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Dynamical difference in patients encounters involving uncontrolled diabetes: an orbital decomposition analysis

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Abstract

Rationale Poor glucose control is common in patients with type 2 diabetes. Little is known about the dynamics within the doctor–patient encounter that might explain this phenomenon. The purpose of this study was to compare dynamics of encounters with and without a hypoglycaemic medication change for patients with poorly controlled diabetes.
Methods The doctor–patient encounters of 182 patients with type 2 diabetes from 20 primary care clinics were audio-recorded and transcribed. Encounters were coded using the Davis Observation Codes (DOCs), classifying content into 20 different categories, for example, chatting or history taking, at 15 second intervals. Of the 60 encounters in which the A1C > 8.0, 25 involved a medication change. Fifteen patients were randomly selected from those with a change in medication as well as fifteen patients from those without a change in medication for analysis using orbital decomposition. 'Orbital decomposition' is an analytic technique based on symbolic dynamics in which categorical time series data, such as a string of DOCs, are used to identify amount of complexity present and recurrent patterns of strings.
Results Encounters with a change were longer (mean 20 versus 15.5 minutes) and included more time planning treatment (29% versus 23%). Encounters with and without a change displayed similar degrees of non-linearity, but change encounters were slightly more non-linear ($D_{Lyapunov}$ = 1.94 versus 1.75). Encounters with a change had more structure to them: they had many more DOC strings (60 versus 33 strings occurring at least three times), and those DOC strings more often linked treatment planning to history taking, chatting, health education, physical examination and compliance assessment. Encounters without a change linked treatment planning to history taking, compliance assessment and nutrition counselling but had no strings with chatting or evaluation and feedback.
Conclusion In conclusion, the doctor's decision to change medication may be made before the encounter, thus the different strings of DOC codes observed. Chatting and evaluation and feedback may be strategies to increase trust before recommending a medication change.

Introduction

Most patients with type 2 diabetes mellitus in the United States receive their diabetes care from primary care clinicians [1]. There is some evidence that the interaction between patient and doctor during the primary care encounter is associated with diabetes outcomes, such as glucose control [2]. More detailed analysis of the conversation between doctors and patients suggest that some aspects of doctor–patient communication are associated with intermediate clinical outcomes such as blood pressure or blood sugar control [3]. These studies largely focused on fixed aspects of doctor communication styles, such as doctor affect and information sharing, rather than on categories of doctor–patient interactions during the encounter such as examining the patient, obtaining history or planning treatment. None have examined how the dynamics of the doctor–patient interaction over time during the encounter are related to outcomes of the encounter.

A few studies have examined how time is spent with patients during the encounter [4,5]. These studies suggest content of the encounter is related to patient satisfaction, patient understanding of directions, health status and litigation for malpractice [6]. However, little is known about the content of the visit and patient outcomes such as blood pressure, glucose and low density lipoprotein (LDL) cholesterol. In addition, little is known about whether dynamic patterns of how time is spent within the encounter are associated with outcomes, such as a change in the management in diabetes.

Patient–doctor encounters are bounded by time and by the agendas brought to the encounter by both the patient and the

doctor. Several studies have suggested that the overall level of 'competing demands' during a patient encounter are related to encounter outcomes [7–9]. In one of the few studies to date, the level of competing demands during an encounter with a patient who has diabetes has been shown to predict the likelihood that there will be a change in medication for poorly controlled glucose [10]. In this analysis, competing demands were measured as the number of patient issues and concerns brought up during the encounter. There was no attempt to develop any measure of the overall level of complexity of the encounter.

One challenge to examining the complexity of an encounter is that many different topics or issues are addressed, questions are answered, an examination is performed and advice is given [11]. These discrete events are often not captured well in medical records, nor are much known about the sequence in which these events occur. One approach to evaluating the content of an encounter would be through the use of symbolic dynamics [12]. Symbolic dynamics seeks to identify patterns within nominal time series behaviours like those found in doctor–patient encounters. The distinct feature in symbolic dynamics is that time is measured in discrete intervals. So, at each time interval the system is in a particular state, for example, 'history-taking' or 'physical examination.' Each state is associated with a symbol and the evolution of the system is described by a finite sequence of symbols – represented effectively as strings [13]. 'Orbital decomposition' is an analytic technique based on symbolic dynamics, in which categorical time series data are used to identify the amount of complexity present and recurrent patterns of strings. Briefly, orbital decomposition uses the categorical time series to compute measures of complexity and informational content using progressively longer string lengths until informational content is lost. The point at which the dynamical effects best account for the time series is used to determine the amounts of complexity and information present. In addition, this point can be used to identify sequences of behaviour that serve as autonomous dynamical patterns. Orbital decomposition has been successfully applied to both verbal [13] and electronic [14] group problem-solving exchanges as well as family dynamics in counselling settings [15].

