Handgrip strength as a screening tool for diabetes in resource-constrained settings: a potential solution to overcome barriers to diagnosis

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Abstract

Background Information

Diabetes mellitus is an escalating global health concern, especially in low and middle-income countries. Handgrip strength (HGS), a measure of muscle strength, emerges as a potential non-invasive and affordable screening tool for diabetes, particularly in areas with limited healthcare access.

Objective

To investigate the relationship between handgrip strength and blood glucose regulation in non-diabetic young adults and to provide valuable insights into the potential of handgrip strength as a preventive and affordable approach to managing diabetes.

Methods

A cross-sectional study included 59 University of Ilorin students aged 18-21 in Nigeria. Handgrip strength was measured with a dynamometer, and its links to blood glucose markers (fasting blood glucose, 2-hour post-prandial glucose, and HbA1c) were explored using multiple regression models.

Results

Findings revealed significant associations between HGS and glucose regulation markers, particularly FBS, among males. The relationship was evident in females only after adjusting for body mass index (BMI). Furthermore, a notable connection between HGS and 2-hour post-prandial glucose levels was observed in females but not males. However, no significant associations were found between HGS and serum insulin levels across genders.

Conclusion

Our study introduces handgrip strength (HGS) as a practical, cost-effective screening tool for blood glucose regulation disorders in resource-constrained settings. However, the study's limitations, such as a small sample size and demographic restrictions, underscore the need for future research to validate HGS's real-world efficacy in diverse populations.

Keywords: Handgrip strength, blood glucose regulatory markers, diabetes screening tool

Introduction

Diabetes mellitus is a global health concern, with a rapid increase in diagnosed cases and a projected rise to 625 million adults affected by 2045, primarily in low and middle-income countries (1-3). Managing diabetes comes with substantial lifetime medical costs, especially for complications, with Africa expected to bear a significant burden despite low contributions to global diabetes care expenses (4).

In 2017, the International Diabetes Federation estimated diabetes-related health expenditure at $3.3 billion, with Nigeria alone incurring direct costs ranging from $1.071 billion to $1.639 billion (5). In the United States, diabetes is a leading cause of death, contributing to 69,091 deaths and impacting an additional 234,051 deaths (6).

Africa recorded over 298,160 diabetes-related deaths in 2017, with 6% of all mortality attributed to diabetes, most significantly in the 30-39 age group, and 77.0% of diabetes-related deaths occurred in individuals under 60 years old (5). Diabetes is linked to severe complications and adverse health outcomes (7).

In resource-constrained settings, obstacles like difficult access to healthcare and expensive transportation frequently cause patients to put off receiving treatment. To close this gap, trained volunteers known as Community Health Workers (CHWs) provide vital healthcare and education to underserved rural communities in developing countries (8).

As expensive tools like blood glucometers may go unused owing to budget restrictions and safety concerns surrounding blood samples, CHWs require accessible and inexpensive biomedical tools for effective sickness detection and diagnosis (4).

An alternative screening tool that shows promise in resource-constrained settings is handgrip strength, a simple measure of muscle strength that correlates well with other strength measures, such as quadriceps strength (8). Handgrip strength has been associated with metabolic syndrome, type 2 diabetes mellitus, and overall mortality (9); (10); (11). It indicates overall strength and physical activity level, as it measures the force produced by the muscles controlling the hand using a hand dynamometer (12).

Studies have investigated resistance exercises' positive impact on glucose metabolism, improving muscle function and insulin-mediated glucose uptake in skeletal muscle, although the exact mechanism is not fully understood (13).

Considering its relevance to various diseases like diabetes, malnutrition, and functional disability, handgrip strength testing with affordable and durable hand dynamometers has gained prominence (4). With limited access to healthcare in nations like Nigeria, this strategy offers a preventive and economical way to control diabetes (4). By utilising handgrip strength as a screening tool, barriers to diagnosis, such as high costs and limited access to healthcare professionals, can be overcome, facilitating early identification and intervention in high-risk populations.

Therefore, this study aims to investigate the relationship between handgrip strength and blood glucose regulation in non-diabetic young adults. By establishing this connection, the study intends to provide valuable insights into the potential of handgrip strength as a preventive and affordable approach to managing diabetes, ultimately reducing the economic implications of the disease, particularly in resource-constrained settings.

