

Case Series



Integrated Ayurvedic Dietary and Yogic Protocol in Type 2 Diabetes Mellitus: A case series

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ABSTRACT:

Background: Type 2 Diabetes Mellitus (T2DM), chronic metabolic disorder which is associated with insulin resistance and glucose underutilization. Conventional management approaches provide symptomatic relief albeit short-lived, failing to address core metabolic imbalance. Ayurveda identifies correction of *Agni* (digestive and metabolic) and *dosha* balance with regimen-based approach (*Ahara-Vihara*) individualized to person as a key strategy. This case-series provides details outcome of integrated dietary and yogic protocol in patients with poorly controlled T2DM. **Methods:** Five patients of uncontrolled T2DM were provided with personalized Ayurveda based dietary regimen along with therapeutic *yoga* modules for period of 24-weeks. Diet was *Prakriti*-based and customized to food availability and patients glycemic status to include low-glycemic foods, nutritional millets, culinary herbs, herbal drinks and therapeutic time restricted eating. *Yoga*-based therapeutic lifestyle involved practice of 60-minutes guided training modules involving *asana-pranayama* and relaxation techniques. Fasting blood sugar (FBS), postprandial blood sugar (PPBS), glycated-hemoglobin (HbA1C), Insulin levels, Homa-IR, weight, BMI (Body Mass Index) and waist circumference were recorded. **Results:** Improvement was reported across multiple clinical, biochemical and metabolic domains related to glycemic control which includes HbA1c, FBS, PPBS, Fasting Insulin, HOMA-IR, weight, BMI and waist circumference among 5-participants over a period of 24 weeks. 2 patients able to discontinue insulin, 1 patient achieved drug free diabetes control while 1 female patient with a history of repeated spontaneous abortions conceived and delivered healthy full-term baby. Patients also experienced weight reduction, improved digestion, appetite and sleep as well as improved physical and mental stability. **Conclusion:** Incorporating Ayurvedic dietary principles with practice of *yoga* showed marked improvement of glycemic status and insulin sensitivity in patients of T2DM. This holistic non-pharmacologic approach provides safe, effective, sustainable and individualized treatment strategy consistent with Ayurvedic principles of metabolic correction. Large scale clinical trials needed to validate findings of study.

KEYWORDS: Case Series, Diet Therapy, Glycated Hemoglobin, Type 2 Diabetes Mellitus (T2DM), *Yoga*

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1. INTRODUCTION

Type 2 Diabetes Mellitus (T2DM) is chronic metabolic disorder characterized by hyperglycemia due to insulin resistance or deficiency. Worldwide, it affects around 590 million estimated to rise to 853 million by 2050 (IDF). [1] Despite many pharmacological options, most patients fail to achieve optimal glycemic control and face long-term drugs dependence and side effects. Conventional therapy target mainly on glycemic regulation rather than correcting underlying metabolic dysfunction, highlighting need for integrative approaches including diet and lifestyle modifications. [2] In India factors like limited self-care, low awareness, dietary non-compliance, family structure, financial constraints and medications contribute to inadequate control. [3]

Through Ayurvedic perspective, T2DM correlates with *Prameha*, caused by vitiated *Kapha* and *Vata* dosha, impaired *Agni* and obstructed *srotas* (channel). *Aharaniyama* (diet) and *Vihara* (lifestyle) therapies aim to restore metabolic homeostasis. Ayurveda emphasizes local, seasonal and vegetable-based diets incorporating all six tastes, low-glycemic foods and individualized approaches. Therapeutic time-restricted meal and calorie control help restore metabolism, enhance insulin sensitivity thereby lowering blood sugar. [4, 5] Complementary *yoga* interventions including *asanas*, *pranayama* and meditation regulate autonomic nervous system and support metabolic balance. [6, 7]

Rationale for this case series is to provide clinical evidence that integrated Ayurvedic diet and therapeutic *yoga* can improve glycemic control, insulin sensitivity,

reduce or discontinue anti-diabetic drugs thereby enhancing quality of life, with systemic benefits include successful full-term pregnancy in a previously affected patient.

