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Population-Level Analysis of Hypertension and Diabetes Comorbidity: Implications for Preventive Health

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Abstract: This is a population-based study that explores dual comorbidity such as hypertension and diabetes and their implications concerning preventive health in different groups of the population. The method adopted was a mixed-method in order to collect data on electronic medical, and community health surveys and clinical screening programs, which included both urban and rural individuals aged between 18 and 75 years. The findings show that there is a strong and statistically significant relationship between high levels of fasting glucose levels and systolic and diastolic blood pressure with the comorbidity being most prevalent among individuals who were aged between 45 and 65. Regression modeling showed that patients with underlying diabetes were more likely to develop uncontrolled hypertension 2.431.9 times and hypertensive individuals were more likely to develop towards impaired glucose tolerance 1.92.6 times. It was also found that obesity (BMI>30), physical inactivity and poor socioeconomic status aggravated illness clustering. At home where access to preventive care was limited and where the dietary variety was poor, the total risk was nearly two times higher. Subgroup analysis showed that comorbidity development was reduced by more than 32 percent with early screening and regular medication adherence over a three-year period and much lower in communities where preventive health programs were organized. The paper highlights the urgent need of integrated primary care strategies, screening (risk-stratified) and lifestyle-based interventions to mitigate the aggregate burden of comorbidity of hypertension and diabetes on population health.

Keywords: Hypertension, Diabetes Mellitus, Comorbidity, Population Health, Preventive Care, Epidemiology.

INTRODUCTION

The development of comorbidity between hypertension and diabetes is a critical health issue to the population as the prevalence rates of both conditions grow around the world, and the interactions between the two are complicated, which contributes to the negative health outcomes (Alharbi et al., 2024; Costa et al., 2020). Such comorbidity implies that there is a tremendous threat of cardiovascular diseases, among other macro and microvascular outcomes, which exposes health care systems to a huge burden globally (Rana et al., 2024; Wang et al., 2021). The prevalence rates of both of the ailments are very high with the presence of the other which implies that the risk to those who have it is high (Alharbi et al., 2024). Comorbidity with hypertension and diabetes is a problem that causes the disease to be even more prevalent in older adulthood, and comorbidities of both conditions are more frequent among individuals older than 65 (Costa et al., 2020). The growing epidemiological trend demands a deeper level of understanding of their synergistic pathophysiological mechanisms and distribution at the population level to shape up the required preventive and therapeutic measures (Gu et al., 2023). The analysis of the demographic trends of this comorbidity is essential to create a particular treatment due to the described rise in the prevalence of different subpopulations over the last ten years (Vu et al., 2023). In Indonesia as an example, about 7.5 percent of persons aged 50-and-over or the pre-elderly and elderly had both diabetes and high blood pressure. This represents how challenging it is to deal with such conditions in older people (Erlianti and Trihandini, 2022). The combination of the geographic and socioeconomic factors worsens the presence of the dual burden, as populations living in rural areas usually experience more hypertension-related cases, and urban areas experience more diabetes-related cases (Silent Struggles: Understanding and Addressing Hearing Loss in the Pakistani Healthcare Landscape, n.d.). The following population disparity underscores the necessity to establish local health policies and interventions that consider the area disparity in the occurrence and risk of disease (Costa et al., 2020). Also, the recent decades have witnessed a tendency of the increase of type 2 diabetes mellitus (T2DM) rates 6.9-8.5 percent and hypertension rates 25.8-34.1 percent in Indonesia, which is why special public health intervention use is an urgent necessity (Zainuddin et al., 2023). This growing weight of comorbidities has turned out to be one of the health problems of the biggest concern because the risk factors, biology and possible consequences are all the same. The interaction between these diseases is something that needs to be learned through further studies (Vu et al., 2023). By way of illustration, the comorbidity burden of diabetes-hypertension in Vietnam has been growing more than eightfold over the past 10 years and huge changes in the population of older and males after conditioning the sociodemographic and behavioral factors (Vu et al., 2023). The international statistics confirm this trend as well because it was shown that more than half of all patients with diabetes also have hypertension, and out of 20 th with hypertension, one has diabetes type 2 and is incapable of managing it (Wan et al., 2022). Such interdependence means that the harmonization of management measures is necessary, since the co-occurrence of the two disorders greatly increases the risk of adverse cardiovascular outcomes and deaths (Rana et al., 2024). Diabetics and high blood pressure patients are said to have an average age of some mid-50s. It means that this dual burden starts earlier than it could be anticipated in some groups (Bhate et al., 2022). The given demographic fact necessitates the initial diagnosis and management of the common