Materials and methods

Participants

One hundred students from the University of Ilorin, Nigeria, were initially recruited for this study. The recruitment process started on the 10th of July to the 10th of August 2023 and was conducted through advertisements on social platforms, and participants were selected on a “first come” basis. All samples were collected, and procedures were carried out on the 15th and 16th of August 2023. Due to incomplete data, information from only fifty-nine recruited students was used for the final computation and analysis of results.

Inclusion criteria

The data collected for this study included currently enrolled students aged 18-30 years who exhibited normoglycemia with fasting blood glucose levels ranging from 70-100 mg/dL. Participants were also required to have no significant health conditions or physical impairments that could affect their grip strengths or fasting blood glucose levels.

Exclusion criteria

Students with missing information, a history of elevated blood glucose or a diagnosis of diabetes, and those who were unwilling or unable to undergo handgrip strength measurements as part of the study protocol were excluded from the analysis.

Dependent variables

This study's dependent variables were glycaemic control and insulin resistance among non-diabetic students. As indicators, glycaemic control was assessed using HbA1c, fasting blood glucose, and 2-hour postprandial blood glucose. HbA1c is a marker for hyperglycaemia and provides information about blood plasma glucose levels over 2–3 months. An HbA1c above 7% and a 2-hour postprandial plasma glucose greater than 140 mg/dL indicate poor glycaemic control (14).

Glycaemic control

HbA1c, also known as glycated haemoglobin, is formed when haemoglobin is exposed to plasma glucose through non-enzymatic pathways. It serves as a marker for hyperglycaemia and monitors blood plasma glucose levels over a prolonged period. Several factors, such as a high-fat diet, smoking (15), and body fat (16), can influence HbA1c levels. Two-hour postprandial blood glucose, measured two hours after a meal, is an essential indicator of postprandial plasma glucose levels, which play a significant role in overall glycemic control.

Insulin resistance

A fasting serum insulin above ten µIU/mL was diagnostic of insulin resistance (17). In addition to serum insulin, fasting venous blood samples were collected to measure plasma glucose, C-peptide, and glycated haemoglobin levels. Plasma glucose was measured using a modified hexokinase enzymatic method, serum insulin was measured by radioimmunoassay, and glycated haemoglobin was measured using high-performance liquid chromatography (18).

Independent variables

Handgrip strength

It was assessed using a dynamometer and is associated with various chronic diseases (19), cognitive decline (20), length of hospital stays, and mortality. Before measuring handgrip strength, participants were given instructions and a warm-up for their hands and fingers. The measurements were taken while participants stood with their feet hip-width apart and arms straight, slightly away from the body. Each hand was tested thrice, with a rest period between trials (21).

Relative handgrip strength

Relative HGS was calculated by dividing absolute HGS (kg) by BMI (reported as kg/BMI). This measure was used to adjust for the relationship between mass and force, considering both muscle quality and the combined effect of fat mass and muscle mass (22).

Height and body weight

Height and body weight were measured using standardised procedures (23). Participants' standing height was measured with a stadiometer, and body weight was measured using a digital scale. Body mass index (BMI) was calculated by dividing the body weight (kilograms) by the square of height (meters) (kg/m^2).

Waist/hip ratio

Waist circumference was measured between the narrowest point between the ribs and hips, while hip circumference was measured at the point where the buttocks extended the most using a tape (24). Two consecutive recordings were made for each site.

Co-variates

The covariates in this study included sociodemographic characteristics, lifestyle factors, and self-reported family history of diseases. Sociodemographic characteristics covered age (years, continuous), gender (male/female), country, and ethnicity. Lifestyle factors included self-reported exercise, drinking, and smoking.

Statistical analysis

A cross-sectional analysis was conducted and recorded as means (standard deviations) for continuous variables and frequencies for categorical variables. Differences between groups were assessed using ANOVAs or chi-square tests for continuous or categorical variables. Multiple linear regression models examined the association between glucose regulation and grip strength. IBM SPSS Statistics Version 25.0 (IBM Corp., Armonk, New York, USA) was used for all statistical analyses.

Results

Overall, data from 59 subjects (male 30 = 50.8 % and female 29 = 49.2 %) with a mean age of 18 to 21 years were used for this study. Dominant HGS ranged from 11.5 - 29.8 kg with an interquartile range (IQR) of 18.4 – 25.1 kg (6.7 kg) in females and from 15.0 – 33.2 kg with an IQR of 21.6 – 27.4 kg (5.8 kg) in males (Table 1).