2. METHODS

This study was prospective interventional case series conducted at Diabetes Specialty outpatient department (OPD) at KLE Ayurveda hospital between December 2021 and October 2022 to evaluate clinical outcomes of integrative Ayurvedic dietary and *yogic* protocol in patients with uncontrolled T2DM. Purposive sampling technique was used to select patient from OPD. Follow-up was reported both in person and via teleconsultation as well.

Inclusion Criteria:

- Diagnosed cases of T2DM as per ADA 2021 criteria.
- Age between 30-60 years.
- HbA1c level between 8 to 13.5%, FBS range between 140 to 360 mg/dL.
- Willingness to participate.

Exclusion Criteria:

- Type 1 Diabetes Mellitus.
- Severe systemic illness (Renal, Hepatic or Cardiac diseases)
- Unwillingness to comply with regimen.

Since this case series involved patient managed under routine clinical practice at diabetes specialty OPD of KLE Ayurveda Hospital, no experimental or invasive procedure were performed, hence as per institutional policy no separate IEC approval was obtained, while written informed consent was obtained from all participants.

Patient Information: In this case series, 5 patients i.e. 2 males, two of them have positive family history of T2DM. Among that one female aged 33 years having history of recurrent miscarriage. Mean of basic demographic clinical profile mention in table 1.

Table 1. Baseline Demographic and Clinical Profile (n = 5)

Parameter	Case 1	Case 2	Case 3	Case 4	Case 5
Age (years)	36	53	33	57	33
Gender	Male	Male	Female	Female	Female
Duration of DM (years)	2	6	6	6	5
FBS (mg/dL)	204	357	321	174	146
PPBS (mg/dL)	326	380	396	209	278
HbA1c (%)	9.2	10.5	13.5	8.4	10.1
Insulin (μ U/L)	33.1	10.05	11.91	20.96	5.35
HOMA-IR	16.68	8.85	9.44	9.0	1.80
Weight (kg)	96	65	76	75	62

Waist (cm)	118	98	103	96	90
BMI (kg/m ²)	33.2	22.5	26.3	26.0	21.5

Clinical Findings: Clinically, all patients had classical symptoms of T2DM like polyuria, polydipsia, polyphagia, fatigue and lethargy, secondarily constipation and disturbed sleep etc. *Ati-Madhura Ahara* (excess sweet food intake), *Atinidra* (excess sleep), *Avyayama* (absence of exercise) were most important *nidana* (causative factors) while *Atipipasa* (excessive thirst), *Atikshudha* (excessive hunger), *Swedadhikya* (excessive sweating) were major *Lakshana* with *Medovaha* (channels carrying fat tissue) and *Mutravaha Srotas* (channels of transport of urine) involvement. *Nadi Pariksha* revealed *Kapha-Vata Nadi* in all patients which supported *Prameha* diagnosis with varying sub-types. Detailed baseline and clinical timeline of patients mentioned in table 2 and 3 respectively.

Table 2: Baseline Chronological Timeline of Five Patients Before Ayurvedic–Yogic Intervention

Case	Age / Sex	Duration of T2DM (years)	Approx. Onset / Progression	Main Symptoms Before Presentation	Past Medical / Family History	Previous/Current medication
1	36 / M	2	Gradual onset over 5 years; uncontrolled for last 2 years	Polyphagia, excessive sweating with foul odor, constipation, frequent urination	No smoking/alcohol; no chronic illness	Irregular OHA (anti-diabetic drugs), non-compliant
2	53 / M	6	Persistent hyperglycemia for 6 years, worsening last 3 month	Polydipsia, polyuria, excessive sweating, appetite increase	No chronic illness; family history +	Insulin glargine 40 U HS + aspart 20 U BID + Tb. Janumet BD (Sitagliptin 5mg + Metformin 500mg)
3	33 / F	6	Worsening 6 month ago; poor control for 2	Polyuria, dry mouth, sweating, stress,	No systemic illness; emotional stress	Irregular metformin 1000 mg/day; discontinued 6

