ORIGINAL ARTICLE

Development of a model to predict closure of chronic wounds in Germany: Claims data analysis

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Abstract

Patients with chronic leg ulcer, pressure ulcer, or diabetic foot ulcer suffer from significant disease burden. With a view to improving healthcare provision sustainably, a predictive model of time to closure (time-to-event analysis) based on claims data was developed. To identify potential predictors of wound closure, clinical information absent from statutory health insurance (SHI) data was modelled. In patients with leg ulcers, age of the patient (hazard ratios [HR] 0.99), increasing number of comorbidities (HR 0.94), inpatient stays (HR 0.74), and treatment by a specialised wound care professional (HR 1.18) were significant predictors of time to closure (adjusted model). In almost all models, the number of inpatient stays and of comorbidities predicted a lower probability of healing. In addition, the age and the sex of the patient were found to be significant predictors in some models (leg ulcer: HR 0.99; pressure ulcer: HR 0.99). Increasing number of comorbidities and inpatient stays were predictors for closure time in all models. Since these predictors may give an indication of wound severity, further clinical information should be considered in future models, as also indicated by the moderate values of the *c*-statistics. This requires future data linkage between SHI and primary studies (eg, registers).

KEYWORDS
chronic wounds, predictors, statutory health insurance, wound closure

1 | INTRODUCTION

Patients with chronic leg ulcer, pressure ulcer, or diabetic foot ulcer have reduced quality of life, require high medical and nursing care, and are cost intensive for the healthcare system.[1-6] At an annual prevalence of 1.04% in 2012, more than 786 000 persons in Germany had chronic wounds that year, including 326 000 patients who received wound treatment.[7] Due to demographic changes and an increase in underlying diseases in the elderly population, further growth in chronic wound cases can be expected.[8,9]

Factors that influence the healing process are of great relevance for identifying the causes of prolonged treatment or wound closure disorders. To date, a number of factors that influence wound healing have been reported. Compression therapy has a significant influence on wound healing in patients with leg ulcer.[10-13] Wound duration has been shown to be a risk factor.[12-17] Wounds that have failed to heal in the

previous 3–6 months have a much smaller chance of healing.[15] Moreover, a wound size of greater than 10 cm^2 is associated with lower probability of healing.[15,16,18-22] Furthermore, a greater number of wounds is associated with a lower probability of healing.[20,21,23] Additionally, predictive factors such as vascular interventions, previous medical treatment, severity, patient age, and wound infection have been reported.[10,14,17,19-21,23-25]

In the present study, the predictors reported in the literature were used to analyse routine data. Administrative data such as statutory health insurance (SHI) claims data are based on a large population. Claims data are administrative data of German insurance funds. About 85% of the German population is covered by SHI (70 million people) and 11% are covered by complementary private health insurance.[26] Apart from size, the absence of recall and selection bias is one of the advantages of this data set. Since wounds primarily affect older people, unhindered access to the study population, regardless of frailty, is a further advantage in comparison to cost-intensive primary studies. In addition to studies of patterns of care, quality of care, resource consumption, and the evaluation of care concepts, the data are increasingly used to develop predictive models. Hence, the aim of this study was to identify possible predictors of wound closure using SHI data.

2 | METHODS

2.1 | Data source

For the present analysis, data from an SHI operating nationwide, the DAK (DAK-Gesundheit), was used. A random sample of approximately 2.3 million DAK-insured persons in 2010 constituted the data set. The sample of insured persons was anonymised by the DAK and made available to the institute for scientific research. In addition to the sociodemographic details of the insured people, such as age and gender, outpatient and inpatient care data, prescriptions, and medical aids data[26] were analysed.

2.2 | Case definition

Our study population included insured persons of the DAK sample with a new chronic wound in 2013 (incident cases) who did not have a wound in the previous 2 years. Wound dressings are a basic part of wound treatment. In addition, we used predefined wound medical prescriptions based on a product-specific PZN (Pharmazentralnummer, standard national identification code) to identify patients with active wounds.