Table 1: Sample Clinical Characteristics and biomarkers showing Mean, Quartiles, Interquartile Range & Standard deviation of Continuous variables and Percent (%) of Categorical variables (N = 59)

	Mean	**Median**	**Min**	**Max**	**25%**	**75%**	**Interquartile Range (%)**	**Std Dev**
HGS Right Hand (kg)	22.95	22.70	11.50	33.2	20.1	26.2	6.1	4.534
HGS Left Hand (kg)	21.46	21.20	13.80	31.80	18.2	24.9	6.7	4.543
Absolute HGS (kg)	46.22	45.60	28.40	67.80	41.4	52.4	11.0	8.706
Relative HGS (m^2)	2.13	2.12	0.98	3.81	1.82	2.39	0.57	0.520
BMI (Kg/m^2)	22.32	22.00	15.40	38.6	19.4	23.8	4.4	4.304
Waist/Hip Ratio	0.79	0.80	0.70	1.1	0.7	0.80	0.1	0.078
Pulse Pressure (mmHg)	49.34	49.00	30.0	68	43.0	57.0	14.0	9.278
Fasting Blood Glucose (mmol/L)	4.86	4.80	3.60	6.4	4.5	5.3	0.8	0.560
HBA1c (%)	3.73	3.42	0.51	8.58	2.87	4.59	1.72	1.396
2-hour Postprandial Glucose (mmol/L)	5.20	5.20	3.90	7.6	4.5	5.7	1.2	0.779
Serum Insulin (µIU/L)	18.86	14.09	5.88	158.55	10.58	19.59	9.01	20.522
	N	(%)						
Gender								
Male	30	50.8						

Female	29	49.2
Age		
18-21	19	32.2
22-25	38	64.4
26-30	2	3.4
Smokes		
Yes	0	0.0
No	59	100.0
Alcohol Intake		
Yes	6	10.2
No	53	89.8
Does Exercise		
Yes	29	49.2
No	30	50.8
Hand Dominance		
Right	51	86.4
Left	8	13.6

BMI denotes body mass index
HBA1c denotes glycated haemoglobin
HGS denotes Handgrip strength

In this study, HGS < 18kg was defined as low while HGS >18kg was defined as normal, fasting blood sugar between 3.9-5.9mmom/l and 2HPG < 7.8 mmol/l was defined as the normal range of blood glucose levels. HGS values recorded from study subjects were within the normal range with a mean of 21.07kg and 18.70kg for dominant and non-dominant hands, respectively.

The dominant HGS in females (mean = 21.4 ± 4.53) was significantly reduced (p = 0.005) when compared to males (mean = 24.6 ± 4.06). (Table 2). Non-dominant HGS ranged from 13.8 - 25.8 kg with an interquartile range (IQR) of 15.7 – 21.2 kg (5.5 kg) in females and from 14.7 – 31.8 kg with an IQR of 20.5 – 26.1 kg (5.6 kg) in males. The non-dominant HGS in females (mean = 18.9 ± 3.61) was significantly reduced (p = 0.001) when compared to males (mean = 24.0 ± 4.09). (Table 2)

Table 2: Clinical Characteristics and biomarkers by sex

	Males		Females		
	Mean	Std Dev	Mean	Std Dev	p-value
HGS Right Hand (kg)	24.62	4.06	21.37	4.53	0.008
HGS Left Hand (kg)	24.01	4.09	18.97	3.61	0.000
Absolute HGS (kg)	4975	8.27	42.87	7.99	0.003
Relative HGS (m^2)	2.37	0.61	1.93	0.40	0.003
BMI (Kg/m^2)	21.59	3.47	22.85	5.13	0.357
Waist/Hip Ratio	0.82	0.06	0.77	0.09	0.020
Pulse Pressure (mmHg)	53.65	8.02	44.55	8.14	0.000
Fasting Blood Glucose (mmol/L)	4.69	0.64	5.01	0.44	0.042
HBA1c (%)	3.81	1.24	3.61	1.56	0.519
2-hour Postprandial Glucose (mmol/L)	5.15	0.75	5.22	0.83	0.818
Serum Insulin (µIU/L)	17.40	8.76	15.65	9.01	0.449
	N = 30	**%**	**N = 29**	**%**	
Age					
18-21	6	20.0	13	44.83	
22-25	23	77.0	15	51.72	
26-30	1	3.0	1	3.45	
Smokes					
Yes	0	0.0	0	0.00	
No	30	100.0	29	100.00	
Alcohol Intake					
Yes	1	3.3	5	17.24	
No	28	93.4	24	82.76	
Missing	1	3.3	0	0.00	
Does Sports					
Yes	19	63.3	10	34.48	
No	11	36.7	19	65.52	
Hand Dominance					
Right	27	90.0	25	86.21	
Left	3	10.0	4	13.79	

