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A Tale of Two Eras: Mining Big Data from Electronic Health Records to Determine Limb Salvage Rates with Podiatry

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Abstract

Aims/Hypothesis: Diabetes foot complications remain very prevalent in the US and world-wide, and a major risk for devastating amputations. We evaluated the impact of establishing a fully integrated and specialized Podiatry service into a large tertiary academic health system to implement structured and targeted preventative foot care on limb salvage rates.

Methods: Cross-sectional cohorts' data mining analysis was conducted of all encounters for diabetes and any foot complications between 2000–2005 and 2010–2015, preceding and after full implementation of podiatry service, respectively. The primary outcome was the change in major non-traumatic lower extremity amputations. Secondary outcomes included minor non-traumatic lower extremity amputations, other diabetic foot complications, limb salvage procedures as documented by procedural coding, and location (outpatient, inpatient, ED) of service rendered.

Results: We analyzed 100 million patient encounters that met the above criteria. Compared with the initial cohort, integration of specialized podiatry services resulted in a significant decrease in the number of major amputations from 127 to 85/year ($p < 0.05$), and halved the amputations rate from 0.004% to 0.002% ($p < 0.05$). Rates of minor lower extremity amputations remained

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AUTHOR CONTRIBUTIONS

B.S. drafted the manuscript. B.S., C.H., W.Y., and RPB researched data and reviewed and edited the manuscript. W.Y. assisted with statistical analysis and interpretation. B.S. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No Animals/Humans were used for studies that are the basis of this research.

CONSENT FOR PUBLICATION

Not applicable.

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CONFLICT OF INTEREST

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unchanged ($p>0.10$), while the rates of preventative procedures including foot ulcer debridement doubled (0.0002% to 0.0004%; $p<0.03$). Diagnoses of diabetic foot complications increased significantly ($p<0.05$) and shifted toward the outpatient setting.

Interpretation: Full integration of specialized Podiatry service led to a significant decrease in major amputation rates, supporting teamwork between podiatry and diabetes health-care providers is essential to performing timely diabetic foot complications management, preventative procedures leading to limb salvage, and a shift in the care location.

Keywords

Diabetic foot; limb salvage; amputation; debridement; podiatry

1. INTRODUCTION

Diabetes-related foot complications, including foot ulcerations [1], infections, deformities, and Charcot osteopathic arthropathy remain as prevalent and devastating complications of diabetes in the United States (US) and worldwide. Other diabetes-associated complications such as diabetic peripheral neuropathy and peripheral vascular disease further challenge the management and treatment of diabetic foot disease, ultimately leading to lower extremity amputations [2–5]. After years of systematic decline in US diabetes-related amputation rates [6], recent data presented from the Center of Disease Control and Prevention (CDC) reported that amputation rates have been increasing for the past 4 years [7]. This is in spite of advances in targeted wound care products, recommendations for interdisciplinary clinical and surgical teams, and improvement of overall diabetes medical care.

In fact, many patients with diabetic foot disease fear major lower extremity amputation more than death [8]. These feared amputations have been shown to lead to poor quality of life, increased risk of contralateral limb amputation, and increased mortality rates [2–5]. For instance, evidence from independent cohorts show that one-year mortality rates following a higher level amputation, either below-knee or above-knee, approach 40% in diabetes [9], while the 5-year mortality rates are as high as 80% [10, 9].

This data underlines a further need for establishing effective diabetic limb salvage programs worldwide. An increased awareness of the beneficial role of podiatrists as integral team members for such multi-specialty limb salvage programs is emerging in contributing to reduce major lower extremity amputations [11–13]. Services that can be provided by podiatrist range from performing annual diabetic foot exams, management and prevention of diabetic foot ulcers, diabetic foot infection management, and complex foot and ankle reconstructions for various foot and ankle deformities [3]. Podiatrists are thus oftentimes gatekeepers of the multidisciplinary team, focusing on diabetic limb preservation, which can lead to a reduction of foot complications [14, 15]. Recent data from both Medicare and commercially insured populations databases reported that simply visiting a foot specialist was associated with reduced hospitalizations rates and protected patients from undergoing lower extremity amputation [14, 15].

