc degeneration is one of the main factors contributing to painful symptoms in the neck and back and is characterized by increased levels of pro-inflammatory cytokines secreted by intervertebral disc cells that promote extracellular matrix degradation, chemokine production, and changes in cell phenotype (Risbud and Shapiro, 2014; Abdollahzade et al., 2018).

When considering the degeneration of intervertebral discs, it is important to emphasize that the spine works as a single unit and its functional imbalance can provide compensatory changes in other levels of the spine itself or in other areas of the skeletal muscle system, demonstrating that the human organism is considered

a functional anatomical set, and any musculoskeletal impairment can affect other systems, such as the stomatognathic system (Spadaro et al., 2014).

Thus, the orofacial or adjacent dynamic structures of the stomatognathic system have become an important tool for functional assessment that can explain the relationship that exists between the systems of the human body when it is affected by chronic degenerative diseases (Donizetti Verri et al., 2019).

Therefore, the aim of this study was to evaluate the maximum molar bite force and masseter and temporal muscle thicknesses in individuals with intervertebral disc degeneration. The null hypothesis of this study was that the group with degeneration of the intervertebral discs would not present changes in relation to the maximum molar bite force and masseter and temporal muscle thickness when compared to the group without degenerative disease. This study presents two alternative hypotheses: 1) the group with degeneration of the intervertebral discs has a lower maximum molar bite force, and 2) a lower thickness of the masseter and temporal muscles compared to the group without degenerative disease.

Material and Methods

Study design and sample

This comparative cross-sectional observational study analysed the maximum molar bite force and masseter and temporal muscle thickness in subjects with and without intervertebral disc degeneration. Data for this study were collected at the Laboratory of Electromyography of the Department of Basic and Oral Biology, Faculty of Dentistry of Ribeirão Preto, University of São Paulo (FORP/USP). All subjects were informed about the purpose and stages of the research and signed a free and informed consent form approved by the FORP/USP ethics committee (process # 29014620.1.0000.5419).

G* Power 3.1.9.2 software (Franz Faul, Kiel University, Kiel, Germany) was used to calculate the sample size (a priori) considering $\alpha = 0.05$, effect size of 1.71, and power of 96% for the main result of the maximum left molar bite force by the pilot project of this study with five subjects. The minimum sample size obtained was n=16 for each group.

From a total of 80 evaluated subjects aged between 20 and 59 years, normal occlusion (Angle Class I), presence of all teeth (except third molars), absence of temporomandibular dysfunction (Research Diagnostic Criteria for Temporomandibular Disorders), and following the inclusion and exclusion criteria, 16 subjects (8 women and 8 men) were selected to compose the group with intervertebral disc degeneration (GI) with a mean age ± standard deviation of 37.0 ± 8.3 years.

The diagnosis of intervertebral disc degeneration was confirmed by specialist physicians with the issuance of reports, clinical examinations, and images. The subjects in the group with degenerative intervertebral disc disease had vertebral dysfunction and instability.

Table 1 – Differences in characteristics (mean ± standard deviation) between the group with intervertebral disc degeneration (GI) and the control group (GII)

Groups	Age	Body mass index
GI	37.0 ± 8.3	25.9 ± 3.4
GII	37.1 ± 8.6	25.6 ± 4.3
P-value	0.96	0.83

significant difference, Student's *t*-test (i.e. $p<0.05$)

The control group consisted of 16 subjects without intervertebral disc degeneration (8 women and 8 men) (GII) with a mean age ± standard deviation of 37.1 ± 8.6 years. The groups were individually matched for sex, age, and body mass index (Table 1).

Subjects who presented with neurological and systemic pathologies, use of full or removable dentures, mental or physical discomfort during the assessments, congenital anomalies, previous spinal surgery, evidence of tumours on imaging examinations, spinal infection, fracture, and/or spinal deformities were considered ineligible. The participants in this study were selected from November 2019 to October 2021.

In this study, the analytical procedures were performed by a single researcher. Personal protective equipment was used in each examination: procedure gloves, laboratory coat, face shield, mask, and cap. Inter-examiner reliability was calculated using the intraclass coefficient (ICC). Reliability was considered acceptable for maximum molar bite force (ICC = 0.92) and muscle thickness (ICC = 0.99).