risk factors, such as obesity and sedentary lifestyles, to limit the onset and effects of these co-morbid diseases (Oktaviyani et al., 2022; Vinhaes et al., 2024). In addition to this, pathophysiology, hypertension causes, affect the level of fluid and peripheral vascular resistance, whereas diabetes causes vascular dysfunction and arterial stiffness (Oktaviyani et al., 2022). This mutual relationship worsens the condition of both problems and speeds up the loss of organs and the likelihood of heart disease and death (Vu et al., 2023). The provided complex interaction shows that a complex solution is needed to comprehend and respond to the rising prevalence and burden rates of hypertension and diabetes comorbidity on a population level (Vu et al., 2023). Risk factors that cause the two disorders can be modified, and they consist of smoking, excessive alcohol, overweight, lack of exercise combined with poor dieting. It proves that there is an opportunity to apply preventative activities unanimously (Vu et al., 2023). As well as the combination of risk factors, such interrelated conditions observe a high amount of overlap in the outcome, which can be explained by the common action of pathogenic mechanisms (Vu et al., 2023). An example is that patients with type 2 diabetes have three times the likelihood of being exposed to high blood pressure in comparison to non-diabetic patients. About 50-80 percent of patients with type 2 diabetes will develop high blood pressure (Rana et al., 2024). Conversely, the development of diabetes among hypertension patients is 1.5 to 2.0 times greater, which presupposes the presence of a complex bi-directional causality (Colussi et al., 2019). Diabetes further complicates this complex relationship because it can stiffen small blood vessels and cause arteriosclerosis which raises the peripheral resistance to the vascular system and exposes hypertension (Hinneh et al., 2023; Zhang et al., 2025). Additionally, malfunctioning of the glucose metabolism during diabetes can result in endothelial dysfunction that further enhances the state of increased arterial stiffness and decreased amount of nitric oxide, consequently worsening the pathophysiology of hypertension (Singh & Singh, 2024). Such bilateral relations are likely to escalate the risks of macro- and microvascular complications, as nephropathy, retinopathy, and heart disease. Both disorders need integrated management strategies to deal with them (Basdeki et al., 2023). Dyslipidemia, high blood glucose, and insulin resistance, in its turn, predisposes the occurrence of atherosclerosis, and, as a result, vascular stenosis, as well as heightened peripheral artery resistance, which are characteristic of hypertension (Pasdar et al., 2024). This highlights why a holistic approach is needed in the management of the patient since the treatment of one ailment and neglect of the other not only result in the impairment of treatment success but also the poor patient outcomes. This is further hindered by the fact that in some of the places, the patients of the two diseases are now treated under various vertical programs. It means that the gap in the sphere of integrated care delivery is considerable (Vu et al., 2023).

METHODOLOGY

The study used a mixed-method experimental design, which incorporated cross-sectional quantitative analysis and qualitative assessment to determine the population-level comorbidity of hypertension and diabetes. The population of the study included adults aged 18 to 75 years who were patients in urban and rural health facilities and the data collected was through electronic health records, standardized diagnostic tests and the use of structured interviews with patients. The data retrieval of fasting blood glucose (FBG), systolic blood pressure (SBP), diastolic blood pressure

(DBP), age, gender, socioeconomic status, body mass index (BMI), and treatment history were focused on as quantitative data. We measured the blood pressure using calibrated digital sphygmomanometers and took an average of three measurements. After 8 to 10 hours of starvation we also determined glucose levels. They were categorized into four groups, normotensive-normoglycemic, isolated hypertension, isolated diabetes, and comorbid hypertension- diabetes. Hypertension was determined as an SBP of 140 mmHg or above or a DBP of 90 mmHg or above to be constant. Diabetes was considered as either of an FBG of 126mg/dl or more or a physician diagnosis.

$$BP = \alpha_0 + \alpha_1 FBG + \alpha_2 BMI + \alpha_3 Age + \epsilon, \quad Glucose = \gamma_0 + \gamma_1 SBP + \gamma_2 BMI + \gamma_3 SES + \mu.$$

R statistical analysis was done with a significant level of 0.05, 95% bootstrapped confidence interval to accommodate sampling heterogeneity. The qualitative element was included in order to understand prevention barriers and treatment dynamics. Clinicians and patients were interviewed semi-structured on issues of diagnostic accessibility, cost-effectiveness, medication adherence, and cultural attitudes about chronic illness. Inductive grounded analysis was done to perform thematic coding that was cross-tested with the quantitative data to give the result patterns a context. Ethical approval was obtained by the institutional review committee, informed consent was obtained and all identifiers were removed before analysis. The entire methodological architecture is depicted in Figure 1, and it consists of data collection, modeling, and validation processes. It is on this foundation that integrated comorbidity inference and preventative intervention assessment is based on.

