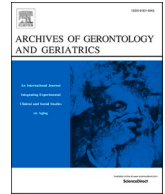




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Original article

Glucose regulation and grip strength in adults: Findings from the Helsinki Birth Cohort Study

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ABSTRACT

Aim: This study aimed to assess the association between grip strength and glucose regulation in a cross-sectional setting.**Methods:** Using data from the Helsinki Birth Cohort Study, 924 men and 953 women were studied at a mean age of 61.6 years. Grip strength was assessed in the dominant hand using a Newtest Grip Force dynamometer. A standard 2-h 75 g oral glucose tolerance test (OGTT) was used to define glucose regulation. The participants were classified into four groups: normoglycaemia, prediabetes (impaired fasting glucose or impaired glucose tolerance), newly diagnosed diabetes and previously known diabetes. The association between grip strength and glucose regulation was assessed using multiple linear regression models.**Results:** Prediabetes was diagnosed in 32.2% and diabetes in 8.4% using the OGTT. A total of 7.8% of the individuals had previously known diabetes. Compared to individuals with normoglycaemia, grip strength was lower for those with newly diagnosed diabetes (-1.8 kg, 95% CI -3.2 to -0.5) as well as those with previously known diabetes (-1.8 kg, 95% CI -3.2 to -0.4) after adjusting for covariates (age, sex, body mass index, physical activity, education and smoking). No difference in grip strength was found when comparing those with prediabetes and normoglycaemia.**Conclusion:** In adults, grip strength was lower among those with known and newly diagnosed diabetes compared to those with normoglycaemia. Together with previous findings on associations between grip strength and chronic diseases, these results support the use of grip strength as an overall health marker in adults.

1. Introduction

With an increase in the aged population, finding methods for predicting and preventing chronic diseases is inevitable in order to reduce severe disability and subsequently reduce health care costs (World Health Organization, 2011). Grip strength has been used as a marker of both muscle strength and quality and is a strong predictor of physical

functioning at older age (Rantanen et al., 1999). Poor grip strength has also been associated with cardiovascular disease events (Silventoinen, Magnusson, Tynelius, Batty & Rasmussen, 2009), and has been shown to predict all-cause and disease specific mortality (Leong et al., 2015). Thus, grip strength is a useful method to assess and predict health-related outcomes in the aging population.

Type 2 diabetes has been associated with decreased muscle quality

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and reduced muscle mass in both upper and lower extremities, with poorest muscle quality among those with longest duration of diabetes (Park et al., 2006). Therefore, one would expect a marker of muscle strength and quality such as grip strength to be associated with different degrees of impairment in glucose regulation. However, previous reports on the association between grip strength and type 2 diabetes have been inconsistent, some showing an association while others have found no relationship between the two variables (Kunutsor, Isiozor, Khan & Laukkanen, 2020; Leong et al., 2015). In addition, there are only sparse data on the association between grip strength and prediabetes, i.e. impaired fasting glucose (IFG) or impaired glucose regulation (IGT), however, these studies have suggested a decrease in grip strength among those with prediabetes compared to those with normoglycaemia (Hu et al., 2019; Manda et al., 2020).

The aim of this study was to further investigate the relationship between grip strength and different stages of impairment in glucose regulation, including prediabetes, newly diagnosed diabetes and previously known diabetes. We hypothesised that more severe disturbances in glucose regulation would be associated with poorer grip strength.

2. Methods

2.1. Study population

The study population has been described previously (Åström et al., 2019). Briefly, this cross-sectional study was part of the Helsinki Birth Cohort Study and used data from a sub-population consisting of 8760 individuals born at the Helsinki University Central Hospital in 1934–1944. The cohort members visited child welfare clinics and were still living in Finland in 1971, when all Finnish residents received a unique personal identification number. In the year 2000, a sample of 2902 individuals were selected using random-number tables and were invited to a clinical examination. A total of 2003 individuals participated in this clinical examination carried out between 2001 and 2004. This study included 1877 individuals who had data available on both glucose regulation and grip strength.

The study complies with the guidelines of the Declaration of Helsinki and the study protocol was approved by the Ethics Committee of Epidemiology and Public Health of the Hospital District of Helsinki and Uusimaa, as well as the National Public Health Institute. A written informed consent was acquired from all participants.