However, access to podiatric services among Medicaid beneficiaries and uninsured in the US, as well as in many other countries [16] remains limited. There is also a paucity of academic institutions or healthcare systems with an integrated Podiatry division dedicated to prevent diabetic foot complications and promote limb preservation.

The main objective of this analysis was to evaluate the impact of establishing a fully integrated and specialized Podiatry service at the University of Michigan Health System (UMHS), a large tertiary academic health system overseeing the care of more than 80,000 patients with diabetes, to provide structured and targeted diabetic foot care. A comprehensive approach was utilized to compare the era following podiatry integration with a preceding period when no such service was available. The analysis included the following: 1) Limb salvage rates as determined by major and minor lower extremity amputations performed, 2) Diagnosis of diabetic foot complications and implementation of limb salvage-related procedures, and 3) Location of services rendered.

2. METHODS

2.1. Establishment and Integration of Podiatry Subdivision

Podiatry services were initiated at UMHS in 2006 as a pilot outpatient clinic staffed by a single podiatrist provider appointed in the Division of Metabolism, Endocrinology and Diabetes. This successfully and quickly evolved to a *Podiatry Subdivision* with a team of five board-certified podiatrists fully integrated into the entire outpatient Diabetic clinics, with an expansion of privileges comprising the outpatient, inpatient, and emergency settings, an active inpatient Podiatry consultation service, and an accredited Fellowship Training Program in Limb Salvage and Wound Care. The main goals are to detect and manage diabetes foot complications and promote limb salvage.

2.2. Study Design

This was a cross-sectional cohort investigation which mined and analyzed big data from single unified Electronic Medical Records (EMR) at UMHS that includes all outpatient clinics and inpatient settings with fully developed and implemented innovative tools readily available for subjects' data mining, adherence monitoring, and outcome measures. The EMR system has been in place for 25 years and is tailored for diagnosis recognition as queried.

The counts and rates of diabetic foot complications were analyzed during two distinct eras: 2000–2005, preceding the establishment of podiatry services, and 2010–2015 following the full establishment of the podiatry program and subdivision as described above. Inclusion criteria were adult ambulatory patients age 18 and patient encounters with diabetes mellitus and a concomitant diabetic foot complication. ICD-9, and conversion codes for ICD-10, of any listed diagnosis of diabetes (250.xx) in addition to osteomyelitis of foot or ankle (730.xx), ulcer foot (ICD-9 707.xx), cellulitis and abscess of toe, foot, or unspecified digit (681.x), and gangrene (785.4), were included. Our EMR mining system was then programmed to include limb salvage procedural codes, based on Common Procedure Terminology (CPT) for higher-level amputations (CPT 84.13–84.19), minor lower extremity amputations (CPT 84.10–84.12), wound debridement codes (CPT 97597 – 97598; 11042 –

11047), bioengineered alternative skin grafting (CPT 15275–15278) and incision and drainage codes (CPT 10060 – 10061; 10140; 10120), when a diabetic foot complication was identified.

2.3. Outcome Measures

The primary outcome was the change in the counts and rates of major non-traumatic lower extremity amputations. Secondary outcomes included counts and rates of minor nontraumatic lower extremity amputations, rates of diabetic foot complication diagnoses and limb salvage procedures as documented by procedural coding, and evaluation of the location of service rendered (e.g. outpatient, inpatient, ED).

2.4. Analyses

Absolute counts of amputations, diagnosis codes, and procedural codes for diabetic patients were obtained via data mining and acted as the numerator. The total diabetic patient encounters, by setting, served as the denominator for each era to determine the prevalence of each event. Proportionality testing was performed and statistical analysis was completed using SPSS statistical software, version 22 (SPSS Inc., Chicago, IL) and SAS software (Copyright © 2002–2012 SAS Institute Inc., Cary, NC, USA).