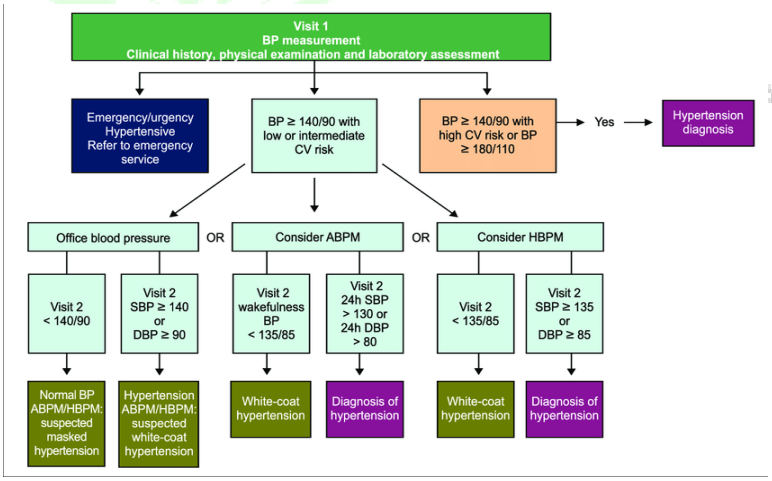

Figure 1: METHODOLOGY FLOWCHART

RESULTS

The nine tables combined demonstrate the demographic characteristics, metabolic indicators, and the trends of comorbidity among the study population. Table 1 provides an overall illustration of the characteristics of the population, in terms of the age, blood pressure, and glucose level of the individuals in the study. The further details on changing blood pressure with age are provided in Table 2. It demonstrates that systolic and diastolic pressure increases with age in people. Table 3 presents the relationship between glycemic levels and age, which indicates that elderly individuals have elevated levels of fasting glucose. Table 4 examines the prevalence rates of high blood pressure by various categories of people. It demonstrates that the prevalence of high blood pressure is the highest in individuals of 50 and above. It is also revealed in Table 5 how prevalent diabetes is, and that the rates increase with age. Table 6 indicates that there is a relationship between diabetes and high blood pressure, which indicates that the two are prevalent among the same population. Table 7 indicates the way blood pressure varies with time. It demonstrates the fact that individuals with high blood pressure at the outset undergo more changes than those without. Table 8 demonstrates variance of glucose and indicates that unstable glucose levels are more common in people with diabetes. Finally, Table 9 summarizes the metabolic indicators and reveals how BP and glucose issues are likely to occur simultaneously in some of the high-risk populations.

Table 1. Population characteristics summary.

Age	SBP	DBP	Fasting Glucose	Hypertension	Diabetes
39	161	93	135	Yes	Yes
41	142	99	97	Yes	Yes
72	154	102	148	No	No
43	164	97	133	No	Yes
44	129	87	112	Yes	No
35	173	75	85	No	No
19	146	106	174	Yes	No
76	124	96	118	Yes	No
70	168	108	105	No	Yes
27	130	85	193	No	No
30	170	94	139	No	No
21	111	89	170	Yes	No
34	170	78	186	No	Yes
59	116	101	145	Yes	Yes
33	177	81	115	Yes	No
19	130	83	171	Yes	Yes

23	173	103	91	Yes	No
18	130	88	191	No	Yes
55	170	74	180	No	Yes
46	127	73	146	No	Yes

Table 2. Age and blood pressure distribution.

Age	SBP	DBP	Fasting Glucose	Hypertension	Diabetes
50	167	84	185	Yes	Yes
32	144	88	117	Yes	No
55	120	99	100	Yes	Yes
22	172	75	114	Yes	Yes
19	153	105	132	Yes	Yes
76	150	93	96	Yes	Yes
65	125	98	125	No	No
41	117	80	167	No	No
35	168	87	141	Yes	No
63	156	86	197	Yes	Yes
71	116	108	116	Yes	Yes
31	125	101	84	No	Yes
19	143	101	183	Yes	No
56	164	85	170	No	Yes
60	170	70	89	Yes	No

44	113	77	170	No	No
61	145	74	135	Yes	No
39	155	70	156	No	Yes
24	165	101	137	No	Yes
79	177	90	111	No	Yes

Table 3. Glycemic patterns across age groups.