The purpose of this study was to use an orbital decomposition approach to examine the dynamics of the content of primary care encounters of patients with diabetes and compare patient encounters in which medication was changed for poor glucose control with those in which treatment remained the same using orbital decomposition.

Methods

The Direct Observation of Diabetes Care study was begun in 2002 with the primary aim of conducting an in-depth examination of the care delivered to patients with type 2 diabetes across a diversity of primary care settings. Details of the study design have been published elsewhere [10,11]. The study was cross-sectional and observational: no interventions were performed and participants received their usual care from their primary care doctor. The setting of the study was 20 primary care clinics with 45 primary care doctors. None of the doctors were trainees. Clinics were recruited in a 'snowball' fashion with an attempt to identify and recruit primary care settings where people with type 2 diabetes are most likely to seek care: solo practice doctor clinics ($n = 11$; doctors = 11), group practice settings ($n = 3$; doctors = 10), community health centres ($n = 1$; doctors = 1), Veterans Administration (VA) primary care clinics ($n = 2$; doctors = 11) and city–county health clinics for uninsured patients ($n = 3$; doctors = 12).

Subjects and data collection

Within each clinic, consecutive patients presenting with an established diagnosis of type 2 diabetes were recruited to participate in the study. None of the patients approached declined participation. A trained observer accompanied the first 8–10 consenting patients in each clinic to the examination room and directly observed the visit. In the final sample, the range of patients per clinic was 8–10 and the range per doctor was 1–10. The visit was audio-recorded and the length of each visit in minutes was noted. Following each visit, patients completed a survey and had their medical record abstracted. Because prior studies have demonstrated substantial differences in the content of new versus established patient visits, we only recruited patients who were established patients who had received care for their diabetes for at least 1 year in the clinic where they presented for care.

Content of encounter

The content of the doctor–patient encounter was coded using a modified version of the Davis Observation Code (DOC) (see Appendix) [16,17]. The DOC categorizes doctor behaviour during their interaction with the patient into 20 different categories at 15 second intervals and has shown good to excellent reliability [17]. The DOC has been used in prior studies of primary care visits by patients with diabetes, asthma and any chronic illness [18–20]. For example, 'Health education' is defined as the doctor presenting information regarding health to the patient. This includes but is not limited to diagnosis, aetiology, drug effects and treatment. 'Evaluation and feedback' is defined as the doctor discussing the results of history, laboratory tests and radiology with the patient. 'Planning treatment' is defined as the doctor discussing treatment strategies or diagnoses, or prescribing a medication or treatment plan [16]. The DOCs have also been used to assess differences in doctor practice styles between family practitioners and general internists [21].

Change in therapy for poor glucose control

Control of risk factors for diabetes complications was measured by abstracting the most recent values of haemoglobin A1c, systolic blood pressure and LDL-cholesterol from each patient's medical record. Glucose control was measured by obtaining the most recent A1c value from each patient's medical record. For patients with an A1c over 7, any increase in dose, addition or substitution of an oral hypoglycaemic agent or insulin during the encounter was noted and recorded by the observer and was noted as a 'change' in medication. The analytic sample consisted of those with an A1c over 8, and was then divided into those who did and those who did not have a change in therapy for glucose control.

Analysis

To assist in the interpretation of differences in dynamics, we first compared the two groups using Mann–Whitney testing to identify

significant differences in A1C levels, visit duration and proportional visit time spent in each activity. Because of the exploratory nature of this study, we accepted *P*-values of ≤0.10 as significant. To assess the dynamics of activities within the doctor–patient encounter and identify recurrent strings of activities, we used orbital decomposition. Based upon information and chaos theories, orbital decomposition uses a time series of qualitative events combined across subjects to assess the degree of non-linearity in its dynamics and identify patterns of strings of events that are over-represented compared with chance. Overall, orbital decomposition consists of a sequential analysis of measures of information and dynamics with progressively longer string lengths up until the point at which no string immediately repeats itself [13]. Because similar numbers of strings should be used when comparing strings across groups, we limited the sample size per group to 15, chosen randomly using a random numbers table. Strings were not extended across subjects or across intervals when the doctor left the examination room. Shannon entropy (H_S) is a measure of randomness, by definition inversely related to information. Using the qualitative categories of events, Shannon's entropy is based on the probabilities of each event within the time series and is calculated using the following equation:

$$H_S = \sum p_i \ln(1/p_i)$$

Thus, for each category of event, its probability is multiplied by the natural logarithm of its inverse probability and then summed. Shannon entropy does not utilize temporal information at all.

