Original Article

Effects of the hydrolyzed collagen supplement Colnatur Sport® on endurance training and performance of runners

CARLOS ELVIRA-ARANDA[1], ROSER DE CASTELLAR-SANSÓ[2], MARÍA JOSÉ GOMIS-GOMIS[1], JAIME ENRIQUE GÓMEZ-PATERNINA[1], JOSÉ ANTONIO PÉREZ-TURPIN[1]

[1]*Research Group in Sciences of Physical Activity and Sports, University of Alicante, Spain*
[2]*Medical Director, Ordesa Laboratories, S. L., Barcelona, Spain*

ABSTRACT

The main purpose of this observational prospective pilot study was to evaluate the effects of hydrolysed collagen supplementation, in endurance training, in the performance of runners. A cohort of sixty-one subjects (women with an age = 44 ± 5 years; height = 1.65 ± 0.4 m; weight = 58.4 ± 5.2 kg; men with an age = 51 ± 3 years; height = 1.82 ± 0.2 m; weight = 74.4 ± 3.1 kg) received a collagen supplement (11 g / day) during 16 weeks. They performed a 21 kilometre endurance test (21KmET) at baseline and after 16 weeks of follow up. Squat Jump (SJ) and Counter Movement Jump (CMJ) tests were measured before and after each 21KmET and biochemical analyses and a bioimpedance were performed after each 21KmET. Subjects underwent three sport training sessions a week and a supplement intake during the follow up. Regarding the 21KmET time, there were significant differences between before and after supplementation intake ($p < .05$) and a higher pain perception was assessed with a visual analogue scale at the second 21KmET ($p < .05$). Significant improvements were observed in handgrip strength, SJ and CMJ after 16 week of supplement intake. Conclusions: A programmed endurance training improves the functionality of the runner in long-distance events and a periodic intake of hydrolysed collagen could help a better performance because it improves the conditions of muscles and joints.
Keywords: Collagen; Runners; Training; Supplement; Sport medicine; Nutrition; Health.

Cite this article as:
Elvira-Aranda, C., De Castellar-Sansó, R., Gomis-Gomis, M.J., Gómez-Paternina, J.E., & Pérez-Turpin, J.A. (2023). Effects of the hydrolyzed collagen supplement Colnatur Sport® on endurance training and performance of runners. *Journal of Human Sport and Exercise, 18*(1), 259-269. https://doi.org/10.14198/jhse.2023.181.20

Corresponding author. *Research Group in Sciences of Physical Activity and Sports, University of Alicante, Spain. https://orcid.org/0000-0002-4689-7277*
E-mail: cea.elvi@gmail.com
Submitted for publication September 16, 2021.
Accepted for publication November 19, 2021.
Published January 01, 2023 *(in press* February 02, 2022).
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi:10.14198/jhse.2023.181.20

INTRODUCTION

Sedentary behaviours are directly related to physiological and psychological problems (Lavielle-Sotomayor et al., 2014). A regular habit of physical activity is associated with decreases in overweight and obesity (Tremblay et al., 2011). Running has become a very popular physical activity that contributes to a healthy lifestyle (Janssen et al., 2020). Currently in the European Union, there are approximately 50 million participants in this sport (Janssen et al., 2017).

The benefits of the career have been extensively studied. Runners have between 45 and 70% less risk of mortality due to cardiovascular diseases (Oja et al., 2016). It seems clear that running, understood as regular exercise, represents levels of physical activity high enough to translate into lower mortality (Lavie et al., 2015). Williams (2011) observed that in people who did running training the risk of inherited obesity was reduced. The higher caloric expenditure produced in intense physical activity seems to contribute to changes in BMI, as recorded by Brown et al. (2012) when comparing this parameter between a population that walked and another that ran. The lifestyle that athletes tend to adopt, such as not smoking and consuming very little alcoholic beverages, seems to contribute to maximizing the positive effects of physical activity on health (O'Keefe et al., (2014). In addition, running has also been seen to exert positive effects on certain neurological conditions, such as Parkinson's and Alzheimer's (Chakravarty et al., 2008).