To evaluate the setting where diabetics with a foot complication were being diagnosed and treated, in both eras, we calculated a ratio of outpatient diabetic foot complications to the acute care setting (total of inpatient and emergency diabetic foot complications). The latter era, 2010–2015, was divided by the former, 2000–2005, to determine relative diabetic foot complication setting. The ratio can be described with the following formula:

$$\frac{\text{Proportion of Outpatient: Acute care setting in 2010 – 2015}}{\text{Proportion of Outpatient: Acute care setting in 2000 – 2005}}$$

A ratio greater than 1 indicates care occurring more commonly in the clinical (outpatient) setting. A ratio less than 1 indicates care in the acute care setting. In addition, the magnitude of the number indicates the amount of care provided in each location.

Statistical significance difference of less than 5% ($p < 0.05$) was assumed to be significant for type I errors.

3. RESULTS

In 2000, 140 individuals identified carrying a primary diagnosis of diabetes concomitant with an eligible diagnosis of foot complications were treated at UMHS, resulting in 247 encounters. By 2005, the number of diabetic patients with foot complications seen at UMHS increased to 256 individuals, which resulted in 463 encounters. During this era, the care for these patients was provided by multiple services including orthopedics, vascular, physical medicine and rehabilitation, without any standardization in the type of foot care provided or in the diagnosis coding for the foot complications.

In contrast, in the second era, 2010–2015, after the expansion and the full integration of the podiatry service, the number of individuals carrying a diagnosis of diabetes concomitant with an eligible diagnosis of foot complication that were treated at UMHS increased from 713 and 1306 encounters in 2010, to 1814 individuals and 3300 encounters in 2015, respectively, consistent with an average annual 129% growth from 2006 until 2015.

The absolute counts of major lower extremity amputations were reduced significantly from an annual average of 127 to an average of 85 each year ($p < 0.05$), while the rate of major lower extremity amputations was reduced in half from 0.004% to 0.002% ($p < 0.05$) (Fig. 1). In contrast, the rates of minor lower extremity amputations in patients with diabetes and foot complications remained more or less unchanged at approximately 0.005% ($p > 0.10$), and absolute numbers of minor lower extremity amputations remained consistent with an average of 142 versus 156 per year ($p > 0.10$) in the former and latter era, respectively (Fig. 1).

Table 1 shows the frequency of various types of diabetes foot complications encountered at UMHS during these eras. As shown, the rates of diagnoses of diabetic foot complications including: acute osteomyelitis ($p < 0.0001$), chronic osteomyelitis ($p < 0.05$), unspecified osteomyelitis ($p < 0.05$), diabetic foot ulcer plus atherosclerosis ($p < 0.01$), cellulitis of the foot ($p < 0.01$) and toe ($p < 0.01$), and diabetic foot ulcer ($p < 0.0001$) increased. These increases were in contrast with a decrease in the total inpatient encounters associated with diabetes foot complications after podiatry services were introduced.

Parallel to an increase in the diagnosis of diabetic foot complications, we found a significant increase in the number of limb salvage procedures being performed compared with the prior era. For instance, wound debridement codes (CPT 11042–11045), which include debridement of full-thickness ulcerations to either subcutaneous tissue, muscle/tendon, or bone averaged at approximately 232 wound debridements per year during the era preceding podiatry, while these averaged 1210 debridements per year during the era with fully established podiatry services. Specifically, the rate of diabetic foot ulcer debridements doubled from 0.0002% to 0.0004% of all encounters ($p < 0.03$) (Table 2). All other procedural codes did not change significantly as a result of podiatry services.