2.2. Glucose regulation

A standard 2-h 75 g oral glucose tolerance test (OGTT) was carried out on all subjects, except those with previously known diabetes, which was defined by a self-reported history of diabetes, a diabetes diagnosis in medical records, or use of medication for diabetes prior to participating in the study. The 1999 criteria by The World Health Organization (WHO) (World Health Organization, 1999) were used to define disturbances in glucose regulation. Diabetes was defined as a fasting plasma glucose level of at least 7.0 mmol/l or a 2-h glucose level of over 11.0 mmol/l. IGT was defined as a 2-h glucose level of 7.8–11.0 mmol/l, and IFG as a fasting plasma glucose level of 6.1–6.9 mmol/l, both in the absence of diabetes. Those not meeting any of these criteria were defined as having normoglycaemia. The individuals who did not have previously known diabetes and who met the criteria for diabetes at the clinical examination were defined as having newly diagnosed diabetes. Those with IFG or IGT or both were defined as having prediabetes.

2.3. Grip strength

Isometric grip strength was tested using a Newtest Grip Force dynamometer (Newtest Oy, Oulu, Finland) and was measured to the nearest 0.1 kg. The dominant hand was assessed and the maximum value of three squeezes was used in the analysis.

2.4. Covariates

Anthropometric measurements were acquired at the clinical examination. Body mass index (BMI) was calculated as kg/m². Lean body mass was estimated with bioelectrical impedance using the InBody 3.0 eight polar tactile electrode system (Biospace Co., Ltd., Seoul, South Korea). Questionnaires were used to gather information on lifestyle habits, including smoking, as well as information on educational attainment and occupational status. Physical activity was estimated using the validated Kuopio Ischaemic Heart Disease (KIHD) Risk Factor Study 12-month leisure-time physical activity (LTPA) exercise questionnaire (Lakka et al., 1994). The KIHD assigns a metabolic equivalent of task (MET) to both non-conditioning and conditioning activities, and the results are presented as MET-hours per week.

2.5. Statistical analysis

Continuous variables are presented as means and standard deviations (SD), whereas categorical variables are presented as proportions and percentages. Differences between cohort characteristics across the glucose regulation groups were assessed using analysis of variance or the Kruskal-Wallis test for continuous variables and Pearson's chi-square test for categorical variables. Multiple linear regression models were used to assess the association between glucose regulation and grip strength. The results were pooled by sex, as none of the interactions for sex and glucose regulation groups on grip strength were statistically significant (all p-values > 0.40). In model 1, we adjusted for sex and age. In model 2, we further adjusted for BMI. Finally, we further adjusted for educational attainment, smoking status and LTPA in model 3. The covariates used in the analyses were selected based on the literature, as age, obesity, socioeconomic status and lifestyle habits have all been shown to associate with both grip strength and diabetes (Kim, Jeon, & Jeong, 2019; Stenholm et al., 2012; Zheng, Ley & Hu, 2018). All analyses were performed using IBM SPSS Statistics Version 25.0 (IBM Corp., Armonk, New York, USA).

3. Results

A total of 924 men and 953 women were included in this study. The mean age of the participants was 61.6 years (SD 2.9). A total of 147 individuals (7.8%) were classified as having previously known diabetes (Table 1). Based on the OGTT, 157 individuals (8.4%) received a diabetes diagnosis, whereas 604 (32.2%) were diagnosed with prediabetes. The glucose regulation groups differed in age and those with normoglycaemia were more likely to be women, whereas those with newly diagnosed or previously known diabetes were more likely to be men. Body mass index increased gradually across the glucose regulation groups, with the highest BMI in those with known diabetes. For both men and women, those with known diabetes had higher lean body mass compared to the other glucose regulation groups. In addition, smoking habits, education years and leisure-time physical activity differed between the groups. Crude grip strength did not differ between the groups for neither men nor women.

The association between glucose regulation and grip strength is presented in Table 2. When adjusting for age and sex, those with newly diagnosed diabetes had significantly lower grip strength compared to those with normoglycaemia. However, after further adjusting for BMI as well as LTPA, educational attainment and smoking status in the final model, lower grip strength was reported for both those with newly diagnosed diabetes (−1.8 kg, 95% CI −3.2 to −0.5) and previously known diabetes (−1.8 kg, 95% CI −3.2 to −0.4) compared to those with normoglycaemia. The differences were even greater when adjusting for lean body mass instead of BMI in the final model. No differences in grip strength was found between those with prediabetes and normoglycaemia.