Athletes who practice endurance disciplines such as running often use supplements that help improve their athletic performance (Rasmussen et al., 2008, Carlsohn et al., 2011). Supplements such as caffeine appear to have an effect on the performance of endurance athletes by stimulating the central nervous system and the release of epinephrine optimizing cardiovascular function. We also found widespread use of branched chain amino acids (BCAA). Its intake seems to influence the levels of central fatigue, mitigating these effects during endurance tests (Blomstrand et al., 1988). Creatine shows improvements in endurance athletes by playing a fundamental role in the production of phosphocreatine (Rasmussen et al., 2008). Another increasingly used supplement is hydrolysed collagen. Provides essential amino acids. It is an essential nutrient to regenerate and repair elastic and osteoarticular tissues that are subjected to greater physical stress during sports. The increasing use of hydrolysed collagen as a supplement is based on the fact that an efficient absorption of the specific peptides that make up elastic tissues has been demonstrated and that it participates directly in regeneration at the tissue level (Koyama, 2016). With the intake of hydrolysed collagen, markers of bone formation increase (Shaw et al., 2016) and the symptoms of osteoarthritis and rheumatoid arthritis are reduced (Woo et al., 2017). Collagen peptide supplementation in trained athletes may accelerate muscle recovery and lessen muscle pain after intense exercise (Clifford et al., 2019).

Therefore, the objective of this study was to analyse the effects of the intake of the collagen supplement Colnatur Sport® on the recovery and performance processes in athletes after intense resistance exercise and a series of physical tests.

MATERIALS AND METHODS

Participants

Sixty-one participants were recruited, of which 60 met the inclusion criteria (completion of the pre and post-tests, no injuries during the intervention) and 59 completed the follow-up.

All subjects were informed verbally and in writing of the procedure and purpose of this research and the possible risks and gave their informed consent.

The study was carried out in accordance with the Declaration of Helsinki and the protocol was approved by the Ethics Committee of the Technology-Based Company of the University of Alicante, and of the Alicante Science Park.

Design

A single cohort prospective observational pilot study was conducted with a 4-month follow-up. The study was carried out with the participation of the Technological Base Company of the University of Alicante, Kinetic Performance, and the research centre of the University of Granada.

Procedures

Subjects were instructed to generally maintain their daily lifestyle habits, including sports activities and their usual dietary intake, throughout the investigation. After recruitment, all participants were subjected to the same individually adapted training protocol, consisting of a weekly plan of 3 sessions. After one week the initial control was carried out (June and July 2020) and after 16 weeks the final control was carried out (October and November 2020). Between the initial and final control, during the 16 weeks of follow-up, the subjects received the nutritional supplement under study daily: 10 g pure hydrolysed collagen protein enriched with magnesium, manganese, zinc and vitamins B and C, and in powder form. The subjects were instructed to dissolve the entire contents of a dispenser in 150 ml of water, and it was to be taken first thing in the morning.

The athletes performed a stress test in both controls. The test consisted of a 21-kilometer race on a treadmill (*21-kilometre endurance test*: 21KmET), with a previous warm-up that included dynamic mobility for 3 minutes and a 1-kilometer route at a speed of 6km/h. During the 21KmET, the perception of exertion was registered through the Borg scale of perceived exertion (Borg, 1998). At the end of the 21KmET, blood samples were drawn for the analysis of biochemical variables.

Before and after the 21KmET, anthropometric and physical performance values of the participant were recorded (jump tests and grip strength).

Measures

Anthropometry

The anthropometric study was carried out using a DSM-BIA multi-frequency segmental body composition analyser (InBody 270) and weight, percentage of fat, percentage of muscle mass, percentage of residual mass, amount of stored water and symmetries in all body areas were obtained.

Jump test

For the evaluation of physical performance, the subjects performed a lower body strength test. All were duly instructed in the procedure to perform the two types of jumps chosen: counter movement jump with impulse (Counter Movement Jump, CMJ), and squat jump without impulse (Squat Jump, SJ).

Participants had to warm up for 10 minutes, before performing 3 jumps type CMJ and type SJ on a jumping platform, with a minute of rest between jump and jump. The mean of the 3 jumps was used in the statistical analysis. The jump measurement was performed using a force platform (Chronojump from BoscoSystem), as well as their own software for data collection and recording at both sports research centres.

Grip force
A handheld dynamometer (Takei 5001) was used to measure grip strength. Each participant made 3 attempts with both hands at maximum intensity; The results obtained from each attempt were recorded and stored in the database for later processing. The mean of the 3 attempts was used in the statistical analysis.