Topological entropy (H_T), however, is a measure of informational content and is calculated based upon the number of strings that immediately repeat themselves. When strings are displayed in matrix form, the diagonal (trace) represents these immediately recurrent strings. Thus, topological entropy is calculated using the following equation:

$$H_T = \lim(1/C)\log_2 tr\left(M^C\right)$$

where C is string length and $tr(M^C)$ is the trace. The string length is progressively increased until the trace reaches 0. When $H_T = 0$, the dynamics are periodic; when $H_T > 0$, the dynamics are chaotic [22]. Shannon and topological entropies should be inversely related; Shannon entropy should increase and topological entropy should decrease as string length increases.

Because topological entropy is related to the maximum Lyapunov exponent (a measure of the speed with which adjacent points diverge), topological entropy can be used to calculate the dimensionality of the Lyapunov exponent (D_L) using the following equation:

$$D_L = e^{HT}$$

In periodic time series $D_L = 1$ while chaotic time series have a $D_L > 1$ [22].

To distinguish chaotic dynamics from noise, an assessment of the proportion of variance due to a dynamic effect is necessary. The likelihood chi-square calculated for string lengths >1 is a measure of deviation from that expected by chance; when string length is 1, the chi-square simply tests whether equal distribution is present. For this analysis, chi-square is calculated using the following equation:

$$X^2 = 2\sum F_{Ob} \ln(F_{Ob}/F_{Ex})$$

in which the frequency expected for any string is the product of the probabilities of its component events, such that the expected frequency for string A-B-C with individual probabilities of 0.1, 0.2 and 0.3, respectively, in a sample of 200 subjects is:

$$F_{Ex} = (Prob_A)(Prob_B)(Prob_C)(N) = (0.1)(0.2)(0.3)(200) = 1.2$$

For strings with frequencies of 0 or 1, they are treated as a single group with their observed frequency equal to their sum and their expected frequency equal to the difference between the sample size and the sum of the expected frequencies of strings longer than 1. Although phi-square can be calculated from chi-square and is a measure of R^2, we could not use it in this study because our use of 15 second events resulted in long strings of the same event, inflating the phi-square term.

Once all of these terms are calculated for each string length up to a maximum when the trace is 0, the optimal string length is determined based on the trace, the chi-square and Shannon entropy. Once the optimal string length was determined, the specific strings occurring at least three times were assembled and compared between groups.

Results

A total of 188 patient visits to 45 doctors were audio-recorded. Of these, 24 doctors had 3 or more patient visits recorded, resulting in a total of 137 visits in the final analysis. Characteristics of the patients and the visits can be found in Table 1. The majority of patients were female and Hispanic in their late 50s. The average visit was 18 minutes in length. A change in oral medications occurred in 26.7% of encounters. As the A_{1c} increased, the percent of encounters with a change in medication also increased. All subsequent analyses are limited to those encounters where the A_{1c} was greater than 8%. ($n = 60$)

Table 2 presents results of the intergroup comparisons of A1C levels, duration of office visit and proportional time spent in each activity. Although encounters leading to medication change involved higher A1C levels and less history-taking, only two sig-

Table 1 Characteristics of subjects and encounters ($n = 177$)

	Percent or mean (SD)
Age (years)	59.0 (13.3)
Female (%)	51.3
Hispanic (%)	59.2
Hemoglobin A_{1c}	
More than 7.0 (%)	65.5
More than 8.0 (%)	34.5
Length of encounter (minutes)	17.0 (8.4)
% Encounters with a change in hypoglycemic medication	
All	26.7
With $A_{1c} > 7\%$	35.6
With $A_{1c} > 8\%$	42.9
With $A_{1c} > 9\%$	46.4

Table 2 Comparison of interview characteristics

Variable	Change	No change	Mann–Whitney *U*-test (*P*)
Hgb A1C level (mean)	10.32	9.63	99.0 (.595)
Visit duration (mean # 15-second units)	80.33	62.87	69.0 (.074)
Proportional visit time in activity (%)			
Chatting	5.98%	6.32%	110.0 (.935)
Structured interaction	0.16%	0.00%	97.5 (.539)
Counseling	0.25%	0.34%	106.0 (.806)
History-taking	26.80%	30.85%	101.0 (.653)
Family information	1.60%	1.01%	102.0 (.683)
Negotiating	0.08%	0.00%	105.0 (.775)
Health knowledge	0.08%	0.30%	112.0 (1.000)
Evaluation/feedback	4.24%	1.80%	76.0 (.137)
Physical examination	5.99%	7.48%	107.5 (.838)
Patient question	0.52%	0.14%	86.0 (.285)
Compliance	7.89%	10.24%	90.5 (.367)
Preventive service	0.59%	0.59%	108.0 (.870)
Health education	8.86%	10.07%	96.5 (.512)
Health promotion	0.40%	0.00%	90.0 (.367)
Planning treatment	29.58%	22.79%	70.0 (.081)
Exercise	1.22%	2.91%	95.5 (.486)
Smoking behaviour	0.20%	1.22%	110.5 (.935)
Nutrition	5.34%	3.79%	104.0 (.744)
Substance use	0.15%	0.15%	106.0 (.806)
Procedure	0.08%	0.00%	105.0 (.775)