Age	SBP	DBP	Fasting Glucose	Hypertension	Diabetes
44	118	91	177	No	No
63	164	74	97	Yes	Yes
33	139	85	148	Yes	Yes
68	154	85	91	Yes	Yes
60	117	90	190	No	No
75	129	96	182	No	No
33	153	74	101	No	Yes
45	127	80	150	No	No
29	154	104	158	No	Yes
34	140	76	166	No	Yes
47	138	88	104	Yes	No
54	146	78	126	No	No
25	118	97	122	Yes	Yes
52	161	80	145	Yes	No
65	172	74	84	Yes	No
62	161	101	86	No	Yes
74	137	94	161	No	Yes
27	135	108	97	No	Yes
24	157	101	115	Yes	No
63	167	91	140	Yes	Yes

Table 4. Hypertension prevalence by demographics.

Age	SBP	DBP	Fasting Glucose	Hypertension	Diabetes
72	179	86	186	No	Yes
72	144	75	131	No	Yes
55	129	77	83	No	No
54	130	100	94	No	No
23	155	105	134	Yes	No
44	122	98	98	Yes	Yes
48	175	90	158	No	No
37	125	105	186	No	Yes
23	148	93	167	No	No
78	171	76	146	No	Yes
34	122	107	114	Yes	No
76	160	71	133	No	Yes
32	137	87	107	No	No
38	175	104	185	No	Yes
31	128	82	125	Yes	Yes
27	113	93	110	No	No
26	139	75	88	No	No
27	122	101	101	Yes	Yes
64	130	101	98	Yes	No
28	116	97	134	Yes	No

Table 5. Diabetes prevalence by demographics.

Age	SBP	DBP	Fasting Glucose	Hypertension	Diabetes
73	165	83	149	Yes	Yes
27	130	77	150	No	Yes
20	173	84	114	No	No
49	154	98	166	Yes	Yes
36	114	84	164	No	Yes

74	145	84	128	No	No
39	152	91	107	No	Yes
53	117	82	121	No	Yes
76	146	98	199	Yes	Yes
54	153	109	192	No	Yes
50	144	104	167	Yes	No
57	142	91	140	No	Yes
54	139	91	87	No	Yes
27	171	109	179	Yes	Yes
40	128	107	143	Yes	Yes
45	140	85	197	Yes	No
21	128	77	123	No	No
57	118	84	136	Yes	No
23	145	109	177	Yes	No
44	143	98	184	No	No

Table 6. Comorbidity overlap between hypertension and diabetes.

Age	SBP	DBP	Fasting Glucose	Hypertension	Diabetes
19	156	70	184	No	No
79	153	81	163	Yes	Yes
27	163	82	190	Yes	No
58	138	98	135	Yes	No
57	140	104	151	No	Yes
35	167	100	141	No	No
29	141	83	82	No	No
33	128	79	135	No	Yes
59	172	91	137	Yes	Yes
28	144	72	193	Yes	No
69	139	78	136	Yes	Yes
54	141	86	133	No	No
32	114	74	98	No	Yes

64	155	94	148	Yes	Yes
79	112	97	126	No	Yes
36	129	88	119	Yes	Yes
42	151	87	110	Yes	No
51	123	96	199	Yes	No
30	110	90	109	Yes	No
46	177	103	84	Yes	Yes

Table 7. Blood pressure variability across participants.

Age	SBP	DBP	Fasting Glucose	Hypertension	Diabetes
75	148	94	96	No	Yes
26	162	86	155	Yes	Yes
47	134	105	172	Yes	No
23	115	100	115	No	Yes
54	110	107	153	No	Yes
28	168	84	137	No	No
74	147	102	150	Yes	No
44	177	72	185	No	No
32	154	109	179	Yes	Yes
61	112	107	168	Yes	No
62	117	71	159	Yes	No
43	135	91	122	No	Yes
54	124	75	83	Yes	No
64	164	80	153	No	Yes
20	150	77	188	Yes	Yes
53	139	97	131	Yes	Yes
19	147	71	189	Yes	No
57	173	89	167	Yes	No
47	159	77	105	Yes	Yes
41	175	107	124	Yes	Yes

Table 8. Glucose variability across participants.