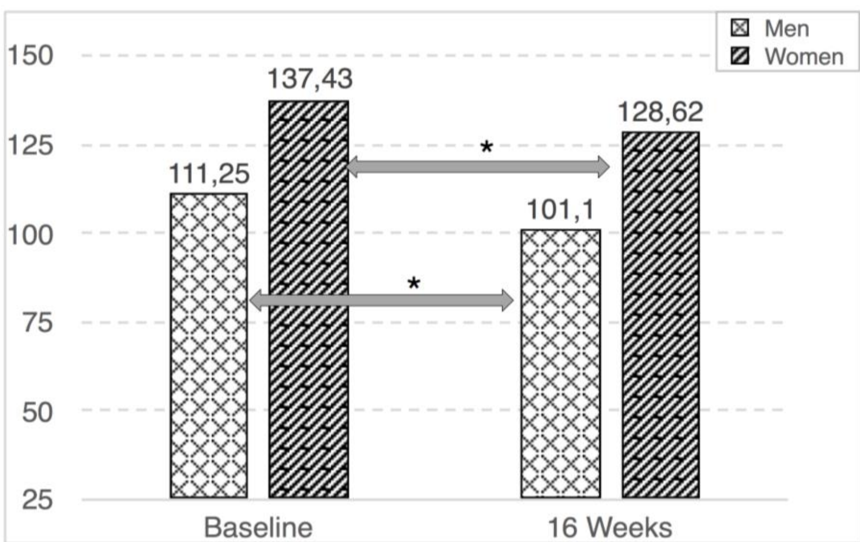
Subjective perception of pain
By means of a visual analogue scale of pain (VAS) the subjective perception of pain was measured. A system was chosen that records the intensity of pain reported by the subject with maximum reproducibility between observers. In addition, the Borg perceived exertion scale was provided during the 21-kilometer test.

Blood extraction
Blood samples were collected by venepuncture in the basilar or brachial vein 5 minutes after the end of the test. Once all the samples had been obtained, they were sent to the laboratory. The ELECSYS β-CrossLaps/serum test and VITROS Integrated Systems were used in the biochemical analyses. An automated five-part Sysmex analysis system was used in haematological analysis.

Statistical analysis
All data were analysed by bidirectional analysis of variance (ANOVA) with repeated measurements, using IBM SPSS Statistics version 23 (SPSS, Inc., Chicago, IL, EE. UU.). If the ANOVA revealed a significant interaction effect (time × group: $p \le .05$) or a trend, post hoc analysis tests (paired t tests and unpaired t tests for pre and post values) were performed using the Bonferroni correction (ap ≤ 0.0125).

RESULTS

The study population was amateur athletes, trained in long-distance running, aged between 45 and 60 years. There were 29 women (weight = 58.4 kg; height = 165.4 cm; IMC = 26.9 Kg/m2) and 30 men (weight = 74.4 kg; height = 182.2 cm; IMC = 22.9 Kg/m2) who completed the follow-up.



*Note: *p < .05.*

Figure 1. Results of the stress test (21km run) before and after taking the hydrolysed collagen supplement for 16 weeks.

Stress test (21KmET)

The mean time invested in the final 21KmET was significantly lower than that obtained in the initial 21KmET, in the overall sample (baseline: 123.34 min; D.T: 18.51 and at 16 weeks: 114.86 min; D.T: 19.46).

This reduction in the time of the 21KmET was significant for the female population (baseline: 137.43 min; D.T: 16.80 and at 16 weeks: 128.62 min; D.T: 20.34) and for the male population (baseline: 111.25 min; D.T: 20.02 and at 16 weeks: 101.1 min; D.T: 18.12) (Figure 1).

Physical performance tests

For muscle performance tests, female athletes showed a significant drop in CMJ jump after baseline 21KmET ($p < .05$), while remaining stable after 21KmET after 16 weeks of training with hydrolysed collagen supplement (see Table 1).

For male athletes, no significant changes were detected in muscle endurance tests after baseline 21KmET or after 21KmET after 16 weeks of training with collagen supplement (see Table 1), except for the SJ jump which improved in the second check ($p < .05$).

Table 1. Physical performance test before (PRE-21KmET) and after (POST-21KmET) of the 21KmET in the baseline control and after 16 weeks with hydrolysed collagen supplement.

Women (n = 29)	**Baseline Control**			**16 Week Control**		
	Pre 21KmET	Post 21KmET	***p***	Pre 21KmET	Post 21KmET	***p***
CMJ	**15.71 (5.2)**	**13.49 (4.7)**	**<.05**	15.83 (5.2)	14.74 (4.7)	.108
SJ	12.01 (4.3)	11.68 (4.5)	.95	12.63 (4.3)	12.02 (4.5)	.204
Right Handgrip	27.91 (3.8)	25.76 (5.8)	.059	27.8 (3.8)	26.86 (5.8)	.176
Left Handgrip	22.76 (2.6)	20.39 (3.1)	.101	21.85 (2.6)	21.45 (3.1)	.132
Men (n = 30)	**Baseline Control**			**16 Week Control**		
	Pre 21KmET	Post 21KmET	***p***	Pre 21KmET	Post 21KmET	***p***
CMJ	21.8 (2.5)	21.5 (1.9)	.122	24.3 (3.2)	23.4 (3.1)	.601
SJ	21.4 (1.7)	20.6 (2.2)	.09	**22.6 (2)**	**23.2 (1.8)**	**<.05**
Right Handgrip	43 (4.4)	41 (3.6)	.321	42.05 (3.9)	40.7 (2.9)	.138
Left Handgrip	41.1 (3.9)	38.4 (3.2)	.078	39.9 (2.4)	38.1 (3.5)	.247

The grip strength tested after the race (21KmET) showed a significant increase after 16 weeks of training with the hydrolysed collagen supplement, both for the right handgrip and for the left handgrip (see table 2) ($p < .05$).