			years	infertility		month ago
4	57 / F	6	Chronic T2DM 6 years; fatigue 6 month ago	Sleepiness, head heaviness, disturbed sleep	Family history + T2DM	Metformin 1000 mg + Glimepiride 5 mg BID
5	33 / F	5	Diagnosed 5 years ago; miscarriage 3 years ago	Polyuria, appetite ↑, disturbed sleep	Recurrent pregnancy loss; family T2DM	Glimepiride 2 mg + Metformin 500 mg; insulin during pregnancy

Table 3. Clinical Timeline of Patients Undergoing Ayurvedic and Conventional Management

Case	Visit Date	Intervention	FBS (mg/dL)	PPBS (mg/dL)	HbA1c (%)	Insulin (mU/L)	HOMA-IR
1	19/11/21	Diet and <i>Yoga</i>	204	326	9.2	33.1	16.68
	24/02/22	Diet and <i>Yoga</i>	146	175	7.8	17.39	4.98
	25/05/22	Diet and <i>Yoga</i>	116	138	6.2	-	-
2	24/12/21	Insulin and Tb. Janumet + Diet and <i>Yoga</i>	357	380	10.5	10.05	8.85
	30/03/22	Insulin and Tb. Tb Janumet + Diet and <i>Yoga</i>	186	250	8.9	5.72	2.32
	30/06/22	Tb. Janumet + Diet and <i>Yoga</i>	164	224	7.8	-	-
3	03/12/21	Metformin (irregular) + Diet and <i>Yoga</i>	321	396	13.5	11.91	9.44
	10/03/22	Diet and <i>Yoga</i>	97	101	6.0	7.80	2.04
	09/06/22	Diet and <i>Yoga</i>	106	118	5.7	-	-
4	24/01/22	Metformin + Glimepiride + Diet and <i>Yoga</i>	174	209	8.4	20.96	9.0
	23/04/22	Metformin + Diet and <i>Yoga</i>	102	112	6.8	21.43	5.71
	23/07/22	Diet and <i>Yoga</i>	108	126	6.2	-	-
5	20/12/21	Irregular medications + insulin + Diet and <i>Yoga</i>	136	278	10.1	5.35	1.80
	12/04/22	Diet and <i>Yoga</i>	101	179	6.8	5.04	1.72
	12/10/22	Diet and <i>Yoga</i>	138	186	6.8	-	-

Diagnostic Assessments: All patients in case series had undergone a thorough clinical and laboratory evaluation (FBS, PPBS, HbA1c, fasting insulin, Homa IR, weight, BMI and waist circumference). Systemic examination was done to rule out complications like neuropathy, retinopathy etc. Diagnosis based on Ayurvedic principles were carried out by *Nadi Pariksha*, *RogRogi Pariksha*

(examination of disease and patient) including *Nidana Panchaka* (five diagnostic tools). Cases revealed *Kapha-Vata* predominance, *Medo Dhatu Dushti* (impaired fat metabolism) and *Agnimandya* (diminished digestive fire). Diagnostic confirmation was done based on criteria stated by ADA (2021) for T2DM (FBS ≥ 126 mg/dL, PPBS ≥ 200 mg/dL, HbA1c $\geq 6.5\%$). Diagnostic

criteria as per Ayurveda was *Prameha purvaroopa* (premonitory stage of *Prameha*). Diagnostic challenges: There were no major diagnostic challenges encountered other than initial irregularity in blood testing and poor awareness about dietary assessment. All enrolled patients were confirmed cases of T2DM as per ADA, differential diagnosis was made to rule out causes of hyperglycemia like Type 1 diabetes, Cushing’s syndrome, metabolic or endocrine diseases based on clinical history and laboratory parameters as well as ayurveda parameters as *apathyanimittaja* (acquired)and *sahaja* (congenital) *prameha* based on *nidana panchaka*. **Prognosis:** Prognosis was assessed considering *dosha* predominance, etiological factor (Congenital/acquired), presence and absence of complications, constitution (obese/lean) and chronicity of disease.