Table 1

Characteristics of study participants from the Helsinki Birth Cohort Study grouped by glucose regulation. Results are presented as means and standard deviations unless otherwise stated.

Variable	NG (n = 969)	Prediabetes (n = 604)	New DM (n = 157)	Known DM (n = 147)	p
Age (years)	61.4 (2.8)	61.9 (3.0)	61.8 (2.9)	61.1 (2.6)	<0.001
Women, n (%)	530 (54.7)	301 (49.8)	67 (42.7)	55 (37.4)	<0.001
BMI (kg/m ²)	26.4 (4.1)	28.2 (4.3)	29.7 (5.8)	31.2 (5.3)	<0.001
Lean body mass (kg)					
Women	47.3 (5.3)	48.2 (6.0)	48.2 (5.2)	51.9 (6.5)	<0.001
Men	64.0 (7.2)	65.3 (8.0)	65.9 (8.9)	68.6 (8.2)	<0.001
Current/ex-smoker, n (%)	570 (58.8)	364 (60.3)	100 (63.7)	111 (75.5)	0.001
Education (years)	12.4 (3.8)	12.2 (3.5)	11.6 (3.4)	11.6 (3.4)	0.026
LTPA (METh/week)	39.8 (27.6)	35.6 (25.7)	36.4 (28.6)	33.0 (24.2)	0.001
Grip strength (kg)					
Women	23.1 (6.0)	23.2 (6.5)	21.6 (5.6)	22.0 (8.2)	0.062
Men	40.8 (9.2)	40.7 (10.0)	38.7 (9.5)	39.3 (9.4)	0.207

NG, normoglycaemia; New DM, diabetes diagnosed at oral glucose tolerance test in 2001–2004; Known DM, diabetes diagnosed before oral glucose tolerance test in 2001–2004; BMI, body mass index; LTPA, leisure-time physical activity; MET, metabolic equivalent of task.

4. Discussion

In this study, we found that individuals with diabetes, including both newly diagnosed and previously known diabetes, had lower grip strength compared to those with normoglycaemia. Controlling for potential confounders did not attenuate these associations. We did not, however, find any differences in grip strength between individuals with prediabetes and normoglycaemia.

Our results confirm the findings from previous studies of an inverse association between diabetes and grip strength. In a recent cross-sectional study of older adults, maximum grip strength relative to BMI decreased linearly when transitioning from normoglycaemia to previously known diabetes in both men and women, whereas a similar trend for absolute grip strength was found only in men. (Liang et al., 2020). The same study also found an inverse association between fasting glucose levels and grip strength in women with normoglycaemia. Some previous studies have also found a difference in grip strength between those with newly diagnosed and previously known diabetes. In unadjusted analysis, Mainous III and colleagues reported approximately 10 kg lower combined grip strength of both hands in those with previously known diabetes compared to those with newly diagnosed diabetes (Mainous, Tanner, Anton & Jo, 2015). Their study, however, focused on

Table 2

Regression coefficients (unstandardised) for the association between glucose regulation and grip strength in the Helsinki Birth Cohort Study.

Glucose regulation ^a	Model 1			Model 2			Model 3		
	b	95% CI	p	b	95% CI	p	b	95% CI	p
Prediabetes	0.4	−0.4 to 1.2	0.377	0.1	−0.7 to 0.9	0.744	0.2	−0.6 to 1.0	0.614
New diabetes	−1.4	−2.8 to −0.1	0.032	−1.9	−3.2 to −0.5	0.006	−1.8	−3.2 to −0.5	0.007
Known diabetes	−1.2	−2.6 to 0.1	0.073	−1.9	−3.3 to −0.5	0.007	−1.8	−3.2 to −0.4	0.013

New diabetes, diabetes diagnosed at oral glucose tolerance test in 2001–2004; Known diabetes, diabetes diagnosed before oral glucose tolerance test in 2001–2004. Model 1: Adjusted for sex and age. Model 2: Further adjusted for body mass index. Model 3: Further adjusted for leisure-time physical activity, education years and smoking status.