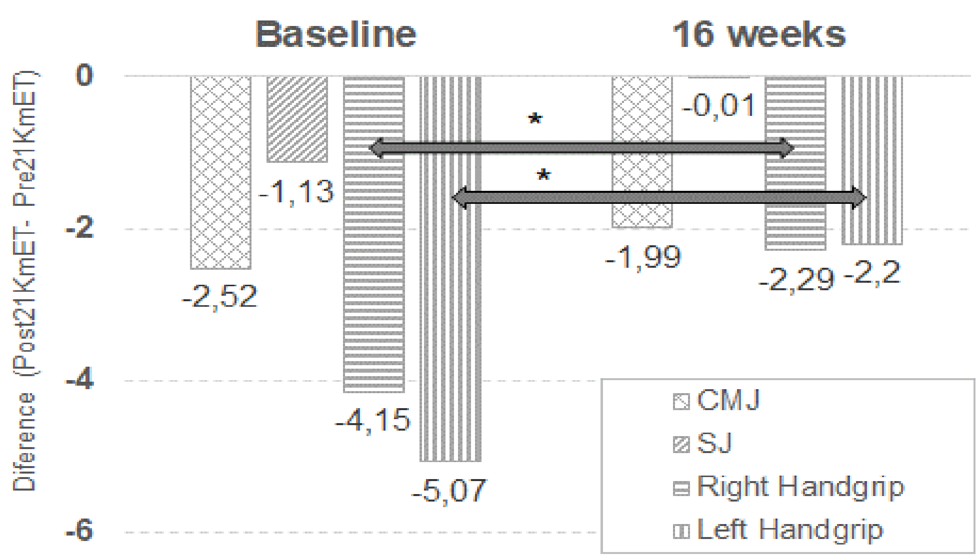
The change in grip strength measured before and after each run showed a significantly greater drop in the initial control than in the control after 16 weeks, for both the right handgrip and the left handgrip ($p < .05$). For the jump tests, numerically there was also a smaller fall, although not statistically significant (see Figure 2).

The VAS scale detected a slight increase in pain perception on 21KmET after 16 weeks of follow-up ($p < .05$).

Table 2. Overall results of physical performance tests measured after each stress test (21KmET).

	Women (n = 29)		**Men (n = 30)**		**Global (n = 59)**	
	Post-21KmET		**Post-21KmET**		**Post-21KmET**	
	Baseline	16 Weeks	Baseline	16 Weeks	Baseline	16 Weeks
CMJ	13.49 (5.5)	14.74 (4.7)	21.5 (1.9)	23.4 (3.1)	17.49 (4.17)	19.07 (4.98)
SJ	11.68 (6.4)	12.02 (4.5)	20.6 (2.2)	23.2 (1.8)	16.14 (5.30)	17.61 (6.12)
RHGa	25.76 (6.0)	26.86 (5.8)	41 (3.6)	40.7 (2.9)	**33.38* (8.84)**	**33.78* (8.14)**
LHGb	20.39 (5.4)	21.45 (3.1)	38.4 (3.2)	38.1 (3.5)	**29.39* (10.6)**	**29.77* (10.1)**
Scale EVA	2.83 (0.27)	2.74 (0.44)	3.3 (0.41)	3.4 (0.48)	**3.06* (0.33)**	**3.07* (0.47)**

Note: [a]Right handgrip; [b]Left handgrip; *p < .05.



*Note: *p < .05.*

Figure 2. Change in strength tests, measured before and after endurance test (21KmET).

Security data

The analytical values recorded after the stress test at the beginning and after 16 weeks of follow-up remained stable (see Table 3). The measurement of the carboxy-terminal telopeptide of serum type I collagen (βCTXs) associated with bone resorption, showed a non-significant decrease (see Table 3).

Table 3. Initial global analytical results in SIN and CON phase of anthropometric and biochemical values.