Therapeutic Intervention: Therapeutic plan was based on *pathya-apathya, ahara-vihara* (dietary and lifestyle

regimen) emphasizing customised *kapha-medohara* along low-glycemic diet tailored to *agni* (digestive and metabolic fire), *medo dhatu dushti* (hampered lipid metabolism) and *dosha* balance, along with structured *Yoga* routine. (Table 4) Yoga sessions were initially supervised by instructor and later continued at home with tele follow up as and when required. Based on strength, flexibility and glycemic status of patients, some modifications were done in training module and diet. This prescribed diet ensured optimal proportion of carbohydrates, protein, fats and fiber to maintain metabolic balance. (Table 5) Ongoing concurrent medications was continued initially and tapered as per clinical response later in coordination with treating physician. This integrated regimen was followed for 24 weeks and summarized in Table 4, while 7-day therapeutic diet regimen plan in Table 6.

Table 4. Administered Therapeutic Intervention Summary

Component	Subcomponent / Example	Duration / Timing	Frequency	Key Elements / Description
Yoga Module	Warm-up	5 minutes	Daily	Gentle exercise
	Asanas	25–30 minutes	Daily (5–6 days/week)	<i>Surya Namaskara, Ardha Kati Chakrasana, Trikonasana, Vakrasana, Bhujangasana, Dhanurasana, Pavanmuktasana</i>
	Pranayama	10–15 min	Daily	<i>Kapalbhati, Anuloma–Viloma, Bhramari</i>
	Relaxation	10 minutes	Daily	<i>Yoga Nidra/guided meditation</i>
Diet Plan	—	6:30–7 am, 9–10 am, 1–2 pm, 4–5 pm, 6–8 pm.	Daily	Morning drink, breakfast, 2 main meals, 1 light snack at regular interval: low-glycemic, <i>kapha–medohara</i> diet rich in millets, pulses, sprouts, vegetables, nuts, seeds, herbal drinks; avoidance of sugar, milk wheat and maida. (Table 6).

Table 5: Diet macro target.

Macronutrient	Gram/day	% of Calories	Sources
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Calories	1200-1600 Kcal	-	Total daily intake
Carbohydrates	175-230 gm	55–58 % (low-GI)	Millets, pulses, vegetables
Proteins	45-70 gm	15–17 %	Green-gram, lentils, boiled-eggs, paneer, nuts
Fats	30-50 gm	26–28 % (healthy fats)	Ghee, coconut, olive oil

Table 6: Seven-day therapeutic diet regimen and menu used in the intervention.