^a Normoglycaemia served as reference.

adults with a healthy BMI of at least 18.5 but less than 25 and the majority of participants were under 65 years. In addition, diabetes was diagnosed using only HbA_{1c} making it likely that some cases of diabetes remained undiagnosed. Thus, their results are not fully comparable to our findings.

In contrast to previous reports, we did not find any association between prediabetes and poor grip strength. This may be due to differences in study methodology and population. In a Chinese study of over 27 000 individuals, lower grip strength was associated with a 52–62% lower odds of prediabetes (Hu et al., 2019). This study, however, measured grip strength normalised to body weight instead of absolute grip strength and defined prediabetes using the American Diabetes Association (ADA) criteria, which has a lower fasting plasma glucose threshold for diagnosing IFG (5.6–6.9 mmol/l) compared to the WHO criteria (6.0–6.9 mmol/l) used in our study (American Diabetes Association, 2014). A higher mean age could also explain why our results differed from previous findings (Manda et al., 2020). Grip strength has been shown to differ between ethnic groups, thus differences in ethnicity between study populations may account for the inconsistent association between prediabetes and grip strength (van der Kooij, Snijder, Peters, & Van Valkengoed, 2015). Finally, hyperglycaemia affects muscle strength and quality to a greater extent in the legs compared to the arms, at least in individuals with diabetes (Park et al., 2007). Therefore, individuals with early stages of impaired glucose regulation such as prediabetes may not yet have experienced any considerable decline in grip strength.

Several potential underlying factors may explain the decreased grip strength in individuals with diabetes. Previous studies have reported an accelerated loss of skeletal muscle mass and increased intramuscular fat infiltration in those with diabetes (Bianchi & Volpato, 2016). This causes a loss in muscle strength but also further aggravates insulin resistance, as skeletal muscle tissue are important sites for glucose uptake (Perkisas & Vandewoude, 2016). Low-grade inflammation has been shown to contribute to the development of diabetes but has also been associated with poor physical performance and could be a mechanism linking diabetes to poor grip strength (Tay, Goss, Locher, Ard & Gower, 2019). Peripheral neuropathy and diabetic hand syndrome, including limited joint mobility, flexor tenosynovitis and Dupuytren's disease are other possible reasons for the loss of grip strength among those with diabetes (Arkkila & Gautier, 2003; Mainous et al., 2015). Diabetes is linked to several comorbidities, such as osteoarthritis and neurodegenerative diseases, and these conditions have also independently been associated with a decline in grip strength (Adamo, Anderson, Koochaki, & Fritz, 2020; Zhang et al., 2002). Finally, individuals with diabetes tend to engage less regularly in physical activity compared to those without diabetes (Morrato, Hill, Wyatt, Ghushchyan, & Sullivan, 2007). As physical inactivity is strongly related to poor physical performance (Patel et al., 2006), lower levels of physical activity in individuals with diabetes could explain why these individuals also have decreased grip strength.

This study benefits from its well-characterised population of both men and women. We were able to accurately classify the participants into different groups of impaired glucose regulation by using the OGTT. We were also able to control for a number of possible confounders. On

the other hand, the cross-sectional design can be considered a limitation as it prevented us from assessing causality. We acknowledge that there may be other confounders that we did not have information on, including diabetes complications such as neuropathy, which is a limitation of this study. The participants originated from a restricted area in Finland, and this should be taken into account when interpreting the results.

In conclusion, grip strength is an accessible and inexpensive method to assess muscle strength and has been associated with age-related conditions such as cardiovascular disease. We further reported lower grip strength among those with both previously known and newly diagnosed diabetes compared to those with normoglycaemia. Our findings therefore support the use of grip strength as a marker of overall health among adults, however, longitudinal studies are needed to investigate how the presence and duration of disturbances in glucose regulation affect grip strength over time.

Credit author statement

Max J. Åström: Conceptualization, Methodology, Formal analysis, Writing – Original Draft, Visualization

Mikaela B. von Bonsdorff: Conceptualization, Methodology, Formal analysis, Writing – Review & Editing, Supervision

Minna K. Salonen: Methodology, Writing – Review & Editing

Eero Kajantie: Methodology, Writing – Review & Editing

Clive Osmond: Methodology, Formal analysis, Writing – Review & Editing

Johan G. Eriksson: Conceptualization, Methodology, Formal analysis, Writing – Review & Editing, Supervision

Declarations

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Informed consent: A written informed consent was acquired from all participants included in this study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Adamo, D. E., Anderson, T., Koochaki, M., & Fritz, N. E. (2020). Declines in grip strength may indicate early changes in cognition in healthy middle-aged adults. *PLoS One*, *15*(4). <https://doi.org/10.1371/journal.pone.0232021>. Article e0232021.