Global (n = 59)	**Baseline**	**16 Weeks**	***p***
Urea	39.95 (8.41)	35.33 (14.61)	.204
Creatinkinasa	132.5 (17.68)	151.5 (82.73)	.224
Sodium	134.25 (10.25)	129.5 (10.61)	**<.05**
Chlorine	103.15 (2.62)	99.83 (1.65)	.482
Magnesium	1.8 (0.14)	1.9 (0.14)	.340
Zinc	140.24 (39.94)	145.63 (57.46)	.394
βCTXs	0.45 (0.24)	0.20 (0.12)	.661

DISCUSSION AND CONCLUSIONS

The objective of this study was to analyse the effects of the intake of the collagen supplement Colnatur Sport® on the recovery and performance processes in athletes after intense resistance exercise and a series of physical tests.

The time in 21 km presented significant differences ($p < .05$) in men and women. The reductions in test time, within a framework of high physical performance and training, were 9 minutes in women and 10 minutes in men. Jendricke et al. (2020) obtained improvements in parameters related to endurance performance capacity and a lower heart rate in the aerobic and anaerobic thresholds, coinciding with those reported in our work. Soenen (2010) observed how collagen supplementation increased the expression of PGC-1α by stimulating fat metabolism. The strong relationship that PGC-1α presents with mitochondrial biogenesis (Margolism and Donato, 2015) and physical performance (Pilegaard and Richter, 1985; Matsukawa et al., 2017) could explain our results in time in 21km.

The CMJ, SJ, right handgrip and left handgrip tests showed less loss in muscle performance after the stress test when they had followed a training supplemented with 10 g of hydrolysed collagen. Similar results have been obtained by Clifford et al. (2019) showed a faster recovery in CMJ tests after the administration of 20g of hydrolysed collagen. The results of the present study point towards a lesser loss of strength with exertion, thus suggesting that the benefit of hydrolysed collagen could mean keeping the muscle in a better condition during exertion.

The importance of strength training seems key to people's health status (Noh and Park, 2020). Huang et al, 2021, there is even evidence that it would reduce the risk of hospitalization for COVID-19 infection (Cheval et al., 2021, Maltagliati et al., 2021). Our results show a greater response capacity after exercise after supplementation, coinciding with the results of Zdzieblik et al., (2021). A plausible explanation would be that the improvements obtained could be caused by a previous insufficient protein intake in the participants (Kirmse et al., 2019) suggesting that a prolonged intake of collagen could be beneficial in phases of low-protein diets (Haya et al., 2009). A limitation of the present pilot study is that a record of dietary intake or consumption habits was not carried out to corroborate this hypothesis. However, these benefits could have similar effects in populations older than 65 years (Zdzieblik et al., 2015) and in premenopausal women (Jendricke et al., 2019).

The observed results show an improvement in physical performance with a decrease in the time used to perform the 21km but with an increase in the perceptual processes of pain. These results contrast with those shown by Clark et al. (2008) where they observed a decrease in joint pain in athletes supplemented with hydrolysed collagen. Arquer et al. (2014) recorded an improvement in pain experienced by participants with tendinopathies during physical activity, in addition to structural changes in the thickness of the affected tendons. Zdzieblik et al. (2021) observed a decrease in knee pain during and after physical activity in women and men. Similarly, long-term beneficial effects have been reported on osteoarthritis (Clark et al., 2008), rheumatoid arthritis (Khare et al., 1995).

Serum type I collagen carboxy-terminal telopeptide (βCTXs) is a marker of bone resorption that may be informative about the degree of bone remodelling associated with exercise. In this study, the changes in (βCTXs) were not significant at a 16-week follow-up, nor were they significant in the study by Clifford et al. (2019) with a shorter-term follow-up. There is evidence that supplementation with collagen hydrolysate for 12 months in postmenopausal women reduces the levels of βCTXs (Köning et al., 2017), which suggests that the population of the present study over 45 years of age and especially women could also benefit from this effect on bone density with longer-term supplementation.

In conclusion, the hydrolysed collagen supplement Colnatur Sport® could provide beneficial effects on the ability to respond to the effort of athletes in the face of higher perceptual pain states. This study was carried out as a pilot without a formal calculation of the sample and without a control group, so many of the results can be indicative and constitute a starting point to propose future formal trials, with a more robust design to confirm the results.

AUTHOR CONTRIBUTIONS

C.E.A. manuscript writing, collected the data, preparation and research design; R.D.C.S. critically reviewed the work, result interpretation and manuscript writing; M.J.G.G. manuscript writing; J.E.G.P. collected the data and J.A.P.T. research design, statistical analysis and result interpretation.

SUPPORTING AGENCIES

This work has been supported by ORDESA S.L. Laboratories. Nutritional supplement was supplied by ORDESA S.L. Laboratories.

DISCLOSURE STATEMENT

R.D.C.S. works for Ordesa S.L. Laboratories. The remaining authors have no conflicts of interest to declare.