A wound was defined as chronic if it did not heal within 8 weeks or if continuous treatment of the

Key Messages

- this study models a clinical outcome "wound closure" based on health insurance data to investigate predictive factors that are highly relevant for potentially improved health care
- the analyses were carried out on the basis of a large, nationwide German statutory health insurance (GKV) (85% of the German population are covered by statutory health insurance)
- the diagnostic and therapeutic measures investigated play a subordinate role in time to closure
- the predictors (increasing number of comorbidities and inpatient stays) may give an indication of wound severity

underlying disease was not required.[27] Therefore, patients with a wound duration of < 8 weeks were excluded from the model.

We examined insured patients suffering from chronic wounds based on the following inclusion criteria:

1. At least one outpatient (ambulatory primary care) or inpatient (hospital-based) diagnostic code of the International Classification of Diseases (ICD–10 GM) was used to identify: leg ulcer: arterial: I70.23, I70.24; venous: I83.0, I83.2, I87.0; not specified: L97, L98.4; diabetic foot ulcer: E10.–E14.74 and E10.–E14.75; pressure ulcer: L89.1–L89.3 and L89.9.
2. At least one of the following wound products: alginates with/without silver, hydrofiber with/without silver, hydrocolloid dressings with/without silver, hydrogel and hydrogel dressings, super absorbent dressings, fine-pored polyurethane foam dressings or hydropolymer dressings with/without silver, polyhexanide or ibuprofen, film dressings or semipermeable transparent dressings or permeable film dressings, coal dressings with/without silver, hydrophobic dressings, active dressings (eg, silver, hyalurone, oxygen, collagen), honey dressings, moist saline compresses/gauzes with/without zinc oxide, impregnated gauze dressings.

2.3 | Definition of time to wound closure: outcome

The main outcome was wound closure, which is the internationally agreed gold standard for effectiveness in the area of wound treatment research. In SHI data,

clinical information and hence the start and end points of wound duration and wound closure are not included as independent information.

Wound dressings have already been shown to be a valid criterion for identifying florid (active) chronic wounds using SHI data.[27,28] Also against the background that every florid wound is treated with a dressing, as every insured person in Germany (99% of the population) has free access to the healthcare system and also to dressings. Furthermore, dressings are used exclusively for the treatment of a wound.

Therefore, active wound duration and the main outcome, wound closure, was modelled on the basis of the first and last prescription (PZN) of predefined specific wound dressings (see section case definition) in combination with a wound diagnosis. The follow-up observation period was 1 year (2014) in order to identify the outcome (12 months without prescription). Follow-up ended during the defined period depending on when the last prescription was issued. The year 2015 was only studied to monitor prescriptions.

Patients were not identified as healed if they (a) had a prescription within the second follow-up period of 12 months, (b) died, or (c) were no longer insured within the predefined follow-up observation period. Patients were censored when they died or were no longer insured within the predefined follow-up observation period.

2.4 | Definition of healing predictors

The following healing predictors were analysed, depending on wound aetiology:

- wound-specific characteristics (infection and diagnostic procedures: vascular diagnosis, smear test, biopsy, and allergy diagnosis),
- causal therapy (compression, pressure distribution such as shoe provision, pressure relief such as mattress systems, vascular surgery),
- local therapy (wound debridement, negative pressure therapy, skin grafts),
- wound-relevant comorbidities (cardiovascular, pulmonary, infection, liver, dermatological, allergological, renal, rheumatological, immunological, neurological, and vascular diseases as well as metabolic disorders, malignant tumours, and lip- and lymphoedema),[29]
- further characteristics (medical wound specialist [dermatologist or surgeon in outpatient care] and hospitalisation due to the wound diagnosis) and sociodemographic characteristics (age, sex).

To obtain these predictors, we used special codes for the utilisation of outpatient (ambulatory primary care) and inpatient (hospital-based) care.[30,31] Given that different treatments are recommended for the indications, a model was constructed for each indication.