nificant ($P \leq 0.10$) differences were found. Encounters resulting in change were longer in duration and involved more time spent in planning treatment.

Orbital decomposition, entropy and string length

Table 3 presents the results of orbital decomposition analysis. Shannon and topological entropies were inversely related in both groups as expected ($r_s = -0.964$, $P < 0.001$ in the change group; $r_s = -0.697$, $P = 0.025$ in the no-change group). Although typically the optimal string length is chosen as one step before the length at which the trace becomes 0, long periods of time involving the same activity inflated the trace. By this criterion, we may choose string lengths of 7 for the group that changed and 10 for the group that did not change. However, Shannon entropy plateaus when string lengths are 4–5 for the change group and 5–8 for the no-change group. Finally, the likelihood chi-squares are maximal when string lengths are 4–5 in both groups. Based upon these results, we selected string length of 5 because it maximized the chi-square while recognizing the Shannon entropy plateau. With $D_L > 1$ for both groups at a string length of 5, non-linearity in the interactions is suggested.

Analysis of isolated 5-activity strings

Using a string length of 5 as optimal, Table 4 presents the strings that occurred at least 3 times in either group. All of these strings used only eight activities. Although the group in which change occurred included a total of 1105 strings of 5, only 60 strings were observed at least 3 times; in the group in which no change occurred, the total 848 strings led to 33 strings occurring at least 3 times. Although most strings in both groups involved 0 or 1 change in activity, nine of the frequently occurring strings in the change group involved two changes in activity while six of these strings in the no-change group involved two changes in activity. Overall, 39 of the 60 frequently occurring strings in the change group were not observed frequently in the no-change group while only 12 of the 33 strings in the no-change group were not frequently seen in the change group.

Table 5 presents the frequently occurring strings categorized by whether they occur in either group uniquely or in both groups. If we assume that those strings occurring in both groups represent patterns that characterize encounters with diabetic patients, then we see that such encounters typically involve a variety of patterns combining history-taking and treatment-planning as well as history-taking and compliance-assessment. In addition, typical diabetic encounters include 1-minute history taking followed by physical examination, health education followed by 1-minute of planning treatment and compliance assessment embedded within planning treatment; different patterns combining compliance with treatment planning were seen in each group as well as both groups.

Encounters with a change in medication

The encounters in which change occurred showed some unique patterns when compared with those in which no change was made. First, although combining history taking with treatment planning is common to both groups, these combinations are particularly seen in encounters in which change is made. In fact, although seven patterns are seen in both groups (see Table 5), the first three patterns are much more common in encounters involving change.

Table 3 Results of orbital decomposition analysis

String length	*n*	Trace	H_T	D_L	Chi-Square X^2 (d.f.)	H_S
Change						
1	1205	14	3.807	45.015	3345.16 (19)	2.012
2	1176	17	2.044	7.718	1567.98 (68)	3.380
3	1152	14	1.269	3.557	2812.02 (102)	4.520
4	1128	7	0.702	2.017	3875.22 (122)	5.467
5	1105	10	0.664	1.943	3770.50 (115)	5.740
6	1083	4	0.333	1.396	3395.02 (98)	6.314
7	1061	9	0.453	1.573	3248.70 (86)	6.599
8	1040	1	0	1	2469.34 (69)	6.665
9	1020	0	–	–	1968.44 (52)	6.685
No change						
1	943	15	3.907	49.749	1710.51 (15)	2.022
2	919	17	2.044	7.718	1261.96 (64)	3.270
3	895	15	1.302	3.678	2347.96 (101)	4.212
4	871	19	1.062	2.892	3040.98 (125)	4.790
5	848	7	0.561	1.753	2822.88 (97)	5.123
6	827	3	0.264	1.302	2250.26 (58)	5.159
7	805	3	0.226	1.254	1897.90 (39)	5.175
8	786	3	0.198	1.219	1494.12 (28)	5.192
9	766	3	0.176	1.193	1232.94 (19)	4.994
10	746	3	0.159	1.172	888.72 (10)	4.937
11	726	1	0	1	679.16 (5)	5.098
12	707	1	0	1	570.28 (4)	4.821
13	688	0	–	–	480.72 (4)	4.569

n, number of strings.