REFERENCES

Adam, M., Spacek, P., Hulejová, H., Galiánová, A., & Blahos, J. (1996). Postmenopausal osteopo-rosis. Treatment with calcitonin and a diet rich in collagen proteins. Casopis Lekaru Ceskych, 135(3), 74-78.

Arquer, A., García, M., Laucirica, J. A., Rius, M., Blàvia, M., Fontserè, J., ... & Puig, D. M. (2014). Eficacia y seguridad de un tratamiento oral a base de mucopolisacáridos, colágeno tipo iy vi-tamina C en pacientes con tendinopatías. Apunts. Medicina de l'Esport, 49(182), 31- 36. https://doi.org/10.1016/j.apunts.2013.12.005

Blomstrand, E., Celsing, F., & Newsholme, E. A. (1988). Changes in plasma concentrations of aro-matic and branched-chain amino acids during sustained exercise in man and their possible role in fatigue. Acta physiologica Scandinavica, 133(1), 115-121. https://doi.org/10.1111/j.1748-1716.1988.tb08388.x

Borg, G. (1998). Borg's perceived exertion and pain scales. Human Kinetics.

Brown, J. C., Winters-Stone, K., Lee, A., & Schmitz, K. H. (2012). Cancer, physical activity, and exercise. Comprehensive Physiology, 2(4), 2775-2809. https://doi.org/10.1002/cphy.c120005

Carlsohn, A., Cassel, M., Linné, K., & Mayer, F. (2011). How much is too much? A case report of nutritional supplement use of a high-performance athlete. British Journal of Nutrition, 105(12), 1724-1728. https://doi.org/10.1017/S0007114510005556

Cermak, N. M., Res, P. T., De Groot, L. C. P. G. M., Saris, W. H. M., & Van Loon, S. L. (2012). Protein supplementation augments the adaptive response of skeletal muscle to resistance-type exercise training: a meta-analysis, The American Journal of Clinical Nutrition, 96(6), D1454-1464. https://doi.org/10.3945/ajcn.112.037556

Chakravarty, E. F., Hubert, H. B., Lingala, V. B., & Fries, J. F. (2008). Reduced disability and mor-tality among aging runners: a 21-year longitudinal study. Archives of internal medicine, 168(15), 1638-1646. https://doi.org/10.1001/archinte.168.15.1638

Cheval, B., Sieber, S., Maltagliati, S., Millet, G., Formánek, T., Chalabaev, A., Cullati, S., Boisgontier, M. (2021). Muscle strength is associated with COVID-19 hospitalization in adults 50 years of age or older. MedRxiv : the preprint server for health sciences, 2021.02.02.21250909. https://doi.org/10.1101/2021.02.02.21250909

Clark, K. L., Sebastianelli, W., Flechsenhar, K. R., Aukermann, D. F., Meza, F… Albert, A. (2008). 24-Week study on the use of collagen hydrolysate as a dietary supplement in athletes with activity-related joint pain. Current Medical Research and Opinion, 24(5), 1485-1496. https://doi.org/10.1185/030079908X291967

Clifford, T., Ventress, M., Allerton, D. M., Stansfield, S., Tang, J. C. Y… Stevenson, E. (2019). The effects of collagen peptides on muscle damage, inflammation and bone turnover follow-ing exercise: a randomized, controlled trial. Amino Acids, 51(4), 691-704. https://doi.org/10.1007/s00726-019-02706-5

Dressler, P., Gehring, D., Zdzieblik, D., Oesser, S., Gollhofer, A., & König, D. (2028). Improve-ment of Functional Ankle Properties Following Supplementation with Specific Collagen Peptides in Athletes with Chronic Ankle Instability. J. Sports Sci. Med, 17(2), 298-304.

Figueres Juher, T., & Basés Pérez, E. (2015). Revisión de los efectos beneficiosos de la ingesta de colágeno hidrolizado sobre la salud osteoarticular y el envejecimiento dérmico. Nutrición hospitalaria, 32 Suppl 1, 62-66. https://doi.org/10.3305/nh.2015.32.sup1.9482

Guillerminet, F., Beaupied, H., Fabien-Soulé, V., Tomé, D., Benhamou, C. L…Blais, A. (2010). Hydrolyzed collagen improves bone metabolism and biomechanical parameters in ovariecto-mized mice: An in vitro and in vivo study, Bone, 46(3), 827-834. https://doi.org/10.1016/j.bone.2009.10.035

Guillerminet, F., Fabien-Soulé, V., Even, P.C., Tomé, D., Benhamou, C. L… Blais, A. (2012). Hydrolyzed collagen improves bone status and prevents bone loss in ovariecto-mized C3H/HeN mice. Osteoporos Int, 23(7), 1909-1919. https://doi.org/10.1007/s00198-011-1788-6