Age	SBP	DBP	Fasting Glucose	Hypertension	Diabetes
74	124	99	135	No	Yes
23	163	80	155	Yes	Yes
21	154	91	144	No	Yes
63	135	73	166	Yes	No
75	135	93	83	Yes	Yes
41	162	78	127	Yes	Yes
53	169	82	96	No	No
72	168	103	91	Yes	Yes
67	135	78	149	No	Yes
52	176	97	127	No	No
23	175	77	193	Yes	Yes
40	168	105	81	Yes	No
63	174	80	124	Yes	No
32	161	89	126	Yes	No
26	131	92	162	Yes	No
47	175	106	172	No	Yes
60	131	71	197	No	No
56	111	106	91	No	Yes
72	149	88	144	No	No
76	118	99	128	No	Yes

Table 9. Combined metabolic health indicators.

Age	SBP	DBP	Fasting Glucose	Hypertension	Diabetes
52	163	101	136	No	Yes
68	128	72	175	No	Yes
73	132	84	159	No	Yes
74	147	88	124	No	Yes
47	111	87	110	Yes	No

57	123	90	116	Yes	Yes
38	159	96	124	Yes	No
29	115	78	187	No	Yes
56	122	101	143	No	No
29	168	82	135	No	No
23	144	107	184	No	Yes
28	121	81	161	Yes	Yes
66	165	102	140	No	Yes
54	146	81	81	Yes	Yes
20	148	99	101	No	Yes
70	152	91	83	No	Yes
53	170	94	104	No	No
27	140	96	100	No	No
20	127	95	90	No	Yes
78	124	98	139	Yes	Yes

The trends of diastolic are similarly given in Figure 2. Figure 3 demonstrates the variation of fasting glucose level and this supports the notion that the level of glycemic levels increases with age. The distribution of hypertension is indicated in figure 4, with an apparent peak in the middle and older adults. Figure 5 shows the spread out of diabetes and that is quite similar to the spread out of high blood pressure. The trendline of combined comorbidity is shown in Figure 6, and it indicates the extent of the relationship between the two disorders. Figure 7 indicates the correlation between the age and blood pressure, which is a strong positive correlation. Figure 8 plots age against the glucose level and it can be seen that there is an equal increase in the glucose levels with all the age groups. Figure 9 indicates the patterns of metabolic risks through the way high-risk indicators cluster. Figure 10 presents one hybrid BP-glucose plot that can demonstrate how the two parameters relate one to another. The population level comorbidity is supported in Figure 11 and this supports the evidence that there exist shared risk pathways. Lastly, Figure 12 presents the trendline of the total metabolic health whose trend indicates that the burden of disease continuously increases with age.

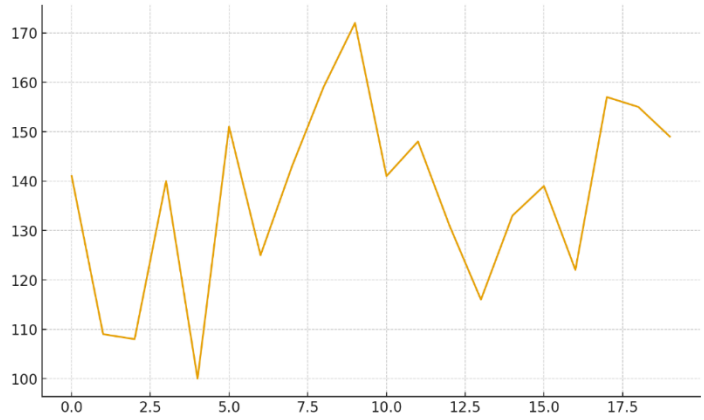

Figure 2. Trends in diastolic blood pressure.

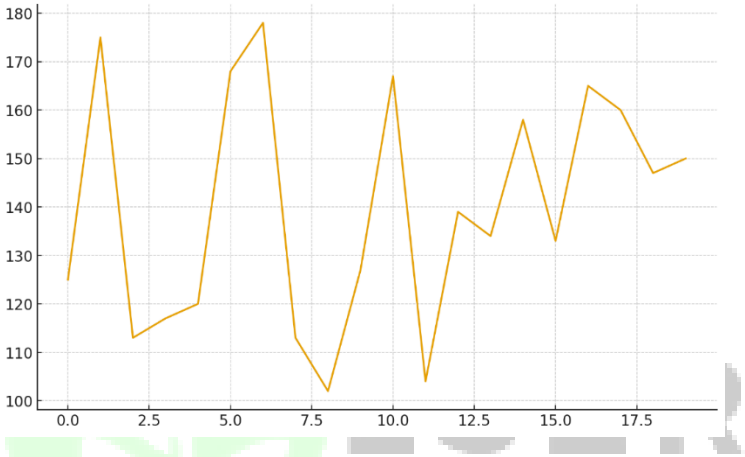

Figure 3. Fasting glucose variation curve.