2.5 | Statistical analysis

Time to closure was assessed by means of Kaplan-Meier analysis stratified for patients with leg, pressure, and diabetic foot ulcers. We identified factors associated with time to wound closure in patients with chronic wounds by estimating hazard ratios (HR) with 95% confidence intervals (95% CI) using Cox proportional hazards models. Kaplan-Meier survival curves and time-dependent explanations were used to assess the proportional hazards assumption.[32] The likelihood-ratio test (significance level $\alpha \leq 0.05$) was used to test the significance of the overall model and transferability of the results to the population. To assess the discrimination, which is a mathematical measure of the representation of model performance, the c-statistic of the model was taken into account.[33,34] A value of 0.5 shows a random effect and 1 a maximum of discrimination.[35] Values between 0.7 and 0.8 are regarded as acceptable and between 0.8 and 0.9 as excellent. Values above 0.8 are rarely reached.[36] The final prediction model was obtained using backward selection (level of significance < 0.01).

The characteristics, such as wound aetiology and sociodemographic characteristics, were collected at baseline (first initial treatment of the wound). The other predictors, such as comorbidities or therapies, were considered over time (for a maximum of 1 year after "wound beginning"). This period was chosen to ensure a temporal dependency between the outcome and the predictors and to avoid an inflation of the effects by cumulative effect modifiers (confounders). Cardinally scaled influence variables were not recoded into a binary dummy variable but were included in the regression as continuous variables. Dummy coding is often practiced and discussed because it is associated with a loss of information.[37] In order to better interpret the cardinally scaled result, in particular mean age, this variable was centred on the mean age.[38]

All analyses were performed using Statistical Analysis System SAS Version 9.4 (SAS for Windows 2000, SAS Institute Inc., Cary, North Carolina).

The study was conducted in accordance with national guidelines for the use of administrative data sets.[39,40] Based on the guidelines, the approval of an ethics committee was not required.

3 | RESULTS

3.1 | Baseline characteristics

The study population for wound closure with incident chronic wounds in 2013 comprised 3745 patients with leg ulcer, 3342 with pressure ulcer, and 791 with diabetic foot ulcer (Figure 1).

The baseline characteristics are shown in Table 1. More than half of wounds healed within the observation period of 1 year. The mean age of patients with leg ulcers was about 78 years, with pressure ulcers 81 years and with diabetic foot ulcers 74 years. The average number of comorbidities was 3.7 in patients with leg ulcers, 3.3 in patients with pressure ulcers, and 4.6 in patients with diabetic foot ulcers. The majority of patients with a leg ulcer had at least one inpatient stay during the first year. On average, patients with leg ulcer had fewer stays compared to the other indications.

3.2 | Time to wound closure

The Kaplan-Meier survival curves (Figure 2) show, for each aetiology, the time to wound closure (first prescription of a wound dressing until last issuance of a wound dressing—maximum 365 days follow-up). The modelled healing probability after 365 days was 36.7% for patients with leg ulcer, 37.8% for patients with diabetic foot ulcer, and 22.1% for patients with decubitus. Furthermore, the curves show that almost 20% of wounds in patients with leg ulcers or diabetic foot ulcers healed after 6 months.
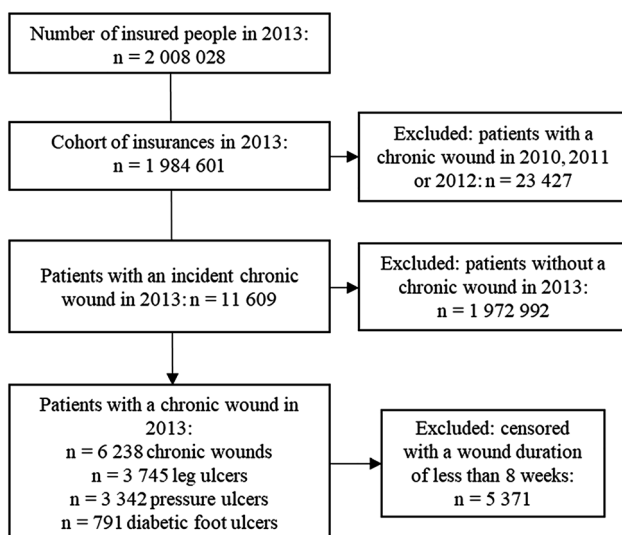

FIGURE 1   Sampling cohort

To identify predictors of wound closure, we performed several Cox regression models for each wound aetiology:

3.3 | Patients with leg ulcers

In the first crude model for patients with leg ulcers, the variables age, number of comorbidities, vascular diagnostics, smear test, vascular surgery, skin grafts, and the number of inpatient stays were found to be negative predictors of wound closure (Table 2). In the adjusted model, controlled for all influencing variables, the significant negative predictors of wound closure were age, number of comorbidities, smear test, and number of inpatient stays, and a positive predictor was health care by at least one medical wound specialist. Thus, many wound treatments in the adjusted model were no longer significant, whereas treatment by a wound specialist became a significant positive predictor of wound closure (Table 3). Therefore, insured persons who were treated by a medical wound specialist at least once show a 18% higher chance of wound closure (HR = 1.18, CI = 1.05–1.31, $P = .004$) than those not treated by a wound specialist. Insured persons also showed a 26% lower chance of recovery with each further inpatient stay (HR = 0.74, CI = 0.67–0.80, $P \leq .001$). Furthermore, the chance of wound closure decreased by 6% with each further comorbidity (HR = 0.94, CI = 0.91–0.97, $P \leq .001$).

3.4 | Patients with pressure ulcers

In patients with pressure ulcers, age, pressure distribution, pressure relief, skin grafts, debridement, and the number of inpatient stays were found to be significant negative wound closure predictors. In the adjusted model, the negative predictors of wound closure were age, gender (male), pressure distribution, pressure relief, and the increasing number of inpatient stays. Women show a 27% higher chance of wound closure than men (HR = 1.27, CI = 1.08–1.50, $P \leq .001$). With every year (of age over 81), the chance of wound closure decreased significantly by 1% (HR = 0.99, CI = 0.99–0.99, $P \leq .001$). Persons with pressure relief (eg, mattress systems) showed a 37% lower chance of recovery than insured persons without a pressure relief (HR = 0.63, CI = 0.54–0.72, $P \leq .001$).

3.5 | Patients with diabetic foot ulcers

In the adjusted model in insured persons with diabetic foot ulcers, increasing number of comorbidities as well as inpatient stays were significant negative predictors of

TABLE 1 Baseline characteristics of patients with a new chronic wound

|		Leg ulcers (n = 3745)	Pressure ulcers (n = 3342)	Diabetic foot ulcers (n = 791)
Wound healing	Number of wounds closed, n (%)	1375 (36.7)	740 (22.1)	299 (37.8)
Sociodemographic data	Sex (female), n (%)	2367 (63.2)	2228 (66.7)	361 (45.6)
	Age (years), mean (SD)	77.9 (12.6)	81.0 (12.5)	73.5 (11.7)
	≤54, n (%)	204 (5.5)	148 (4.4)	57 (7.2)
	55-64, n (%)	328 (8.8)	197 (5.9)	111 (14.0)
	65-74, n (%)	697 (18.6)	417 (12.5)	219 (27.7)
	75-84, n (%)	1184 (31.6)	956 (28.6)	254 (32.1)
	85-94, n (%)	1207 (32.2)	1410 (42.2)	144 (18.2)
	≥95, n (%)	125 (3.3)	214 (6.4)	6 (0.8)
	Comorbidity, mean (SD)	3.7 (1.7)	3.3 (1.7)	4.6 (1.5)
	0, n (%)	82 (2.2)	137 (4.1)	0
	1, n (%)	238 (6.4)	340 (10.2)	12 (1.5)
	2, n (%)	576 (15.4)	660 (19.8)	58 (7.3)
	3, n (%)	857 (22.9)	798 (23.9)	120 (15.2)
	4, n (%)	855 (22.9)	648 (19.4)	193 (24.4)
	5, n (%)	647 (17.3)	444 (13.3)	203 (25.7)
	≥6, n (%)	490 (13.1)	315 (9.5)	205 (25.9)
Diagnostic and infection	Vascular diagnosis, n (%)	1330 (35.5)	640 (19.2)	389 (49.2)
	Smear test, n (%)	341 (9.1)	339 (10.1)	79 (10.0)
	Biopsy, n (%)	255 (6.8)	120 (3.6)	53 (6.7)
	Allergy diagnosis, n (%)	15 (0.4)	4 (0.1)	0
	Infection, n (%)	935 (25.0)	401 (12.0)	251 (31.7)
Causal therapy	Compression therapy, n (%)	1813 (48.4)	n.a.	n.a.
	Pressure distribution (eg, shoe provision), n (%)	893 (23.9)	554 (16.6)	441 (55.8)
	Pressure relief (eg, mattress systems), n (%)	n.a.	1853 (55.5)	n.a.
	Vascular surgery, n (%)	549 (14.7)	n.a.	201 (25.4)
Local therapy	Negative pressure therapy, n (%)	337 (9.0)	205 (6.1)	121 (15.3)
	Skin grafts, n (%)	635 (17.0)	388 (11.6)	220 (27.8)
	Debridement, n (%)	396 (10.6)	220 (6.6)	133 (16.8)
Further characteristics	Medical wound specialist, n (%)	2154 (57.5)	1250 (37.4)	441 (55.8)
	Hospital stays, mean (SD)	0.5 (1.0)	0.4 (0.9)	0.9 (1.3)
	0, n (%)	2602 (69.5)	2434 (72.8)	439 (55.5)
	1, n (%)	690 (18.4)	572 (17.1)	184 (23.3)
	2, n (%)	269 (7.2)	203 (6.1)	93 (11.8)
	≥3, n (%)	184 (4.9)	133 (4.0)	75 (9.5)