Finally, we found an important shift in the location of care for diabetic foot complications between the two eras. The proportion of diabetic foot complications diagnosed in the outpatient setting increased greater than the inpatient setting for several diagnoses between eras. A comparison of the ratio of outpatient to inpatient encounters in each era demonstrates this shift. As an example, chronic osteomyelitis, acute osteomyelitis, and atherosclerosis of extremity with ulcer demonstrated location ratios of 4.99, 2.75, and 2.57, respectively ($p < 0.001$), indicating care of these patients was occurring more frequently in the outpatient setting. In addition, unspecified osteomyelitis, cellulitis of the foot, and of the toe trended toward the outpatient setting with ratios of 1.59, 1.38, and 1.26, respectively ($p < 0.001$). The diagnosis of ulcer of minor limb, except pressure ulcer (707.1x) shifted toward the acute care setting, but was not significant.

4. DISCUSSION

This first-of-its-kind study evaluated the impact of the full integration of a structured podiatry service at a large tertiary care academic facility in the US in the setting of contemporary standard of care for diabetic foot complications through analysis of big data mining from single unified EMR across all outpatient clinics and inpatient settings.

Three major findings were elucidated from our study. First, these data demonstrate that by implementing and improving access to specialized limb salvage care, podiatry services had a critical impact, resulting in reducing in half the rate of major non-traumatic lower extremity amputations in patients with diabetic foot complications. A lack of podiatry accessibility is not isolated to the US. A study from South-West England demonstrates that once foot care services provisions are enhanced, including improved community podiatry staffing, major diabetes-related lower limb amputation incidence is significantly reduced [16]. To the contrary, without this provision, high amputation incidence continued [16].

Previous literature by our team has shown that the major non-traumatic lower extremity amputation to minor nontraumatic lower extremity amputation, or high-low amputation ratio (Hi-Lo), decreased significantly throughout the entire existence of podiatry when compared to the era without podiatry services [14]. Unlike the high-low amputation study, which only demonstrates the change in the ratio of high-level amputations to low-level amputation over time, our current findings support a mechanism by which the major amputation rate decreased.

The mechanism is highlighted by the study's other findings. We demonstrated rates of diagnosis of diabetic foot complications increased significantly for multiple diagnosis codes across various settings. We attribute this to the increased awareness of the podiatric physician in identifying and managing diabetic foot complications both medically and surgically. Also because of the patient's diabetic foot complication, the patient is risk stratified [17, 18] and this increases the frequency of visits from annually for a comprehensive foot exam to many times per year. Thus, the avoidance of major non-traumatic lower extremity amputation leads to an increase in provider visits and a higher rate of diagnosis of diabetic foot complications (Table 1).

Thirdly, the diagnosis of diabetic foot complications is occurring more frequently in the clinical setting and not in an acute care setting (inpatient or emergency setting) as a result of podiatry's growth and scope. This shift was dramatic, as determined by the magnitude of our clinical to acute care setting ratio, with chronic osteomyelitis (4.99), acute osteomyelitis (2.75), and atherosclerosis of the extremity (2.57). The shift was also apparent with unspecified osteomyelitis (1.59), cellulitis of the foot (1.38), and of toe (1.26). Paradoxically, the diagnosis of diabetic foot ulcer appeared to occur more frequently at the hospital. Although not significant, this is directly attributable to the growth of our inpatient podiatry service.

Our findings echo and enhance earlier findings from Skrepnek et al who evaluated the effect of podiatry exclusion from a state Medicaid program which led to a 37.5% increase in diabetic foot infection hospital admissions [19]. By shifting the burden of care to the

outpatient setting, there is considerable implication that the addition of podiatry services results in significant healthcare cost-savings associated with diabetic foot disease.

A weakness of our study is its big data approach and analysis of outcomes. Data collection was largely based on physician coding and billing of diabetic foot complication conditions. While our institution has had unified electronic medical records for greater than 25 years, the era preceding podiatry was obtained strictly from data mining of billing, coding, and diagnosis records and not visualizing the chart. However, literature from Sohn et al. demonstrated mining of diagnostic codes for diabetic foot ulcers and complications is accurate [20, 21].