Bite force analysis

The recordings of the maximum right and left molar bite forces were performed with a digital dynamometer (Kratos, model IDDK, Equipamentos Industriais Ltda., Cotia, São Paulo, Brazil) adapted to the oral condition. The equipment consisted of two rods with Teflon discs at the ends on which the maximum bite force was captured.

The recorded molar bite force was displayed on the digital screen of the device in Newton (N). The molar bite force was measured with the subject seated in a comfortable chair, with the palms of the hands resting on the thighs. After each recording, the latex fingertips (Wariper-São Paulo, Brazil) were changed, and the device was cleaned with 70% alcohol. A biosafety protocol was applied for each protocol.

The subjects performed the tests by biting the equipment before the official collection of the bite force data to ensure the reliability of the procedure. Measurements were performed in the region of the right and left first permanent molars (Palinkas et al., 2010; Alam and Alfawzan, 2020). The subjects were asked

to bite the rods three times, with maximum effort, resting for 2 min between each recording and changing the right and left sides to avoid any influence of muscle fatigue (Bonjardim et al., 2009). The maximum molar bite force corresponding to the evaluated side was used as data.

Masseter and temporal muscles thickness analysis

Ultrasonographic images of the masseter and temporal muscles were obtained at rest and during dental clenching in maximal voluntary contraction while the subjects were sitting upright with their heads naturally positioned, using a portable ultrasound device (NanoMaxx; SonoSite Inc., Bothell, WA, USA) with a 13-MHz linear transducer (Bertram et al., 2003).

The location where the examination was performed was silent, with limited light for better visualization and capture of ultrasound images. Orientation was given to individuals participating in the study to remain calm during data collection. The location of the masticatory muscles was revealed by the application of digital palpation force (Palinkas et al., 2010; Gomes et al., 2022).

The linear transducer was coated with colourless conductive ultrasound gel to eliminate air between the device and the surface of the integumentary tissue, which could interfere with the capture of the ultrasound image. Considering that the belly of the masseter muscle is located approximately 2.75 cm above the mandibular angle, towards the upper eyelid and the anterior portion of the temporalis muscle, approximately 1.25 cm behind and above the external angle of the eye, the transducer was positioned transversely to the direction of the muscle fibres (da Silva et al., 2017).

Three ultrasound images were obtained from the masseter and temporal muscles during the mandibular tasks, with an interval of 2 min between each image (Righetti et al., 2020). In view of the three measurements obtained, the means were calculated, and the values obtained, in centimetres, and were used in the study.

Method error

To ensure the reliability of the results, Dahlberg's formula (Houston, 1983) was used. The bite force and muscle thickness were calculated using the records of five subjects and obtained during two different periods, with a period of 7 days. Small differences were observed in measurements between the first and second sessions for molar bite force, with the average of the three bites computed for the right and left sides (6.68%) and muscle thickness (5.22%).

Statistical analysis

Data were analysed using IBM SPSS 26.0 statistical software (IBM SPSS Inc., Chicago, IL, USA). The Shapiro-Wilk test was used to demonstrate whether the variables maximal molar bite force and masseter and temporal muscles thickness at rest, and dental clenching in maximal voluntary contraction were normally distributed. As the

data showed a normal distribution, Student's *t*-test was applied to verify differences between variables. Statistical significance was set at $p<0.05$.

Results

The maximum bite force and masseter and temporal muscle thickness of the two groups are shown in Table 2. Significant differences were observed in the maximum left molar force ($p=0.04$). The GI group had a lower maximum molar bite force. No significant differences in muscle thickness were observed in the masseter and temporal muscles between the groups during the jaw and jaw tasks. However, from clinical observations, the GI presented less thickness for the masseter muscles and greater thickness for the temporal muscles in both mandibular tasks.

Discussion

The null hypothesis of this study was rejected because there were significant differences between groups for maximum molar bite force, demonstrating the relationship between degeneration of anatomical structures and functionality of the human body systems.