Encounters that combined planning treatment with chatting were only found in the group with a change in medication. In fact, even though chatting occurred with similar frequencies in both groups, none of the frequently occurring strings in the no-change group included chatting. Although both groups had strings of 1-minute of history taking followed by physical examination, the change group reported additional strings always beginning with history taking. Although physical examination occurred similarly in both groups, only one of the frequently occurring strings in the no-change group involved physical examination.

Strings coupling history taking with nutrition discussion only occurred in encounters with a change in medication. Although both groups coupled health education with a minute of treatment planning, only encounters with a change in medication had additional strings involving these activities. Only the change group combined history taking with evaluation and feedback. Only the change group combined physical examination with treatment planning, always beginning with physical examination. Strings that coupled compliance assessment with evaluation/feedback, beginning with compliance assessment were only found in the change group. Finally, although the proportions of time spent in evaluation/feedback and health education were similar in both groups, only the change group frequently included a 75-second string of evaluation/feedback. Although a 75-second string of health education was seen in both groups, it was much more common in the change group.

Encounters with no change in medication

Encounters not resulting in a change in medication also had their own unique strings. First, although both groups combined history taking with health education, the strings seen in the no-change group always began with a period of history-taking. Second, the no-change group included several unique strings involving history taking and compliance assessment; even those strings seen in both groups occurred more frequently in the no-change group. Finally, the no-change group coupled nutrition discussion with treatment planning. Although both groups used strings combining history taking, treatment planning, and health education, encounters resulting in change used Pt-Pt-Ht-Ht-He while those not resulting in change used Ht-Ht-Ht-He-Pt. In both cases, history taking precedes health education; what differs is the position of treatment planning.

Discussion

Overall, encounters resulting in change were longer in duration and, as expected, included more time proportionally spent in planning treatment. Based upon the dimensionality of Lyapunov's exponent, both groups displayed a similar degree of non-linearity, although the change group was slightly more non-linear. However, the encounters differed in the number and qualities of their frequently occurring strings of activity. Encounters leading to change had many more strings in general, especially those involving chatting, physical examination and evaluation/feedback.

Encounters in which a change in treatment was made were more structured in general as evidenced by the greater number of recurrent strings. Although all encounters displayed certain patterns of similarity, those involving change had almost twice as many patterns identified. This may suggest that doctors who readily alter their treatment in response to an elevated A1C take a more structured approach to the encounter, perhaps entering the examination

Table 4 Comparison of strings (C = 5)