It is also important to acknowledge that we cannot attribute these findings solely to the addition of podiatry services at our institution. Continuous progress in the medical management of patients with diabetes, including multiple risk factor control, advances in understanding the pathophysiology of diabetic foot disease and in the local wound care products, reconstructive peripheral vascular surgeries to improve flow in patients with outflow disease [22–25], and effective patient education are other important contributing factors.

Several groups have shown the effect of a multi-or interdisciplinary team on limb salvage [11–13, 22–25] and they are compelling. However, we are the first group to specifically look at the impact of podiatry services on an institution. We are one of the few academic institutions with a fully incorporated podiatry service. Consequently, the (un-)fortunate uniqueness of our situation, where podiatry services were not present at our institution ever, allowed us to compare the eras and investigate trends.

In summary, big data and electronic medical records are important tools to assess treatment trends and present a comprehensive view of a queried disease state. With the addition of podiatry services at our institution, more patients are being diagnosed and managed for diabetic foot complications in the outpatient setting and more limbs are being salvaged. Care for these patients is transformed into an outpatient model of management rather than an acute care service. The amount of major lower extremity amputations has declined while the rates of minor amputations remain flat. Diabetic foot complication diagnoses are increased leading to a proliferation of limb salvage procedures being performed clinically rather than in the acute care setting. Thus, these data provide strong evidence on the powerful effect of a fully operational podiatry service has on significantly reducing diabetic foot complications and on implementing effective preventive strategies compared with a period that preceded this service at our institution. A tailored, team-based approach that includes podiatry services is needed to prevent major foot complications and mitigate diabetic foot complications. It is therefore recommended to include and expand podiatry services to provide comprehensive diabetic foot management and limb salvage.

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Fig. (1).
Rates and counts of major and minor non-traumatic lower extremity amputation.

Table 1.

Rates of Diabetes with any foot complication, organized by setting and era.

Diagnosis (ICD-9)	Setting	2000 — 2005 (%)	2010 — 2015 (%)	% Change between eras	p-value
250.xx — DM	Outpatient	3.87	8.64	123%	<0.0001
	Inpatient	10.22	8.93	-13%	<0.001
	Emergency	3.92	1.41	-64%	<0.0001
730.07-Acute Osteomyelitis	Outpatient	0.08	0.42	425%	<0.0001
	Inpatient	0.7	1.26	80%	<0.0001
	Emergency	0.54	1.11	106%	<0.0001
730.17 — Chronic Osteomyelitis	Outpatient	0.04	0.30	650%	<0.0001
	Inpatient	0.7	0.98	40%	= 0.0043
	Emergency	0.49	0.81	65%	0.0104
730.27 — Unspecified Osteomyelitis	Outpatient	0.42	0.82	95%	<0.0001
	Inpatient	1.97	2.44	24%	= 0.003
	Emergency	1.77	2.14	21%	= 0.0795
440.23 — Atherosclerosis of extremity with ulcer	Outpatient	0.2	0.42	110%	<0.0001
	Inpatient	1.86	1.38	-26%	= 0.0003
	Emergency	0.94	0.91	-3%	= 0.8178
682.7 — Cellulitis of foot	Outpatient	0.71	0.94	32%	= 0.0011
	Inpatient	2.58	2.34	-9%	= 0.1360
	Emergency	2.54	2.56	1%	= 0.9261
681.10 — Cellulitis of toe	Outpatient	0.38	0.52	37%	= 0.0054
	Inpatient	1.11	1.13	2%	= 0.9193
	Emergency	1.09	1.25	15%	= 0.3496
707.1x — Ulcer of minor limb, except pressure ulcer	Outpatient	2.54	2.58	2%	= 0.7599
	Inpatient	4.17	5.37	29%	<0.0001
	Emergency	4.53	4.80	6%	= 0.3890

Table 2.

Counts of wound debridement codes billed during each era.

Outpatient Wound Debridement Procedures		
	Preceding Podiatry (2000–2005)	Podiatry Services (2010 — 2015)
COUNT	1390	7260
AVERAGE (per YEAR)	231.66	1210
RATE	0.0002% *	0.0004% *

* p < 0.03.