BMI denotes body mass index
HBA1c denotes glycated haemoglobin
HGS denotes handgrip strength
Values of absolute handgrip strength were calculated by summating dominant and non-dominant handgrip strength.
Values of relative handgrip strength were calculated from absolute handgrip strength divided by body mass index.

In both sexes, there was a significant difference (female p = 0.03 & male p = 0.04) (Fig 1) in HGS between both hands, suggesting that hand dominance could be a relevant factor in this study. As such, dominant and non-dominant HGS results were also considered independently (Table 3).

Fig 1:

Table 3: Results of Multiple linear regression of handgrip strength (dominant and non-dominant) on blood glucose regulation biomarkers

	Male Handgrip Strength				Female Handgrip strength			
	Dominant		Non-dominant		Dominant		Non-dominant	
	Estimate (SE)	p	Estimate (SE)	p	Estimate (SE)	P	Estimate (SE)	P
Fasting Blood Glucose	0.3758 (0.59)	**0.04**	0.3941 (0.61)	0.07	0.3218 (0.42)	0.09	0.2330 (3.58)	0.22
2-hour Post Prandial	0.1117 (0.76)	0.55	0.1049 (0.76)	0.57	0.3407 (0.78)	0.07	0.3887 (3.39)	**0.04**
HBA1c	0.0184 (1.26)	0.92	0.1277 (1.25)	0.57	0.0587(1.58)	0.76	0.2090 (3.60)	0.28
Serum Insulin	0.2303 (8.82)	0.22	0.2226 (8.83)	0.22	0.0846 (9.14)	0.66	0.0678 (28.48)	0.73

Multiple regression analysis examined the relationships between handgrip strength and the blood glucose regulatory markers, specifically fasting blood glucose, 2 hours postprandial glucose, HBA1c and serum insulin levels. Four different models were tested to account for potential confounders: Model 1 (no adjustments), Model 2 (adjusted for WHR), Model 3 (adjusted for BMI), and Model 4 (adjusted for both WHR and BMI) (Tables 4, 5 and 6).

Table 4: Results of Multiple regression of absolute handgrip strength and relative handgrip strength on blood glucose regulation biomarkers

	Absolute Handgrip Strength				Relative Handgrip strength			
	Male		Female		Male		Female	
	Estimate (SE)	p	Estimate (SE)	p	Estimate (SE)	P	Estimate (SE)	P
Fasting Blood Glucose	0.322 (0.62)	0.09	0.319 (0.42)	0.08	0.139 (0.64)	0.46	0.08 (0.45)	0.68
2-hour Post Prandial	0.067 (0.76)	0.72	0.396 (0.77)	**0.03**	0.287 (0.73)	0.12	0.284 (0.80)	0.14
HBA1c	0.088 (1.25)	0.64	0.085 (1.58)	0.66	0.335 (1.19)	0.07	0.303 (1.51)	0.11
Serum Insulin	0.232 (8.67)	0.21	0.102 (9.12)	0.59	0.227 (8.68)	0.22	0.079 (9.14)	0.68

SE denotes a standard error. HbA1c denotes glycated haemoglobin.

Table 5: Adjusted Relationships of Handgrip Strength with Blood Glucose Regulatory Markers (males n=29)