Arkkila, P. E. T., & Gautier, J. F. (2003). Musculoskeletal disorders in diabetes mellitus: An update. *Best Practice & Research Clinical Rheumatology*, *17*(6), 945–970. <https://doi.org/10.1016/j.berh.2003.11.001>

American Diabetes Association. (2014). Diagnosis and classification of diabetes mellitus. *Diabetes care*, *37*(Supplement 1), S81–S90. <https://doi.org/10.2337/dc14-S081>

Åström, M. J., von Bonsdorff, M. B., Perälä, M. M., Salonen, M. K., Rantanen, T., Kajantie, E., et al. (2019). Telomere length and physical performance among older people—The Helsinki birth cohort study. *Mechanisms of Ageing and Development*, *183*. <https://doi.org/10.1016/j.mad.2019.111145>. Article 111145.

Bianchi, L., & Volpato, S. (2016). Muscle dysfunction in type 2 diabetes: A major threat to patient's mobility and independence. *Acta Diabetologica*, *53*(6), 879–889. <https://doi.org/10.1007/s00592-016-0880-y>

Hu, S., Gu, Y., Lu, Z., Zhang, Q., Liu, L., Meng, G., et al. (2019). Relationship between grip strength and prediabetes in a large-scale adult population. *American Journal of Preventive Medicine*, *56*(6), 844–851. <https://doi.org/10.1016/j.amepre.2019.01.013>

Kim, C. R., Jeon, Y. J., & Jeong, T. (2019). Risk factors associated with low handgrip strength in the older Korean population. *PLoS One*, *14*(3). <https://doi.org/10.1371/journal.pone.0214612>. Article e0214612.

Kunutsor, S. K., Isiozor, N. M., Khan, H., & Laakkonen, J. A. (2020). Handgrip strength—A risk indicator for type 2 diabetes: Systematic review and meta-analysis of observational cohort studies. *Diabetes/Metabolism Research and Reviews*. <https://doi.org/10.1002/dmrr.3365>. Article e3365.

Lakka, T. A., Venalainen, J. M., Rauramaa, R., Salonen, R., Tuomilehto, J., & Salonen, J. T. (1994). Relation of leisure-time physical activity and cardiorespiratory fitness to the risk of acute myocardial infarction in men. *The New England Journal of Medicine*, *330*(22), 1549–1554. <https://doi.org/10.1056/nejm199406023302201>

Leong, D. P., Teo, K. K., Rangarajan, S., Lopez-Jaramillo, P., Avezum, A., Jr, Orlandini, A., et al. (2015). Prognostic value of grip strength: Findings from the Prospective Urban Rural Epidemiology (PURE) study. *The Lancet*, *386*(9990), 266–273. [https://doi.org/10.1016/S0140-6736\(14\)62000-6](https://doi.org/10.1016/S0140-6736(14)62000-6)

Liang, X., Jiang, C. Q., Zhang, W. S., Zhu, F., Jin, Y. L., & Cheng, K. K. (2020). Glycaemia and hand grip strength in aging people: Guangzhou biobank cohort study. *BMC Geriatrics*, *20*(1), 1–10. <https://doi.org/10.1186/s12877-020-01808-0>

Mainous, A. G., III, Tanner, R. J., Anton, S. D., & Jo, A. (2015). Grip strength as a marker of hypertension and diabetes in healthy weight adults. *American Journal of Preventive Medicine*, *49*(6), 850–858. <https://doi.org/10.1016/j.amepre.2015.05.025>

Manda, C. M., Hokimoto, T., Okura, T., Isoda, H., Shimano, H., & Wagatsuma, Y. (2020). Handgrip strength predicts new prediabetes cases among adults: A prospective cohort study. *Preventive Medicine Reports*, *17*. <https://doi.org/10.1016/j.pmedr.2020.101056>. Article 101056.