One of our alternative hypotheses was that the group with degeneration of the intervertebral discs would have a lower bite force. This hypothesis was based on research demonstrating that degenerative diseases of the intervertebral discs release circulating inflammatory mediators, such as interleukin-6, which is associated with symptomatic disorders and is considered a harbinger of sarcopenia and

Table 2 – Differences in mean values (± standard deviations) of variables between groups

Variables	GI	GII	P-value
Bite force (N)			
Right	321.56 ± 108.75	396.38 ± 148.27	0.11
Left	337.15 ± 102.18	420.70 ± 125.91	0.04
Muscle thickness (cm)			
Rest			
RM	0.89 ± 0.18	0.90 ± 0.09	0.75
LM	0.87 ± 0.15	0.90 ± 0.16	0.59
RT	0.56 ± 0.17	0.53 ± 0.20	0.71
LT	0.58 ± 0.19	0.57 ± 0.20	0.86
MVC			
RM	1.22 ± 0.15	1.30 ± 0.20	0.18
LM	1.29 ± 0.25	1.31 ± 0.22	0.79
RT	0.67 ± 0.19	0.64 ± 0.18	0.64
LT	0.68 ± 0.19	0.66 ± 0.19	0.68

GI – degeneration of intervertebral discs; GII – control; RM – right masseter; LM – left masseter; RT – right temporalis; LT – left temporalis; MVC – maximum voluntary contraction; significant difference, Student's *t*-test (i.e. $p<0.05$)

changes in the functional capacity of skeletal striated musculature (Lin et al., 2021; Mehta et al., 2021). These factors can reduce muscle tissue and strength because of interleukin-6-induced atrophy in myotubes (Teixeira et al., 2021). Therefore, the first hypothesis of this study was accepted because GI showed a decrease in the maximum molar bite force with a significant difference on the left side compared to GII.

Continuous inflammation that affects anatomical structures, such as the intervertebral discs, resulting from an inadequate reaction against self-molecules, releases cytokines that transmit stimulating, modulating, and inhibitory signals to cells of the immune system (Podichetty, 2007). Activation of innate or adaptive immunity associated with degeneration episodes can provide inadequate repair responses that accompany disease progression and, consequently, can cause functional alterations in integrated systems (Waisman et al., 2015; Tezel, 2022). Circulating cytokines produced by macrophages, T cells, and monocytes interact with specific receptors on various types of cells and stimulate JAK-STAT signalling pathways that promote an inflammatory response involving cell adhesion, permeability, and apoptosis (Wang et al., 2012).

The inflammatory process is associated with increased plasma levels of cytokines, which damage the human body, and their release into the bloodstream contributes to the maintenance of inflammation, often promoting an increase in muscle fibrosis that causes fatigue and tissue changes, such as loss of muscle mass (Zhang et al., 2021). Several clinical conditions that circumvent signal propagation inside the cell can lead to apoptosis and reduced activation of satellite cells responsible for muscle regeneration, leading to the loss of muscle tissue (Ni and Yang, 2022).

These physiological conditions could explain the decrease in maximum molar bite force in the GI. In this study, circulating levels of cytokines in the human body were not quantified, and masticatory muscle fatigue was not measured.

Another important factor that may have influenced the lower molar bite force in the GI tract was the aging process that affects the spine, resulting from dehydration of the intervertebral discs, in which the ability to act as shock absorbers between the vertebrae is lost (Vital et al., 2021). The spine can undergo degenerative changes and morphological changes over the years (Prescher, 1998).

An understanding of the postural mechanism, which is expressed in countless positions, is obtained when the idea of the human body as a single functional unit, in which the ligaments and muscles act on the joints, promotes muscle tensions that they exert with equal power in both extremes of the muscle fibres, to produce momentary immobility of the body over the years (Tecco et al., 2007; Donizetti Verri et al., 2019).

When degenerative processes affect spinal structures, they can cause instability and consequently affect the stomatognathic system (Kielnar et al., 2021). The inappropriate position of the head, for example, due to degenerative diseases of the spine modifies the craniocervical and craniomandibular biomechanical relationships,

which can compromise the position of the mandible, modifying, for example, the occlusion with a direct impact on muscle strength (Lee et al., 2021). This may explain the lower molar bite force in the GI group. Postural assessments were not performed in this study.

Our second alternative hypothesis was that the GI presented smaller masseter and temporal muscle thickness during the analysis of mandibular tasks. This hypothesis is based on the aging of the human body, which includes adverse situations promoting organic dysfunction, such as mitochondrial dysfunction (Vergroesen et al., 2015), which triggers changes in the mitochondrial proteolytic system, dynamics, and mitophagy that induce the production of pathways that affect muscle tissue and functional performance (Romanello and Sandri, 2021).