Day	Pre-Breakfast (6–7 AM)	Breakfast (9–10 AM)	Lunch (1–2 PM)	Evening (4–5 PM, optional)	Dinner (6–8 PM)
1	Apple cider vinegar, lime	<i>Moong usal</i> (stir-fried green gram), green tea	<i>Jowar roti, dal</i> (lentil soup), <i>sabzi</i> (vegetable dish), salad	Green tea, roasted <i>makhana</i>	Millet <i>khichdi</i> /soup
2	Herbal detox drink with <i>jeera</i> (cumin) and <i>ajwain</i> (carom seeds)	<i>Besan chilla</i> (gram flour pancake), chutney	Brown rice, <i>dal</i> , salad	Fried peanuts/ <i>chana</i>	<i>Ragi ambli</i> (finger millet gruel)
3	Herbal detox drink with <i>methi</i> (fenugreek seeds) and <i>dalchini</i> (cinnamon)	Sprout salad, nuts	<i>Jowar roti</i> , paneer <i>curry</i>	Peanut butter (1–2 tsp)	Vegetable soup, <i>khichdi</i>
4	Apple cider vinegar, lime	Nuts, herbal tea	Millet <i>roti, sabzi, dal</i>	Peanut butter/roasted nuts	Vegetable porridge
5	Herbal detox drink with <i>methi</i> (fenugreek seeds) and <i>dalchini</i> (cinnamon)	<i>Moong dosa</i> (green gram), chutney	<i>Rice, dal</i> , salad	<i>Makhana/chana</i>	<i>Ragi dosa</i> , veg soup
6	Ash gourd juice	<i>Idli, sambar</i>	<i>Jowar roti, sabzi</i> , salad	Roasted peanuts	<i>Moong khichdi</i> , soup
7	Apple cider vinegar, lime	Buttermilk, <i>makhana</i> (fox nuts or lotus seeds)	Mixed millet thali (<i>roti, dal, sabzi</i> , salad)	Green tea, nuts	Light vegetable soup/ <i>ragi ambli</i>

3. FOLLOW UP AND OUTCOMES

Patients were followed up over 3–6-month period with regular evolution during follow-ups. Follow-up assessments include FBS, PPBS, HbA1c, fasting insulin, Homa IR, body weight and waist circumference along with dietary and yoga adherence checkup. Case wise

outcomes in various parameters are presented in table 7, while glycemic parameter trend, changes in fasting-insulin and HOMA-IR and changes in anthropometric parameters are illustrated in figures (figure 1, 2 and 3 respectively).

Table 7. Outcome Summary- Before and after (n = 5)

Parameter		Case-1	Case-2	Case-3	Case-4	Case-5
HbA1c (%)	Before	9.2	10.5	13.5	8.4	10.1
	After	6.2	7.8	5.7	6.2	6.8
FBS (mg/dL)	Before	204	357	321	174	146
	After	116	164	106	108	138
PPBS (mg/dL)	Before	326	380	396	209	278
	After	138	224	118	126	186
Fasting Insulin (μU/mL)	Before	33.1	10.05	11.91	20.96	5.35
	After	17.39	5.72	7.8	21.43	5.04
HOMA-IR	Before	16.68	8.85	9.44	9.0	1.8
	After	4.98	2.32	2.04	5.71	1.72
Weight (kg)	Before	96	65	76	75	62
	After	78	63	57	70	61
Waist Circumference (cm)	Before	118	98	103	96	90
	After	112	93	97.7	91.1	85.4
BMI (kg/m ²)	Before	33.2	22.5	26.3	26.0	21.5
	After	27.0	21.8	19.7	24.2	21.1