	Fasting blood glucose		2-hour postprandial		HBA1c		Serum Insulin	
Absolute HGS	Estimate (SE)	P	Estimate	P	Estimate	P	Estimate	P
Model 1[a]	0.3755 (0.59)	**0.04**	0.1133 (0.76)	0.55	0.0560 (1.26)	0.77	0.2318 (8.82)	0.22
Model 2[b]	0.4543 (0.58)	**0.04**	0.2511 (0.75)	0.42	0.2165 (1.26)	0.52	0.3694 (8.58)	0.14
Model 3[c]	0.5311 (0.56)	**0.01**	0.4231 (0.70)	0.07	0.3239 (1.22)	0.22	0.2435 (8.95)	0.44
Model 4[d]	0.5465 (0.56)	**0.03**	0.4311 (0.71)	0.14	0.3392 (1.23)	0.36	0.3707 (8.74)	0.27
Relative HGS								
Model 1[a]	0.0436 (0.64)	0.82	0.2223 (0.74)	0.24	0.2947 (1.21)	0.11	0.2408 (8.79)	0.20
Model 2[b]	0.2408 (0.64)	0.45	0.2769 (0.75)	0.34	0.3248 (1.22)	0.22	0.3406 (8.68)	0.19

Note: Boldface indicates statistical significance (p<0.05).
SE denotes standard error. HBA1c denotes glycated haemoglobin
[a] Multiple Linear regression analysis
[b] Adjusted for Waist-hip ratio (WHR)
[c] Adjusted for Body mass index (BMI)
[d] Adjusted for WHR and BMI

Table 6. Adjusted Relationships of Handgrip Strength with Blood Glucose Regulatory Markers (females n=30)

	Fasting blood glucose		2-hour postprandial		HBA1c		Serum Insulin	
Absolute HGS	Estimate (SE)	P	Estimate	P	Estimate	P	Estimate	P
Model 1[a]	0.319 (0.42)	0.08	0.396 (0.77)	**0.03**	0.085 (1.58)	0.66	0.102 (9.12)	0.59
Model 2[b]	0.3683 (0.42)	0.15	0.4243 (0.77)	0.08	0.1553 (1.59)	0.73	0.1671 (9.21)	0.69
Model 3[c]	0.4641 (0.40)	**0.04**	0.4336 (0.77)	0.07	0.4801 (1.42)	**0.03**	0.1037 (9.29)	0.87
Model 4[d]	0.4872 (0.41)	0.08	0.4541 (0.78)	0.12	0.4866 (1.44)	0.08	0.1672 (9.39)	0.87
Relative HGS								
Model 1[a]	0.0800 (0.45)	0.68	0.2840 (0.80)	0.14	0.3030 (1.51)	0.11	0.0790 (9.14)	0.68
Model 2[b]	0.1626 (0.45)	0.71	0.3291 (0.81)	0.23	0.3176 (1.53)	0.25	0.1567 (9.23)	0.72

Note: Boldface indicates statistical significance ($p<0.05$).
SE denotes standard error. HBA1c denotes glycated haemoglobin
[a] Multiple Linear regression analysis
[b] Adjusted for Waist-hip ratio (WHR)
[c] Adjusted for Body mass index (BMI)
[d] Adjusted for WHR and BMI

Findings in males and females

While maintaining normal ranges in the blood regulatory markers (FBS, 2-hour Postprandial and HBA1c), serum insulin levels were slightly elevated in both sexes (male 17.40±8.76 female 15.65±9.01).

Fasting blood glucose

In males, a notable finding emerged as absolute handgrip strength was consistently linked to fasting blood glucose levels across all models (P<0.05), irrespective of adjustments made for WHR and BMI (Table 5). This association persisted, highlighting the robustness of the relationship. In contrast, among females, absolute HGS was only found to be associated with blood glucose levels following adjustments to BMI (Model 3) (Table 6).

2-hour post-prandial glucose

The investigation into the relationships between handgrip strength and 2-hour post-prandial glucose levels showed a significant ($p<0.05$) association in females. Notably, no significant relationships were observed in males.

HBA1c

For females, an exciting finding emerged in Model 3, where adjustments were made for BMI. In this scenario, a significant positive relationship was observed between absolute HGS and HBA1c levels. It is worth noting that this association was not observed in males or other models.

Serum insulin

Irrespective of gender, our analyses found no significant associations between HGS and serum insulin levels across all models tested.

Discussion

Our research reveals complex relationships between handgrip strength and blood indicators for diabetes, including fasting glucose, HBA1c, and serum insulin. Notably, even when other regulatory indicators were normal, increased blood insulin levels were seen in both male and female subjects.

Our study highlights a strong and consistent correlation between handgrip strength and fasting blood glucose levels in males, even considering factors like waist-hip ratio and BMI. This suggests handgrip strength is a reliable marker for glucose metabolism in males. However, in females, the connection is evident only after accounting for BMI, indicating that body composition influences this relationship.