Huang, X., Ma, J., Ying, Y., Liu, K., Jing, C., & Hoa, G. (2021). The handgrip strength and risk of depressive symptoms: a meta-analysis of prospective cohort studies. Quality of Life Re-search: an international journal of quality of life aspects of treatment, care and rehabilitation. Advance online publication. https://doi.org/10.1007/s11136-021-02858-6

Janssen, M., Scheerder, J., Thibaut, E., Brombacher, A., & Vos, S. (2017). Who uses running apps and sports watches? Determinants and consumer profiles of event runners' usage of running-related smartphone applications and sports watches. PloS one, 12(7), e0181167. https://doi.org/10.1371/journal.pone.0181167

Janssen, I., Clarke, A. E., Carson, V., Chaput, J. P., Giangregorio, L. M., Kho, M. E., Poitras, V. J., Ross, R., Saunders, T. J., Ross-White, A., & Chastin, S. (2020). A systematic review of compositional data analysis studies examining associations between sleep, sedentary behav-iour, and physical activity with health outcomes in adults. Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme, 45(10 (Suppl. 2)), S248-S257. https://doi.org/10.1139/apnm-2020-0160

Jendricke, P., Centner, C., Zdzieblik, D., Gollhofer, A., & König, D. (2019). Specific Collagen Pep-tides in Combination with Resistance Training Improve Body Composition and Regional Muscle Strength in Premenopausal Women: A Randomized Controlled Trial. Nutrients, 11(4), 892. https://doi.org/10.3390/nu11040892

Jendricke, P., Kohl, J., Centner, C., Gollhofer, A., & König, D. (2020). Influence of Specific Colla-gen Peptides and Concurrent Training on Cardiometabolic Parameters and Performance In-dices in

Women: A Randomized Controlled Trial. Frontiers in nutrition, 7, 580918. https://doi.org/10.3389/fnut.2020.580918

Khare, S. D., Krco, C. J., Griffiths, M. M., Luthra, H. S., & David, C. S. (1995). Oral administra-tion of an immunodominant human collagen peptide modulates collagen-induced arthritis. J Immunol, 155(7), 3653-3659.

Kirmse, M., Oertzen-Hagemann, V., De Marées, M., Bloch, W., & Platen, P. (2019). Prolonged Col-lagen Peptide Supplementation and Resistance Exercise Training Affects Body Composition in Recreationally Active Men. Nutrients, 11(5), 1-16. https://doi.org/10.3390/nu11051154

Koyama I. (2016). Effects of Collagen Ingestion and their Biological Significance. Journal of Nutri-tion & Food Sciences 6(3): 1000504. https://doi.org/10.4172/2155-9600.1000504

König D, Oesser S, Scharla S, Zdzieblik D, Gollhofer A (2018) Specific collagen peptides improve bone mineral density and bone markers in postmenopausal women-a randomized controlled study. Nutrients 10(1):97. https://doi.org/10.3390/nu10010097

Lavie, C. J., Arena, R., Swift, D. L., Johannsen, N. M., Sui, X., Lee, D. C., Earnest, C. P., Church, T. S., O'Keefe, J. H., Milani, R. V., & Blair, S. N. (2015). Exercise and the cardiovascular system: clinical science and cardiovascular outcomes. Circulation research, 117(2), 207-219. https://doi.org/10.1161/CIRCRESAHA.117.305205

Lavielle-Sotomayor, P., Pineda-Aquino, V., Jáuregui-Jiménez, O., & Castillo-Trejo, M. (2014). Actividad física y sedentarismo: Determinantes sociodemográficos, familiares y su impacto en la salud del adolescente [Physical activity and sedentary lifestyle: family and socio-demographic determinants and their impact on adolescents' health]. Revista de salud publica (Bogota, Colombia), 16(2), 161-172. https://doi.org/10.15446/rsap.v16n2.33329

Maltagliati, S., Sieber, S., Sarrazin, P., Cullati, S., Chalabaev, A., Millet, G. P., Boisgontier, M. P., & Cheval, B. (2021). Muscle Strength Explains the Protective Effect of Physical Activity against COVID-19 Hospitalization among Adults aged 50 Years and Older. MedRxiv : the preprint server for health sciences, 2021.02.25.21252451. https://doi.org/10.1101/2021.02.25.21252451

Margolis, L. M., & Rivas, D. A. (2015). Implications of exercise training and distribution of protein intake on molecular processes regulating skeletal muscle plasticity. Calcified tissue interna-tional, 96(3), 211-221. https://doi.org/10.1007/s00223-014-9921-0