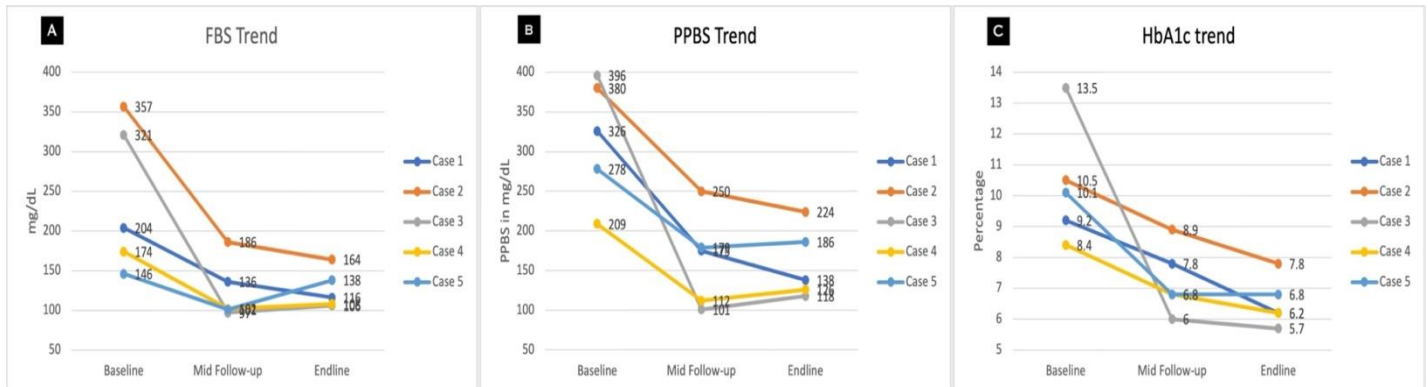


Figure 1: Showing Glycemic parameter trends over 24 weeks of intervention from baseline to mid follow-up and endline (n = 5): (A) FBS, (B) PPBS and (C) HbA1c.

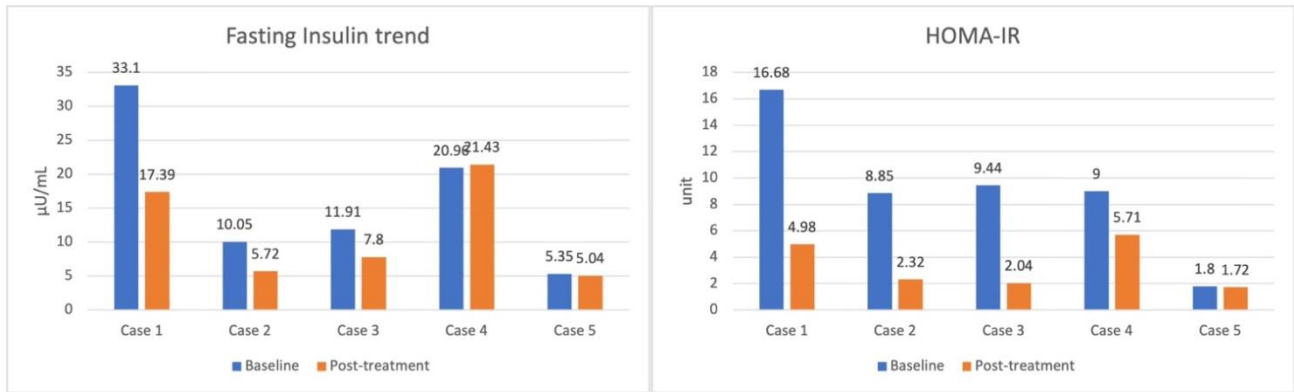


Figure 2: Before-and-after changes in fasting insulin levels (A) and HOMA-IR values (B) in five cases (n = 5).