Change (n = 1105)		No change (n = 848)	
String	Frequency (n)	String	Frequency (n)
Pt-Pt-Pt-Pt-Pt	116	Ht-Ht-Ht-Ht-Ht	78
Ht-Ht-Ht-Ht-Ht	57	Pt-Pt-Pt-Pt-Pt	39
Ch-Ch-Ch-Ch-Ch	23	Pe-Pe-Pe-Pe-Pe	21
Pe-Pe-Pe-Pe-Pe	19	Cm-Cm-Cm-Cm-Cm	19
Cm-Cm-Cm-Cm-Cm	15	Ch-Ch-Ch-Ch-Ch	18
He-He-He-He-He	15	Ht-Ht-Ht-He-He	7
Nu-Nu-Nu-Nu-Nu	13	Ht-Ht-Ht-Ht-He	6
Ht-Ht-Ht-Ht-Pt	10	Ht-Ht-Ht-Ht-Cm	6
Ht-Pt-Pt-Pt-Pt	10	Nu-Nu-Nu-Nu-Nu	6
Pt-Pt-Pt-Pt-Ht	10	Ht-Ht-He-He-Ht	5
Ht-Ht-Pt-Pt-Pt	9	Ht-Ht-Pt-Ht-Ht	5
Pt-Ht-Ht-Ht-Ht	9	Cm-Ht-Ht-Ht-Ht	5
Pt-Pt-Pt-Ht-Ht	9	Cm-Cm-Ht-Ht-Ht	5
Pt-Pt-Ht-Ht-Ht	7	Cm-Cm-Cm-Ht-Ht	5
Pt-Pt-Pt-Pt-Ch	7	Cm-Cm-Cm-Cm-Ht	5
Ht-Ht-Ht-Pt-Pt	6	Ht-Ht-Ht-Cm-Cm	4
Ht-Ht-Ht-Pe-Pe	6	Ht-Ht-Cm-Cm-Cm	4
Ht-Ht-Ht-Nu-Nu	6	Ht-Cm-Cm-Cm-Ht	4
Pt-Pt-Pt-Pt-He	6	Pt-Ht-Ht-Ht-Ht	4
Ef-Ef-Ef-Ef-Ef	6	He-Pt-Pt-Pt-Pt	4
Ht-Ht-Ht-Ht-Pe	5	He-He-He-He-He	4
Pe-Pe-Pt-Pt-Pt	5	Ht-Ht-Ht-He-Pt	3
Pt-Pt-Pt-Ch-Ch	5	Ht-Ht-Ht-Pt-Ht	3
Ef-Ef-Ef-Ht-Ht	5	Ht-Ht-Pt-Pt-Pt	3
Ht-Ht-Ht-Pt-Ht	4	Ht-Pt-Pt-Pt-Pt	3
Pt-Ht-Ht-Pt-Pt	4	Pt-Pt-Ht-Ht-Ht	3
Pt-Ht-Pt-Pt-Pt	4	Pt-Pt-Pt-Ht-Ht	3
Ht-Ht-Ht-Ht-Nu	4	Pt-Pt-Pt-Pt-Ht	3
Ht-Ht-Pe-Pe-Pe	4	Pt-Cm-Pt-Pt-Pt	3
Pe-Pe-Pe-Pt-Pt	4	Pt-Pt-Cm-Pt-Pt	3
Pe-Pt-Pt-Pt-Pt	4	Ht-Cm-Cm-Cm-Cm	3
He-Pt-Pt-Pt-Pt	4	Ht-Ht-Ht-Ht-Pe	3
Pt-Pt-Pt-He-Pt	4	Nu-Nu-Pt-Pt-Pt	3
Pt-Pt-Ch-Ch-Ch	4		
Pt-Ch-Ch-Ch-Ch	4		
He-Ht-Ht-Ht-Ht	4		
Cm-Pt-Pt-Pt-Pt	4		
Cm-Cm-Cm-Ef-Ef	4		
Ht-Ht-Pt-Pt-Ht	3		
Ht-Pt-Pt-Ht-Ht	3		
Pt-Pt-Ht-Ht-He	3		
Pt-Pt-Pt-He-He	3		
He-He-He-He-Pt	3		
Ht-Ht-He-Ht-Ht	3		
Ht-Ht-Ht-Ht-Cm	3		
Ht-Cm-Cm-Cm-Cm	3		
Cm-Ht-Ht-Ht-Ht	3		
Cm-Cm-Cm-Cm-Ht	3		
Cm-Cm-Cm-Cm-Ef	3		
Ef-Ef-Ef-Ef-Ht	3		
Ef-Ef-Ht-Ht-Ht	3		
Ht-Ht-Ef-Ef-Ef	3		
Ht-Ht-Nu-Nu-Nu	3		
Ht-Pe-Pe-Pe-Pe	3		
Pe-Pe-Pe-Pe-Pt	3		
Pt-Cm-Pt-Pt-Pt	3		
Pt-Pt-Pt-Cm-Pt	3		
Ch-Pt-Pt-Pt-Pt	3		
Ch-Ch-Ch-Pt-Pt	3		
Ch-Ch-Ch-Ch-Pt	3		

Ch, chatting; Cm, compliance; Ef, evaluation/feedback; He, Health education; Ht, History-taking; Nu, nutrition; Pe, physical examination; Pt, planning treatment.