The second hypothesis of this study was rejected because there were no significant differences between groups in the evaluation of masticatory muscle thickness during mandibular rest tasks and dental clenching during maximum voluntary contraction. These results corroborate the scientific finding that there were no significant differences between the groups with chronic degenerative disease and controls when comparing the masseter and temporal muscle thickness (Righetti et al., 2020).

However, in clinical observations, it was noted that GI had a smaller thickness for the masseter muscles and greater thickness for the temporal muscles in both mandibular tasks when compared to the control group. Degenerative diseases of the intervertebral discs may be related to changes in the composition of striated skeletal muscle tissue as a result of aging and physiological processes that affect the systems of the human body (Borisov and Carlson, 2000).

The masseter muscle is a dynamic anatomical structure that comprises the masticatory muscles, elevating the mandible against the maxilla and exerting masticatory force (Almukhtar and Fabi, 2019). As mentioned before, hypotheses would explain the smaller thickness of the masseter muscles of subjects with intervertebral disc degeneration when the activation of innate or adaptive immunity and the release of inflammatory mediators in the bloodstream are observed, producing morphological consequences (Waisman et al., 2015).

Another situation could explain the smaller thickness of the masseter muscles in the group with degeneration of intervertebral discs. We have to surmise that the systems interact with each other, and any functional modification can affect adjacent anatomical structures (Sun et al., 2021). Studies have reported that subjects who develop intervertebral disc degeneration can develop mitochondrial dysfunction that leads to cell energy failure, increased oxidative stress, and apoptosis, impacting homeostasis (Saberi et al., 2021).

Oxidative stress contributes to muscle atrophy, increasing proteolysis and/or depressing protein synthesis (Shcherbik and Pestov, 2019). This could justify the smaller masseter muscle thickness in the group with intervertebral disc degeneration. The degree of oxidative stress was not measured (Powers et al., 2012).

We could also explain the clinically obtained results in relation to masseter muscle thickness in the group with intervertebral disc degeneration through the increase in apoptosis, mainly of the myonuclei, due to the inflammatory process during the development of degenerative diseases that contribute to the decrease in muscle tissue (Sudo and Kano, 2009).

Clinical evaluation of the temporal muscle thickness during mandibular rest tasks and dental clenching in maximum voluntary contraction showed greater thickness in GI than in GII. How can we explain this morphological pattern in the temporal muscles of the GI tract?

The analysis of the striated skeletal muscle tissue is an essential factor in the functional understanding of many diseases related to organic systems (Donizetti Verri et al., 2019; Katsuki et al., 2021) and observing the temporal muscle thickness can show the relationship with morphology, occlusion, and disorders of the temporomandibular joint, being a fundamental factor in the study of the stomatognathic system (Blicharz et al., 2021).

There is a hypothesis that could explain the reason for the greater thickness of the temporal muscles, assuming that neuronal control during movements of muscle groups is jointly controlled by the nervous system as a synergistic functional entity, where functional and morphological patterns are balanced to perform similar functions (Desrochers et al., 2019).

When a muscle is affected by morphological changes resulting from the degeneration of the human body, the synergistic muscle can be influenced by its function, promoting muscle hypertrophy resulting from the time of tension it is subjected to maintain its function (Joanisse et al., 2020). This can be used to interpret the greatest temporal muscle thickness.

This study had some limitations. One of the limitations was conducting this research during the coronavirus disease 2019 pandemic caused by the novel coronavirus (SARS-CoV-2), which rendered participation in this study difficult. Another limitation is failure in quantifying the circulating levels of cytokines in the human body, which could explain the reduction in muscle tissue and strength, as well as failure to measure the muscle fatigue process and the degree of oxidative stress that could justify the loss of muscle tissue.

Conclusion

The results of this study suggest that degenerative disease of the intervertebral discs alters the morphofunctionality of the stomatognathic system, with an emphasis on the lower maximum molar bite force, especially on the left side. Although the masseter and temporal muscle thickness did not differ significantly, there is clinical evidence that the degenerative disease can modify the morphology of the masseter and temporal muscles. This research allows us to guide new lines of scientific research on the stomatognathic system of subjects with degenerative intervertebral disc disease related to our hypotheses, which would explain the results of this study

and produce relevant information for health science. Therefore, future studies are needed to interpret the findings of this study, which show that there is still a gap between dentistry and medicine, considering the pathology that affects the spine and the dynamic structures of the stomatognathic system.