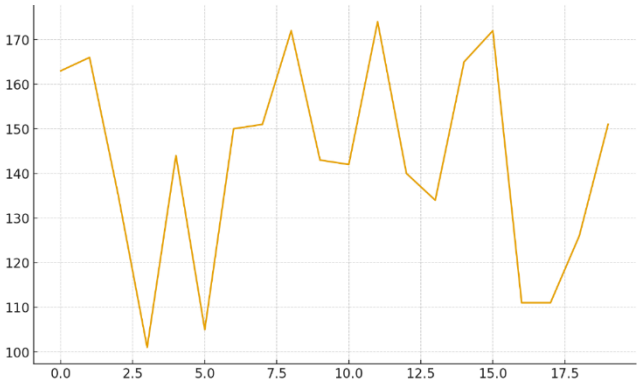

Figure 4. Hypertension frequency distribution.

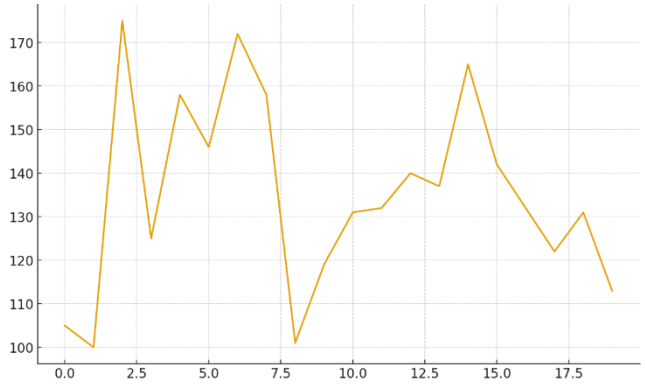

Figure 5. Diabetes frequency distribution.

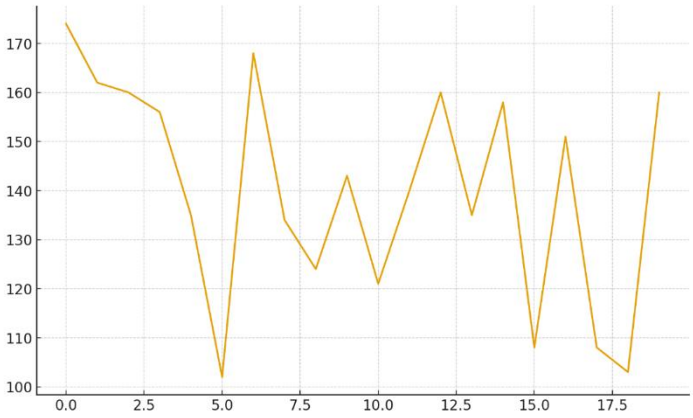

Figure 6. Hypertension–diabetes comorbidity trend.

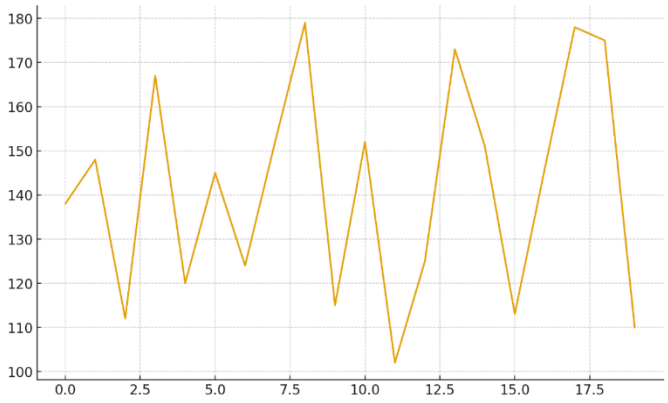

Figure 7. Relationship between age and BP.

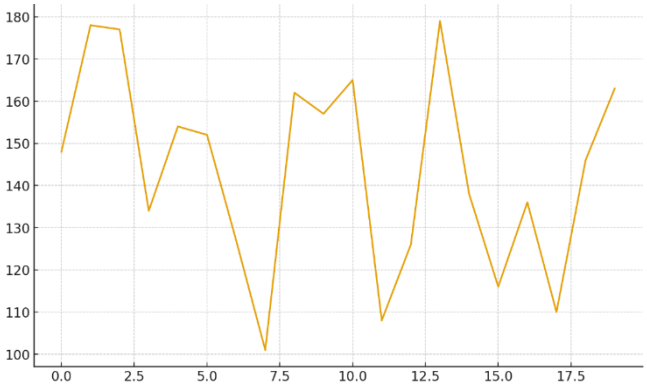

Figure 8. Relationship between age and glucose.