Matsukawa, T., Motojima, H., Sato, Y., Takahashi, S., Villareal, M. O., & Isoda, H. (2017). Upregu-lation of skeletal muscle PGC-1α through the elevation of cyclic AMP levels by Cyanidin-3-glucoside enhances exercise performance. Scientific reports, 7, 44799. https://doi.org/10.1038/srep44799

Noh, H. M., & Park, Y. S. (2020). Handgrip strength, dynapenia, and mental health in older Kore-ans. Science and Reports, 10(1), 4004. https://doi.org/10.1038/s41598-020-60835-4

O'Keefe, J. H., Bhatti, S. K., Bajwa, A., DiNicolantonio, J. J., & Lavie, C. J. (2014). Alcohol and cardiovascular health: the dose makes the poison…or the remedy. Mayo Clinic proceedings, 89(3), 382-393. https://doi.org/10.1016/j.mayocp.2013.11.005

Oja, P., Kelly, P., Pedisic, Z., Titze, S., Bauman, A., Foster, C., Hamer, M., Hillsdon, M., & Stama-takis, E. (2017). Associations of specific types of sports and exercise with all-cause and car-diovascular-disease mortality: a cohort study of 80 306 British adults. British journal of sports medicine, 51(10), 812-817. https://doi.org/10.1136/bjsports-2016-096822

Pilegaard, H., & Richter, E. A. (2008). PGC-1alpha: important for exercise performance?. Journal of applied physiology (Bethesda, Md. : 1985), 104(5), 1264-1265. https://doi.org/10.1152/japplphysiol.90346.2008

Rasmussen, C.; Greenwood, M.; Kalman, D.; Antonio, J. Nutritional Supplements for Endurance Athletes. In Nutritional Supplements in Sports and Exercise; Humana Press: Totowa, NJ, USA, 2008; pp. 369-407. https://doi.org/10.1007/978-1-59745-231-1_11

Shaw, G., Lee-Barthel, A., Ross, M. L., Wang, B., & Baar, K. (2017). Vitamin C-enriched gelatin supplementation before intermittent activity augments collagen synthesis. The American journal of clinical nutrition, 105(1), 136-143. https://doi.org/10.3945/ajcn.116.138594

Soenen, S., Plasqui, G., Smeets, A. J., & Westerterp-Plantenga, M. S. (2010). Protein intake induced an increase in exercise stimulated fat oxidation during stable body weight. Physiology & be-havior, 101(5), 770-774. https://doi.org/10.1016/j.physbeh.2010.08.019

Takeda, S., Park, J. H., Kawashima, E., Ezawa, I., & Omi, N. (2013). Hydrolyzed collagen intake increases bone mass of growing rats trained with running exercise. Journal of the Interna-tional Society Sports Nutrition. 10(35), 1-9. https://doi.org/10.1186/1550-2783-10-35

Tremblay, M. S., LeBlanc, A. G., Kho, M. E., Saunders, T. J., Larouche, R., Colley, R. C., ... Con-nor Gorber, S. (2011). Systematic review of sedentary behaviour and health indicators in school-aged children and youth. The International Journal of Behavioral Nutrition and Phys-ical Activity, 8, 98. https://doi.org/10.1186/1479-5868-8-98

Williams P. T. (2011). Exercise attenuates the association of body weight with diet in 106,737 run-ners. Medicine and science in sports and exercise, 43(11), 2120-2126. https://doi.org/10.1249/MSS.0b013e31821cd128

Woo, T., Lau, L., Cheng, N., Chan, P., Tan, K., & Gardner, A. (2017). Efficacy of oral collagen in joint pain-osteoarthritis and rheumatoid arthritis. Journal of Arthritis, 6(2), 1-4.

Zdzieblik, D., Oesser, S., Baumstark, M., Gollhofer, A., & König, D. (2015). Collagen peptide sup-plementation in combination with resistance training improves body composition and in-creases muscle strength in elderly sarcopenic men: A randomised controlled trial. British Journal of Nutrition,114(8), 1237-1245. https://doi.org/10.1017/S0007114515002810

Zdzieblik, D., Oesser, S., Gollhofer, A., & König, D. (2017). Improvement of activity-related knee joing discomfort following supplementation of specific collagen peptides. Applied physiolo-gy, nutrition, and metabolism, 42(6), 588-595. https://doi.org/10.1139/apnm-2016-0390

Zdzieblik D, Brame J, Oesser S, Gollhofer A, & König D. (2021).The Influence of Specific Bioac-tive Collagen Peptides on Knee Joint Discomfort in Young Physically Active Adults: A Randomized Controlled Trial. Nutrients. 2021;13(2):523. https://doi.org/10.3390/nu13020523