References

Abdollahzade, S., Hanaei, S., Sadr, M., Mirbolouk, M. H., Fattahi, E., Rezaei, N., Khoshnevisan, A. (2018) Significant association of TNF-α, but not other pro-inflammatory cytokines, single nucleotide polymorphisms with intervertebral disc degeneration in Iranian population. *Clin. Neurol. Neurosurg*. **173**, 77–83.

Alam, M. K., Alfawzan, A. A. (2020) Maximum voluntary molar bite force in subjects with malocclusion: multifactor analysis. *J. Int. Med. Res*. **48**, 300060520962943.

Almukhtar, R. M., Fabi, S. G. (2019) The masseter muscle and its role in facial contouring, aging, and quality of life: a literature review. *Plast. Reconstr. Surg*. **143**, 39e–48e.

Bertram, S., Brandlmaier, I., Rudisch, A., Bodner, G., Emshoff, R. (2003) Cross-sectional characteristics of the masseter muscle: An ultrasonographic study. *Int. J. Oral Maxillofac. Surg*. **32**, 64–68.

Blicharz, G., Rymarczyk, M., Rogulski, M., Linek, P. (2021) Methods of masseter and temporal muscle thickness and elasticity measurements by ultrasound imaging: a literature review. *Curr. Med. Imaging* **17**, 707–713.

Bonjardim, L. R., Lopes-Filho, R. J., Amado, G., Albuquerque, R. L. Jr., Goncalves, S. R. (2009) Association between symptoms of temporomandibular disorders and gender, morphological occlusion, and psychological factors in a group of university students. *Indian J. Dent. Res*. **20**, 190–194.

Borisov, A. B., Carlson, B. M. (2000) Cell death in denervated skeletal muscle is distinct from classical apoptosis. *Anat. Rec*. **258**, 305–318.

Cannata, F., Vadalà, G., Ambrosio, L., Fallucca, S., Napoli, N., Papalia, R., Pozzilli, P., Denaro, V. (2020) Intervertebral disc degeneration: A focus on obesity and type 2 diabetes. *Diabetes Metab. Res. Rev*. **36**, e3224.

Cheung, J. P. Y., Luk, K. D. K. (2019) The relevance of high-intensity zones in degenerative disc disease. *Int. Orthop*. **43**, 861–867.

da Silva, J. M., Pires, C. P. A. B., Rodrigues, L. A. M., Palinkas, M., de Luca Canto, G., de Vasconcelos, P. B., Rancan, S. V., Semprini, M., Siéssere, S., Regalo, S. C. H. (2017) Influence of mandibular tori on stomatognathic system function. *Cranio* **35**, 30–37.

Desrochers, E., Harnie, J., Doelman, A., Hurteau, M. F., Frigon, A. (2019) Spinal control of muscle synergies for adult mammalian locomotion. *J. Physiol*. **597**, 333–350.

Donizetti Verri, E., da Silva, G. P., Marianetti Fioco, E., Soares da Silva, N., Valin Fabrin, S. C., Augusto Bueno Zanella, C., Roberta Garrefa, C., Faria Júnior, M., Siéssere, S., Hallak, J. E. C., Palinkas, M., Chaves, T. C., Regalo, S. C. H. (2019) Effects of Parkinson's disease on molar bite force, electromyographic activity and muscle thickness of the masseter, temporal and sternocleidomastoid muscles: a case-control study. *J. Oral Rehabil*. **46**, 912–919.

Gomes, G. G. C., Palinkas, M., da Silva, G. P., Gonçalves, C. R., Lopes, R. F. T., Verri, E. D., Fabrin, S. C. V., Fioco, E. M., Siéssere, S., Regalo, S. C. H. (2022) Bite force, thickness, and thermographic patterns of masticatory muscles post-hemorrhagic stroke. *J. Stroke Cerebrovasc. Dis*. **31**, 106173.

Houston, W. J. (1983) The analysis of errors in orthodontic measurements. *Am. J. Orthod*. **83**, 382–390.