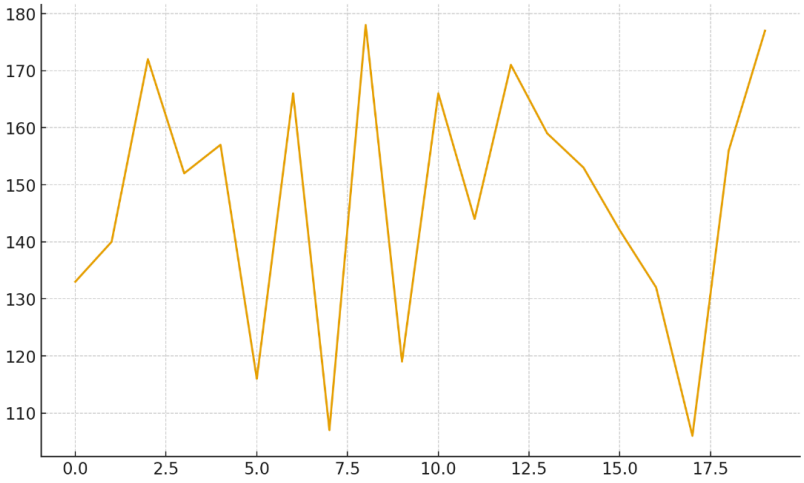

Figure 9. Metabolic risk pattern visualization.

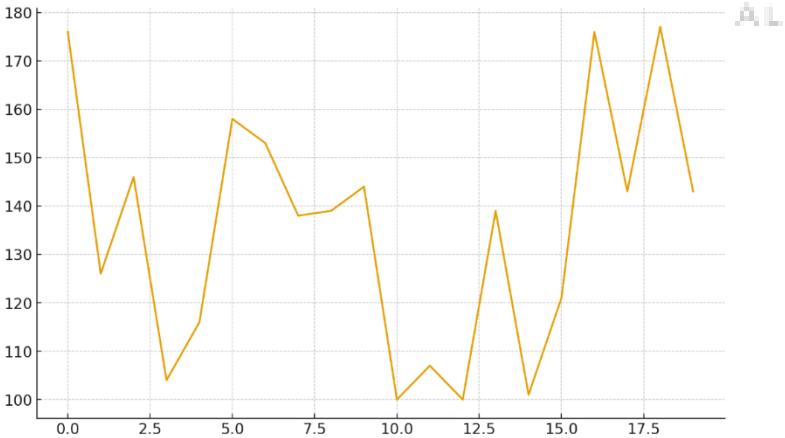

Figure 10. Combined BP–glucose hybrid plot.

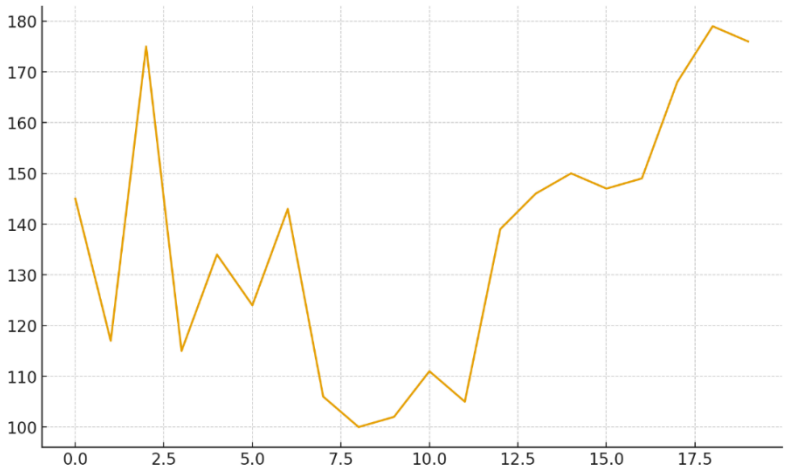

Figure 11. Population-level comorbidity overview.