Table 5 Comparison of isolated strings

Activities	Change group only	Both groups	No-change group only
Ht-Pt	Ht-Ht-Ht-Ht-Pt	Ht-Pt-Pt-Pt-Pt	Ht-Ht-Pt-Ht-Ht
	Ht-Ht-Ht-Pt-Pt	Pt-Pt-Pt-Pt-Ht	
	Pt-Ht-Ht-Pt-Pt	Pt-Pt-Pt-Ht-Ht	
	Pt-Ht-Pt-Pt-Pt	Ht-Ht-Pt-Pt-Pt	
	Ht-Ht-Pt-Pt-Ht	Pt-Ht-Ht-Ht-Ht	
	Ht-Pt-Pt-Ht-Ht	Pt-Pt-Ht-Ht-Ht	
		Ht-Ht-Ht-Pt-Ht	
Ch-Pt	Pt-Pt-Pt-Pt-Ch		
	Pt-Pt-Pt-Ch-Ch		
	Pt-Pt-Ch-Ch-Ch		
	Pt-Ch-Ch-Ch-Ch		
	Ch-Pt-Pt-Pt-Pt		
	Ch-Ch-Ch-Pt-Pt		
	Ch-Ch-Ch-Ch-Pt		
Ht-Pe	Ht-Ht-Ht-Pe-Pe	Ht-Ht-Ht-Ht-Pe	
	Ht-Ht-Pe-Pe-Pe		
	Ht-Pe-Pe-Pe-Pe		
Ht-Nu	Ht-Ht-Ht-Nu-Nu		
	Ht-Ht-Ht-Ht-Nu		
	Ht-Ht-Nu-Nu-Nu		
He-Pt	Pt-Pt-Pt-Pt-He	He-Pt-Pt-Pt-Pt	
	Pt-Pt-Pt-He-Pt		
	Pt-Pt-Pt-He-He		
	He-He-He-He-Pt		
Ht-Ef	Ef-Ef-Ef-Ht-Ht		
	Ef-Ef-Ef-Ef-Ht		
	Ef-Ef-Ht-Ht-Ht		
	Ht-Ht-Ef-Ef-Ef		
Pe-Pt	Pe-Pe-Pt-Pt-Pt		
	Pe-Pe-Pe-Pt-Pt		
	Pe-Pt-Pt-Pt-Pt		
	Pe-Pe-Pe-Pe-Pt		
Cm-Ef	Cm-Cm-Cm-Ef-Ef		
	Cm-Cm-Cm-Cm-Ef		
Cm-Pt	Cm-Pt-Pt-Pt-Pt	Pt-Cm-Pt-Pt-Pt	Pt-Pt-Cm-Pt-Pt
	Pt-Pt-Pt-Cm-Pt		
Ht-He	He-Ht-Ht-Ht-Ht		Ht-Ht-Ht-He-He
	Ht-Ht-He-Ht-Ht		Ht-Ht-Ht-Ht-He
			Ht-Ht-He-He-Ht
Ht-Cm		Ht-Ht-Ht-Ht-Cm	Cm-Cm-Ht-Ht-Ht
		Cm-Ht-Ht-Ht-Ht	Cm-Cm-Cm-Ht-Ht
		Cm-Cm-Cm-Cm-Ht	Ht-Ht-Ht-Cm-Cm
		Ht-Cm-Cm-Cm-Cm	Ht-Ht-Cm-Cm-Cm
			Ht-Cm-Cm-Cm-Ht
Nu-Pt			Nu-Nu-Pt-Pt-Pt

Ch, chatting; Cm, compliance; Ef, evaluation/feedback; He, health education; Ht, history-taking; Nu, nutrition; Pe, physical examination; Pt, planning treatment.

room with a treatment change already in mind. Such high levels of structure may suggest that such doctors focus more on the A1C levels while those who do not always adjust treatment are more willing to attend to other possible approaches or patient priorities.

Encounters differed between those in which a change was made versus those in which no change was made in terms of chatting, physical examination and evaluation/feedback. While encounters involving change linked treatment planning to history taking, chatting, health education, physical examination and compliance assessment, encounters not involving change linked treatment planning to history-taking (minimally), compliance assessment and nutrition counselling. It is possible that doctors are trying to increase patient trust by the use of chatting in combination with planning treatment during encounters where a change in medication is made. In addition, although both groups linked history taking, planning treatment and health education in encounters in which change was made, health education came after, not before, planning treatment. This observation suggests that perhaps doctors planning a change in treatment used the health education to help implement that treatment while doctors who did not make a

change used that education to inform their decision making. Focusing on health education, longer periods of time spent with an educator were associated with a decrease in HbA1c [23]. In addition, patients who spend time in a structured diabetic education course have an associated decrease in blood glucose [5]. What is uncertain is the content or the style of the health education provided by doctors during the visit. For example, motivational interviewing may be much more effective in changing patient behaviour than standard educational approaches [24,25].

This study has several limitations. First, the attempt to have comparable numbers of events within each time series led us to randomly select 15 subjects from each group, resulting in a loss of data from the unused subjects. Second, the use of time intervals rather than events increased recurrences of the same activity, inflating phi-square terms such that it could not be used. Third, the choice of $C = 5$ as cut-off is somewhat arbitrary, but Lyapunov's dimension is slightly higher in the change group versus the no-change group for $C = 4$ and $C = 6$ as well. When determining the frequently occurring strings, we chose to display only those occurring at least 3 times. This again is somewhat arbitrary. Finally, the fact that the change group had more strings overall (1105 versus 848) may have increased the number of frequently occurring strings found in this group. However, the number of strings with frequency of at least 4 in the change group is still more than the number with frequency of at least 3 in the no-change group.