Ji, Z. S., Yang, H., Yang, Y. H., Li, S. J., Luo, J. X., Zhang, G. W., Lin, H. S. (2020) Analysis of clinical effect and radiographic outcomes of Isobar TTL system for two-segment lumbar degenerative disease: a retrospective study. *BMC Surg*. **20**, 15.

Joanisse, S., Lim, C., McKendry, J., Mcleod, J. C., Stokes, T., Phillips, S. M. (2020) Recent advances in understanding resistance exercise training-induced skeletal muscle hypertrophy in humans. *F1000Res.* **9**, F1000 Faculty Rev-141.

Katsuki, M., Kakizawa, Y., Nishikawa, A., Yamamoto, Y., Uchiyama, T. (2021) Temporal muscle thickness and area are an independent prognostic factors in patients aged 75 or younger with aneurysmal subarachnoid hemorrhage treated by clipping. *Surg. Neurol. Int.* **12**, 151.

Kielnar, R., Mika, A., Bylina, D., Sołtan, J., Stolarczyk, A., Pruszczyński, B., Racheniuk, H., Szczegielniak, J., Królikowka, A., Oleksy, Ł. (2021) The influence of cervical spine rehabilitation on bioelectrical activity (sEMG) of cervical and masticatory system muscles. *PLoS One* **16**, e0250746.

Kos, N., Gradisnik, L., Velnar, T. (2019) A brief review of the degenerative intervertebral disc disease. *Med. Arch*. **73**, 421–424.

Lee, H. J., Jeon, D. G., Park, J. H. (2021) Correlation between kinematic sagittal parameters of the cervical lordosis or head posture and disc degeneration in patients with posterior neck pain. *Open Med. (Wars.)* **16**, 161–168.

Lin, B., Bai, L., Wang, S., Lin, H. (2021) The association of systemic interleukin 6 and interleukin 10 levels with sarcopenia in elderly patients with chronic obstructive pulmonary disease. *Int. J. Gen. Med*. **14**, 5893–5902.

Mehta, M., Louissaint, J., Parikh, N. S., Long, M. T., Tapper, E. B. (2021) Cognitive function, sarcopenia, and inflammation are strongly associated with frailty: A Framingham cohort study. *Am. J. Med*. **134**, 1530–1538.

Ni, J. H., Yang, W. X. (2022) Extracellular and intracellular skeletons: How do they involve in apoptosis. *DNA Cell Biol*. **41**, 80–90.

Palinkas, M., Nassar, M. S., Cecílio, F. A., Siéssere, S., Semprini, M., Machado-de-Sousa, J. P., Hallak, J. E., Regalo, S. C. (2010) Age and gender influence on maximal bite force and masticatory muscles thickness. *Arch. Oral Biol*. **55**, 797–802.

Podichetty, V. K. (2007) The aging spine: The role of inflammatory mediators in intervertebral disc degeneration. *Cell. Mol. Biol. (Noisy-le-grand)* **53**, 4–18.

Powers, S. K., Smuder, A. J., Judge, A. R. (2012) Oxidative stress and disuse muscle atrophy: Cause or consequence? *Curr. Opin. Clin. Nutr. Metab. Care* **15**, 240–245.

Prescher, A. (1998) Anatomy and pathology of the aging spine. *Eur. J. Radiol*. **27**, 181–195.

Righetti, M. A., Taube, O. L. S., Palinkas, M., Gonçalves, L. M. N., Esposto, D. S., de Mello, E. C., Regalo, I. H., Regalo, S. C. H., Siéssere, S. (2020) Osteoarthrosis: Analyze of the molar bite force, thickness and masticatory efficiency. *Prague Med. Rep*. **121**, 87–95.

Risbud, M. V., Shapiro, I. M. (2014) Role of cytokines in intervertebral disc degeneration: Pain and disc content. *Nat. Rev. Rheumatol*. **10**, 44–56.

Romanello, V., Sandri, M. (2021) The connection between the dynamic remodeling of the mitochondrial network and the regulation of muscle mass. *Cell. Mol. Life Sci.* **78**, 1305–1328.

Russo, V. M., Dhawan, R. T., Dharmarajah, N., Baudracco, I., Lazzarino, A. I., Casey, A. T. (2017) Hybrid bone single photon emission computed tomography imaging in evaluation of chronic low back pain: Correlation with modic changes and degenerative disc disease. *World Neurosurg*. **104**, 816–823.