Morrato, E. H., Hill, J. O., Wyatt, H. R., Ghushchyan, V., & Sullivan, P. W. (2007). Physical activity in U.S. adults with diabetes and at risk for developing diabetes, 2003. *Diabetes care*, *30*(2), 203–209. <https://doi.org/10.2337/dc06-1128>

Park, S. W., Goodpaster, B. H., Strotmeyer, E. S., de Rekeneire, N., Harris, T. B., & Schwartz, A. V. (2006). Decreased muscle strength and quality in older adults with type 2 diabetes: The health, aging, and body composition study. *Diabetes*, *55*(6), 1813–1818. <https://doi.org/10.2337/db05-1183>

Park, S. W., Goodpaster, B. H., Strotmeyer, E. S., Kuller, L. H., Broudeau, R., Kammerer, C., et al. (2007). Accelerated loss of skeletal muscle strength in older adults with type 2 diabetes: The health, aging, and body composition study. *Diabetes care*, *30*(6), 1507–1512. <https://doi.org/10.2337/dc06-2537>

Patel, K. V., Coppin, A. K., Manini, T. M., Lauretani, F., Bandinelli, S., Ferrucci, L., et al. (2006). Midlife physical activity and mobility in older age: The INCHIANTI study. *American Journal of Preventive Medicine*, *31*(3), 217–224. <https://doi.org/10.1016/j.amepre.2006.05.005>

Perkisas, S., & Vandewoude, M. (2016). Where frailty meets diabetes. *Diabetes/Metabolism Research and Reviews*, *32*(Supplement 1), 261–267. <https://doi.org/10.1002/dmrr.2743>

Rantanen, T., Guralnik, J. M., Foley, D., Masaki, K., Leveille, S., Curb, J. D., et al. (1999). Midlife hand grip strength as a predictor of old age disability. *Journal of the American Medical Association*, *281*(6), 558–560. <https://doi.org/10.1001/jama.281.6.558>

Silventoinen, K., Magnusson, P. K., Tynelius, P., Batty, G. D., & Rasmussen, F. (2009). Association of body size and muscle strength with incidence of coronary heart disease and cerebrovascular diseases: A population-based cohort study of one million Swedish men. *International Journal of Epidemiology*, *38*(1), 110–118. <https://doi.org/10.1093/ije/dyn231>

Stenholm, S., Tiainen, K., Rantanen, T., Sainio, P., Heliövaara, M., Impivaara, O., et al. (2012). Long-term determinants of muscle strength decline: Prospective evidence from the 22-year mini-Finland follow-up survey. *Journal of the American Geriatrics Society*, *60*(1), 77–85. <https://doi.org/10.1111/j.1532-5415.2011.03779.x>

Tay, J., Goss, A. M., Locher, J. L., Ard, J. D., & Gower, B. A. (2019). Physical function and strength in relation to inflammation in older adults with obesity and increased cardiometabolic risk. *The Journal of Nutrition, Health & Aging*, *23*(10), 949–957. <https://doi.org/10.1007/s12603-019-1260-4>

van der Kooij, A.-L. L., Snijder, M. B., Peters, R. J., & Van Valkengoed, I. G. (2015). The association of handgrip strength and type 2 diabetes mellitus in six ethnic groups: An analysis of the HELIUS study. *PLoS One*, *10*(9). <https://doi.org/10.1371/journal.pone.0137739>. Article e0137739.

World Health Organization. (1999). Definition, diagnosis and classification of diabetes mellitus and its complications: Report of a WHO consultation. *Part 1, Diagnosis and Classification of Diabetes Mellitus*. Retrieved from <https://apps.who.int/iris/handle/10665/66040> Accessed Sep 16, 2020.

World Health Organization. (2011). Global health and aging. Retrieved from https://www.who.int/ageing/publications/global_health.pdf Accessed Aug 13, 2020.

Zhang, Y., Niu, J., Kelly-Hayes, M., Chaisson, C. E., Aliabadi, P., & Felson, D. T. (2002). Prevalence of symptomatic hand osteoarthritis and its impact on functional status among the elderly: The Framingham study. *American Journal of Epidemiology*, *156*(11), 1021–1027. <https://doi.org/10.1093/aje/kw141>

Zheng, Y., Ley, S. H., & Hu, F. B. (2018). Global aetiology and epidemiology of type 2 diabetes mellitus and its complications. *Nature Reviews Endocrinology*, *14*(2), 88. <https://doi.org/10.1038/nrendo.2017.151>