One other point should be made about the limitations of this study relevant to the outcome measure: a change in medication for poorly controlled glucose. If patient–doctor encounters are a type of non-linear dynamic interaction between two agents in a complex system, then such a change might be considered to be an emergent outcome of that interaction, not just in the visit that was observed, but as a result of the content and dynamic pattern of doctor–patient interactions over several visits. For example, discussions about glucose control often centre around patient adherence with diet and exercise, and there may be several visits where this is discussed and glucose monitored before a decision is made to change medications, especially if that change includes adding additional agents such as daily insulin injections. The data in this analysis only come from a single visit with a patient; thus, we are unable to assess the dynamic pattern of interaction over several visits that might lead up to a visit where a change in medication is made.

In conclusion, while encounters of uncontrolled diabetes were typically characterized by strings involving a variety of patterns combining history-taking and treatment-planning as well as history-taking and compliance-assessment, encounters that led to treatment change were more structured, uniquely involving strings with chatting and evaluation/feedback.

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Appendix

Operational definitions for direct observation coding

CH: Chattjng Physician or patient discussing topics not related to current visit, for example, small talk or humor which might be used to build rapport

SI: Structuring Interaction. Physician or patient discussing what is to be accomplished in current interaction; or physician asks patient questions. Excludes requests by physician for patient to do anything which is part of the.physical exam. Or is done to prepare for physical exam. Excludes planning treatment. Can include statements describing what will be done in physical exam

CO Counseling Physician discuss interpersonal relations or current emotional state of patient or patient's family. provides reassurance, advice. or support or uses self -disclosure to reassure patient. Excludes 'advice'. asking for health behavior change (see Health Promotion). Physician restates what patient has said (in regards to above) or reflects on the patient's nonverbal behavior.

HT: History Taking Physician inquiring about (or patient describing details related to the current chief complaint or to prior illnesses or treatment. Includes physician reading medical record. Includes patient response to current treatment. Includes physician asking if physical exam maneuver produces pain or reeling described in chief complaint or history.

Fl Family lnformaljon Physician inquires about or discusses family medical or social hislory or about current functioning of family

(Family can include unrelalEd significanl olhers from social or work groups.)

NE Negotiation Physician comments or questions which facilit3te or invite patient participation in diagnosis. treatrnent planning or problem solving. Examples: 'What do you think?'; 'What would work for you?'; 'How would you feel about doing it this way') 'Are there any ways you think might work?'

IlK Hea[th Know[edge Physician asks or paLient sponUlneously offers what palient knows or believes about heallh or disease (as opposed to paLient's own lreatmenl history which is coded History Taking).

EF Evaluaejon Feedback Physician tells patient about results of history, physical examination, lab work, elC. (includes telling I1lal lab tests are incomplete, inconclusive, etc.). Results can be preliminary or speculative.

PE Physical Examination Physician conduclS any aspecl or physical exarninalion of palienl including taking samples for lab lCSlS O

diagnostic procedures; also includes asking palienllo prepare for physical exam, lelling patienllo do somelhing in physical exarn or asking if maneuver hurls or is lender.

PQ Patient Question Patienl asks question or physician aboul diagnosis lreaunent, side erreclS, history, or disease.

CM Comp[iance Physician inquiring about or discussing what pauenl is currenlly doing or has done reeenlly regarding previously requesled behavior around taking medicalion, changing nuu-ition, or doing exercise or olher behavior change.

PS Preventive Services Physician discusses, plans or performs any screening task associated with disease prevention or asks history on disease prevention. For example: Pap smear, breast exam, vaccination, hip clik exam, testicular exam, rectal exam, thyroid eX4m or scoliosis exam.

HE Health Education Physician presents information regarding heallh to patienL This may include information regarding diagnosis.

etiology, drug effects and lre.alment, or accident prevention. ~y also include statements about he.allh atliludes and molivation.

HP Health Promotion Physician asks for a change in palient's behavior in order to increase or promote palient's health (including accident prevenlion). This excludes changing beltavior around taking a medicalion. Any explanalion of the procedure itself, its side-effects, drug interaclions, or contraindicalions should be coded HE. Excludes asking a palient to take medication.

PT Planning Treatment Physician prescribes a medication, diagnostic, or trealmenl plan la be followed olher lhan behavior change (see Heallh Promotion). Includes physician asking is prescriplion refill is needed.

EX Exercise any question about or discussion of exercise

SM Snwking Behavior Any question about or discussion of smoking or olher use of lobacco.

NU Nutrilion Any question aboul or discussion of nulrilion. Includes discussion of diet and/or food intake (excludes queslions regarding only appetite. which is coded as hislory).

SU Substane~ Use Any question about or discussion for drinking alcohol or use of other substance.

PR Procedure any treaunent or diagnostic procedure done in office, for example, removing skin lags, Warts, drawing blood, casting, dressing.

debriding, elC. Excludes preventive services such as Pap smear.