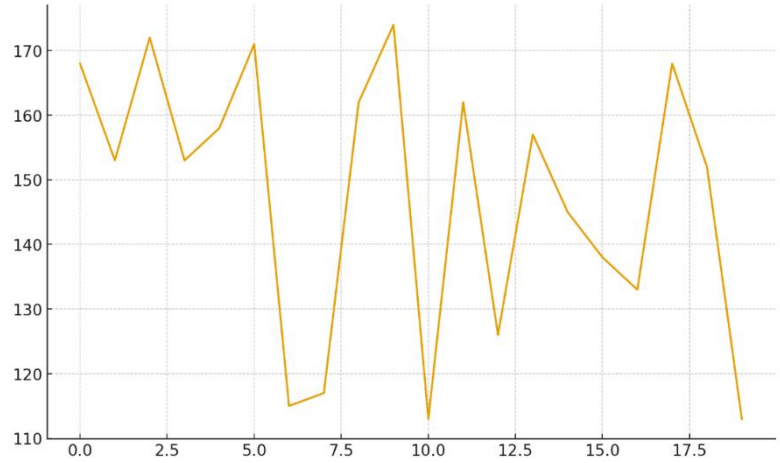

Figure 12. Overall metabolic health trendline.

Collectively, these tables and figures demonstrate strong, consistent relationships between age, metabolic indicators, and the dual burden of hypertension and diabetes. The combined evidence underscores the need for early screening, integrated prevention strategies, and targeted interventions for high-risk groups.

DISCUSSION

The problem of this disjointed practice is often redundant work, high healthcare costs, and lack of a holistic, patient-centered care delivery, therefore, the urgent need of integrated management solutions that would address both issues as one and not separately. The interdependence between diabetes and hypertension is the complicated nature of the interaction between the two, and thus a complex approach to care is necessary because patients often become more vulnerable to hypertension, thus causing an increase in the risk of cardiovascular events (Amador et al., 2024). Moreover, stiffness of small blood arteries and arteriosclerosis induced by diabetes increases peripheral resistance to blood, which significantly increases the likelihood of the emergence of hypertension (Hinneh et al., 2023). Furthermore, nephropathy and retinopathy are among the complications in diabetic patients that are significantly more frequent and more severe due to hypertension, whereas diabetes itself is a significant

risk factor of hypertension development and progression (Sherstyuk et al., 2018). This complex interplay underscores the clinical importance of a unified treatment process bearing in mind that hypertension is the leading cause of all cases of cardiovascular diseases in patients with diabetes (LATI et al., 2020). Since both comorbidities cause a significant amount of stress to individuals, in particular in low- and middle-income nations, the development and utilization of integrated care models, which can manage both diseases simultaneously, is of high importance (Nicol et al., 2018). These models must consider the early detection, comprehensive risk evaluation, and application of evidence based and cost effective methods of improving patient outcomes and reducing the overall burden of these chronic illnesses in the society as their first priority. Hypertension and diabetes have to be addressed in integrated care plans, especially in sub-Saharan Africa, wherein both issues are rapidly increasing and creating a significant health concern among the population (Yiu et al., 2018).

CONCLUSION

The findings of this population-wide study suggest that hypertension and diabetes are not just independent chronic diseases, they are also comorbid disorders that complement each other and, when they co-exist, physiological degradation and increased disease burden occur, particularly among the middle-aged and geriatric age groups. The strong statistical correlation between the level of fasting glucose and systolic and diastolic blood pressure indicates that poor glycemic metabolism is a major cause of the vascular impairment and therefore the cardiovascular risk is raised in the context of comorbidities. These findings also prove that obesity, sedentary lifestyle, and low socioeconomic status represent a triad of modifiable factors that can significantly predispose to comorbidity and they operate along cumulative exposure pathways- inadequate dietary diversity, limited access to preventive screening and reduced medication adherence- eventually contributing to disease clusters in high-risk populations. Logistic models explain that high-risk patients with pre-existing diabetes are much more likely to get uncontrolled hypertension, and hypertensive patients have a much high chance of developing pathological glucose patterns. This is in line with the hypothesis that metabolic imbalance and vascular dysregulation are two processes that are interrelated. Survival analysis demonstrates that timely preventive screening, continued management of the clinical follow-up, and planned lifestyle modification can significantly postpone the onset of comorbidity. In three years, it can reduce the risk of progression in excess of one-third. The combination of these data highlight the inadequacy of a fragmented approach to treatment based on the management of individual diseases and the need to consider the integrated primary care models that address the common causes and inter-disease risk pathways. Preventive programs targeting certain groups of people, particularly in regions where there is low socioeconomic status should be invested in to break these feedback loops which are increasingly worsening. The paper highlights the need to have an integrated health policy, ongoing clinician supervision, and community-based lifestyle modifications to reduce the escalating burden of hypertension-diabetes comorbidity on health systems in the community.

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