The results for males are consistent with previous studies highlighting the impact of enhanced muscle metabolism and testosterone levels on insulin sensitivity (25); (26). Testosterone has been shown to promote muscle glucose uptake and function (27), making muscles a vital site for glucose absorption. A stronger handgrip may indicate better neuromuscular junction efficiency, potentially influencing metabolic processes like glucose regulation (28).

In females, the relationship between handgrip strength (HGS) and glucose metabolism appears complex. The findings suggest that factors like body fat percentage, typically higher in females (29), may confound the HGS-glucose metabolism connection. Increased adiposity has been linked to insulin resistance and glucose disruption (30). After adjusting for BMI, the relationship becomes significant, highlighting the potential mediation of body composition, especially fat mass, in this connection. Adipose tissue's role as an endocrine organ-releasing factor, including adipokines, can influence insulin sensitivity and glucose metabolism (31), with implications for insulin resistance pathogenesis. The interplay between muscle and fat tissue in females is intricate, involving hormones and adipokines, warranting further investigation.

Our study, in line with Niemann et al.'s findings (32), revealed no direct link between handgrip strength and serum insulin levels. However, Lazarus et al.'s study in 1997 reported a modest correlation (33), indicating the variability of this relationship across different populations and methodologies. Although stronger muscles might be expected to enhance glucose uptake and influence insulin levels, our results suggest complex physiological mechanisms are at play. Factors like fasting, trauma, and certain diseases influence skeletal muscle mass balance, which can accelerate muscle protein breakdown. Insulin, a pivotal hormone, controls essential proteins such as FOXO transcription factors (34). These insights provide a valuable understanding of the intricate connection between muscle strength and insulin function.

We identified a notable association between handgrip strength and 2-hour post-prandial glucose levels, but this was evident only in females and not males. A similar study by Huang in 2023 emphasised that the effect of handgrip strength on Type 2 Diabetes Mellitus (T2DM) could be influenced by factors such as BMI and gender (35). This gender divergence in results underlines the need to consider gender-specific physiological pathways when using handgrip strength as a diabetes screening tool.

For females, the significant correlation may be attributed to the role of estrogen, which is known to modulate muscle function and insulin sensitivity. Studies by Chidi-Ogbolu & Baar (36) and Camporez et al. (37) support this assertion, indicating estrogen's potential to enhance insulin-stimulated glucose uptake in muscles (38).

On the other hand, the relationship in males is more intricate due to testosterone's fluctuating effects on insulin sensitivity. While testosterone's influence on muscle strength is well-documented, its impact on insulin sensitivity can vary based on age and general health. This observation aligns with findings by Dhindsa et al., 2016 (39), complicating the establishment of a direct link between handgrip strength and post-prandial glucose levels in males.

Our study's salient observation is the link between handgrip strength and HbA1c levels, especially when considering BMI. This association sheds light on the intricate interplay of hormonal and metabolic factors in the human body. Similarly, Mainous III et al., 2015, highlighted that handgrip strength negatively correlated with HbA1c levels (40), strengthening the credibility of HbA1c as a marker for prolonged glucose control.

The association between muscle, fat tissue, and glucose regulation is persistent, indicating the importance of handgrip strength as a potential indirect indicator of long-term glycemic control in areas with limited resources. This assertion is consistent with the findings of Jang et al., 2020, who explored the relationship between relative handgrip strength and prediabetes based on HbA1c levels and emphasised the significance of sex differences (38).

Hormones like testosterone and estrogen influence body fat distribution and muscle metabolism, impacting long-term glucose regulation and HbA1c levels. Testosterone promotes abdominal fat storage and muscle growth, while estrogen affects fat distribution and plays a distinct role in muscle metabolism. The interplay of muscle's glucose uptake and fat tissue's release of adipokines, along with hormones like insulin and thyroid hormone, shapes the complex relationship between handgrip strength and HbA1c levels.

Conclusion

The results of this study show that handgrip strength (HGS) can be a valuable measure for determining diabetes risk and directing prompt treatment. By incorporating HGS evaluations into healthcare, exercise-based programs can help individuals control their blood sugar levels. HGS is a cheap, non-invasive screening technique that is especially helpful for community health workers in areas with limited resources. In developing nations, it can close diagnostic gaps and reduce budgetary constraints. The study's limitations, including its small sample size and concentration on students, call for more research to expand its application.

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