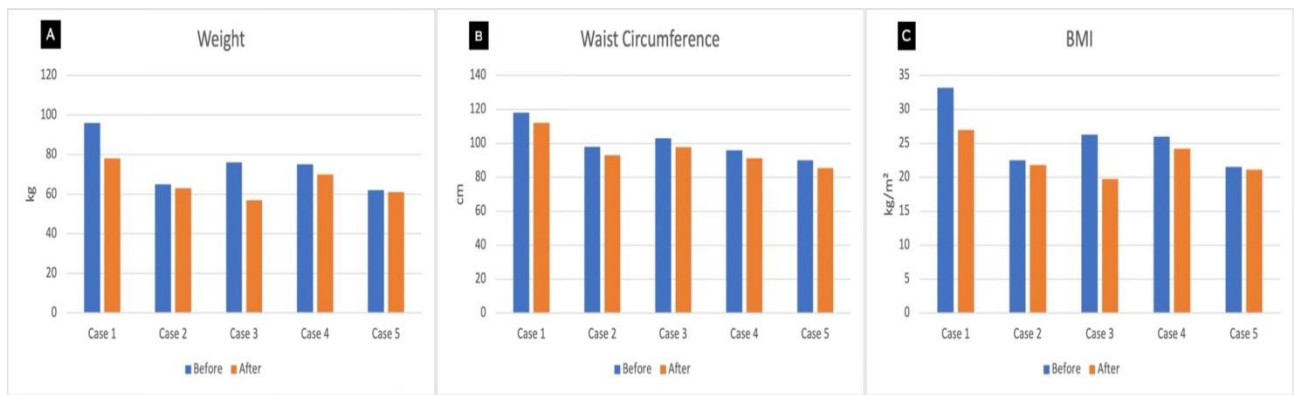


Figure 3: Showing Before-and-after changes in anthropometric parameters: (A) weight, (B) waist circumference, and (C) BMI in five cases (n = 5)

Clinical Course:

Case 1: Demonstrated marked improvement in polyphagia and sweating along with weight reduction of 18 kg and HbA1c drop down 9.2% to 6.2%.

Case 2: Insulin was gradually stopped, HbA1c dropped from 10.5% to 7.8% and energy level also improved.

Case 3: Attained almost complete normalization of glycemic parameters (HbA1c 13.5% to 5.7%) with improved mood, digestion and sleep quality.

Case 4: Noted relief in fatigue, heaviness and disturbed sleep, also HbA1c reduced from 8.4% to 6.2%.

Case 5: Maintained normal glucose level throughout pregnancy (HbA1c 10.1% \rightarrow 6.8%) as well delivered a healthy baby.

Subjective Outcome: Patients experienced improvement in excessive thirst, fatigue, appetite disturbance and mental stress. Improved digestion with sleep quality and emotional balance was frequently noted along with improved self-efficacy and adherence to lifestyle modification.

Adherence and Tolerability: Adherence was monitored through direct follow-up visit as well telephonic review through diet logs and *yoga* checklists and adherence percentage calculated based on completed sessions versus advised sessions. interventions were well tolerated with maintaining adherence above 90%.

Adverse Events (AE): AE was noted and assessed for severity and relation to intervention. No hypoglycemic

events, adverse effects or intolerance to dietary or Yogic protocol was noted during intervention.

Illustrative Vignette: One 33-year-old female with uncontrolled diabetes and previously infertility, experienced restored metabolic status and invigoration along with pregnancy within six months delivering healthy full-term baby, indicating systemic healing potential of integrated approach of diet and *Yoga*

4. DISCUSSION

Current case series highlights practical utility of integrated Ayurvedic dietary and Yogic protocol in patients with type 2 diabetes mellitus. All five patients reported marked improvements across multiple glycemic parameters includes FBS, PPBS, HbA1c (figure 1) and anthropometric parameters like weight, BMI and waist circumference (figure 3). Improvement was noted consistently over period of 24 weeks, indicating that structured lifestyle modification (diet and *yoga*) can positively influence metabolic function.

Ayurveda explains, *Prameha* (T2DM) as diseases develop from *kapha* vitiation, combining with excess *meda* and *kleda* of body. *Samprapti* (etiopathogenesis) compromises *agnimandya*, *meda-dushti* and *srotorodha* (channel obstruction). Diet planned for these patients aims on correcting these factors through *Agnideepana* (improving metabolic fire) *Amapachana* (clearing metabolic toxins) and *kapha-Medohara* (fat dissolving) principles. Spices adopted in protocol including *jeera*, *ajwain*, *methi* and *dalchini* which supports digestion and act as antioxidant as well lipid lowering. Modern literature also supports use of low-glycemic foods which include millets, legumes, sprouts and pulses for

reducing PPBS and HbA1c. Herbs like cinnamon and fenugreek known to improve insulin sensitivity. Nuts, seeds, green tea and healthy fats like olive oil are rich in antioxidants and help reduce oxidative stress. Taken together, a low-GI, high-fiber plant-based diet with controlled meal timing may contributed in improving glycemic parameters. [9-12]