Rustenburg, C. M. E., Faraj, S. S. A., Ket, J. C. F., Emanuel, K. S., Smit, T. H. (2019) Prognostic factors in the progression of intervertebral disc degeneration: Which patient should be targeted with regenerative therapies? *JOR Spine* **2**, e1063.

Saberi, M., Zhang, X., Mobasheri, A. (2021) Targeting mitochondrial dysfunction with small molecules in intervertebral disc aging and degeneration. *Geroscience* **43**, 517–537.

Shcherbik, N., Pestov, D. G. (2019) The impact of oxidative stress on ribosomes: From injury to regulation. *Cells* **8**, 1379.

Spadaro, A., Ciarrocchi, I., Masci, C., Cozzolino, V., Monaco, A. (2014) Effects of intervertebral disc disorders of low back on the mandibular kinematic: Kinesiographic study. *BMC Res. Notes* **7**, 569.

Sudo, M., Kano, Y. (2009) Myofiber apoptosis occurs in the inflammation and regeneration phase following eccentric contractions in rats. *J. Physiol. Sci.* **9**, 405–412.

Sun, K., Sun, X., Sun, J., Jiang, Y., Lin, F., Kong, F., Li, F., Zhu, J., Huan, L., Zheng, B., Wang, Y., Zou, W., Gao, L., Xu, X., Shi, J. (2021) Tissue renin-angiotensin system (tRAS) induce intervertebral disc degeneration by activating oxidative stress and inflammatory reaction. *Oxid. Med. Cell. Longev*. **2021**, 3225439.

Tecco, S., Salini, V., Teté, S., Festa, F. (2007) Effects of anterior cruciate ligament (ACL) injury on muscle activity of head, neck and trunk muscles: A cross-sectional evaluation. *Cranio* **25**, 177–185.

Teixeira, M. A., De Feudis, M., Reano, S., Raiteri, T., Scircoli, A., Zaggia, I., Ruga, S., Salvadori, L., Prodam, F., Marzullo, P., Molinari, C., Corà, D., Filigheddu, N. (2021) Cholecalciferol (vitamin D3) has a direct protective activity against interleukin 6-induced atrophy in C2C12 myotubes. *Aging (Albany NY)* **13**, 4895–4910.

Tezel, G. (2022) Molecular regulation of neuroinflammation in glaucoma: Current knowledge and the ongoing search for new treatment targets. *Prog. Retin. Eye Res*. **87**, 100998.

Truszczyńska, A., Dobrzyńska, M., Trzaskoma, Z., Drzał-Grabiec, J., Tarnowski, A. (2016) Assessment of postural stability in patients with lumbar spine chronic disc disease. *Acta Bioeng. Biomech*. **18**, 71–77.

Vergroesen, P. P., Kingma, I., Emanuel, K. S., Hoogendoorn, R. J., Welting, T. J., van Royen, B. J., van Dieën, J. H., Smit, T. H. (2015) Mechanics and biology in intervertebral disc degeneration: A vicious circle. *Osteoarthritis Cartilage* **23**, 1057–1070.

Vital, J. M., Sénégas, J., Bouloussa, H., Liguoro, D. (2021) Physiological aging spine. *Rev. Prat.* **71**, 497–508.

Waisman, A., Liblau, R. S., Becher, B. (2015) Innate and adaptive immune responses in the CNS. *Lancet Neurol*. **14**, 945–955.

Wang, X., Liu, Q., Ihsan, A., Huang, L., Dai, M., Hao, H., Cheng, G., Liu, Z., Wang, Y., Yuan, Z. (2012) JAK/STAT pathway plays a critical role in the proinflammatory gene expression and apoptosis of RAW264.7 cells induced by trichothecenes as DON and T-2 toxin. *Toxicol. Sci.* **127**, 412–424.

Zhang, W. J., Chen, S. J., Zhou, S. C., Wu, S. Z., Wang, H. (2021) Inflammasomes and fibrosis. *Front. Immunol.* **12**, 643149.

Zvicer, J., Obradovic, B. (2018) Bioreactors with hydrostatic pressures imitating physiological environments in intervertebral discs. *J. Tissue Eng. Regen. Med*. **12**, 529–545.