Yoga was also integrated in daily routine or intervention protocol. *Yoga* protocol which includes *Surya Namaskara*, *Bhujangasana*, *Pranayama* and *Yoga Nidra* known to enhance glucose absorption through activating pancreatic function, reducing sympathetic overactivity. Also help in lowering stress thereby improving sleep and mental calmness by enhancing parasympathetic activities, which in turn support better glycemic control. Multiple effect of metabolic correction and stress reduction parallel with Ayurvedic concept of *Samprapti-Vighatana*. [13, 14]

Strength of this series is that, only structured Ayurvedic diet and *yoga* protocol was used without adding new anti-diabetic medications, despite improvement was seen in multiple glycemic parameters. One patient stopped insulin and another one with previous infertility delivered a healthy baby. Continuous monitoring noted both biochemical and symptomatic outcomes. Although, small sample size and absence of control group limit generalization of findings. Adherence may also have varied because lifestyle practices were partly self-reported. Longer follow-up needed to understand whether improvements can be maintained over long period of time.

Take away: Overall, integrated Ayurveda and *Yoga* protocol was safe, simple, have no adverse effects and cost-effective, improve overall physical and mental health promote long term lifestyle change, things medicine cannot. It may serve as supportive inclusion in diabetes management. Larger controlled studies needed with objective biochemical markers [15] to ensure these findings and explore biological mechanisms involved.

5. CONCLUSION

This case series highlights effective management of long-standing, uncontrolled T2DM through integrated dietary and yogic approach which include structured Ayurvedic diet and yoga regimen given over 24-weeks in 5 patients, during which improvements were noted among various glycemic (HbA1c, FBS, PPS, Fasting Insulin and HOMA-IR) and anthropometric parameters (weight, waist circumference and BMI). One patient discontinued insulin and no adverse events was reported in any patient. Integrated dietary and yogic protocols were safe and sustainable. Targeting underlying pathophysiological pathway as well as defective lifestyle associated with T2DM. Outcomes support clinical utility and relevance of integrated diet and *yoga* in T2DM management, though future larger controlled studies are warranted to confirm efficacy, mechanism of action and long-term impact on metabolic outcomes.

Declaration of Patient Consent – The authors confirm that they have acquired a patient consent form, in which the patient or caregiver has granted permission for the publication of the case, including accompanying images and other clinical details, in the journal. The patient or caregiver acknowledges that their name and initials will

not be disclosed, and sincere attempts will be undertaken to safeguard their identity. However, complete anonymity cannot be assured.

Patient perspective –

Patient 1- "Earlier I was always sweating, feeling bloated and hungry again and again, my weight kept increasing and I felt dull whole day. After starting Ayurvedic diet and yoga, I lost a lot of weight, my digestion also good now, I feel lighter now a days also & confident and I feel healthy".

Patient 2- "I was taking insulin since years, but my sugar was never under control. I always felt weak and tired all day. After strictly following this diet plan and yoga, my sugar came down naturally and I could completely stop insulin gradually. Now I feel more energetic and freer from daily injections which were very big relief for me and my family."

Patient 3- "I was stressed, moody and my sugar never came in normal. I even stopped medicines because of their side effects. After following Ayurvedic diet and yoga strictly, my sugar came normal over time, I feel calm and my overall health both physical and mental has improved."

Patient 4- "I previously felt heavy and sleepy even after taking medicines regularly after this Ayurvedic diet and yoga, my head heaviness and tiredness is reduced very much. Now I can control my diabetes naturally without need of medicines."

Patient 5- "Earlier I lost my pregnancy because of my high sugar levels. After initiating Ayurvedic diet and yoga, my sugar was normal throughout pregnancy, and I delivered a healthy baby now I felt like me and my child both got new life."

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Declaration of Generative AI

The authors declare this manuscript was written without the use of generative artificial intelligence tools. All the content, including text generation, data analysis and references was developed and reviewed by the author without assistance from AI technologies.

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