Abbreviations: n.a., not assessed; SD, standard deviation.

wound closure. With each further comorbidity, the chance of closure decreased by 12% (HR = 0.88, CI = 0.81–0.95, $P \leq .001$).

It was possible to rule out multicollinearity in all models. All adjusted models achieved between a random (< 0.5) and a moderate (0.7–0.8) effect level of discrimination with a value of 0.62 in patients with leg ulcers and 0.61 in patients with diabetic foot or pressure ulcers in the c-statistics. The likelihood-ratio test results of all models showed a significance level below 0.01. Thus, the results

FIGURE 2 Survival (wound healing) in incident chronic wound
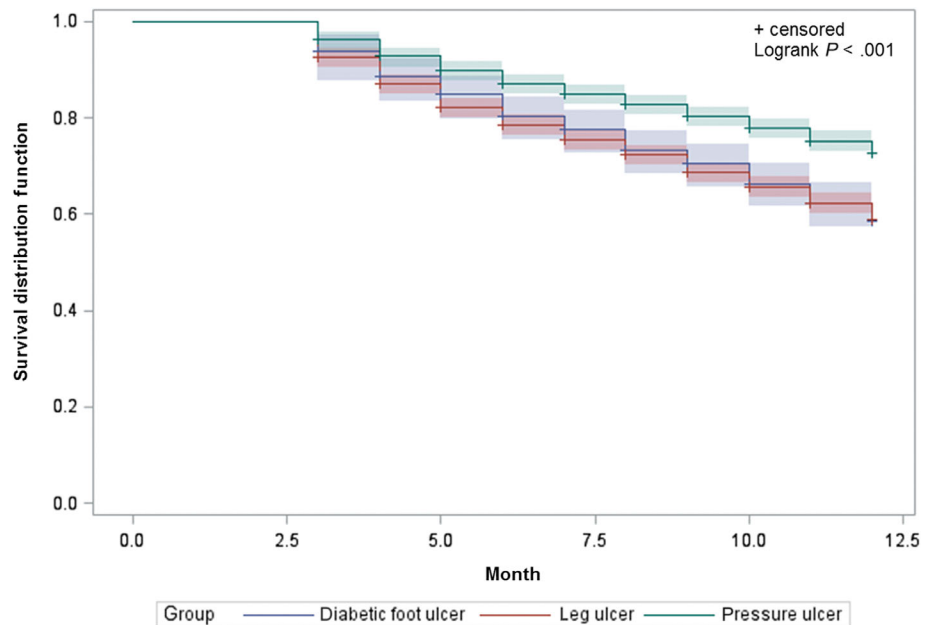
TABLE 2 Crude Cox regression model

	Leg ulcers		Pressure ulcers		Diabetic foot ulcers	
	HR (95% CI)	*P*	HR (95% CI)	*P*	HR (95% CI)	*P*
Sociodemographic data						
Female[a]	1.01 (0.91–1.13)	.795	1.22 (1.04–1.43)	.013	1.25 (1.00–1.57)	.055
Centred age[b]	0.99 (0.98–0.99)	≤.001	0.99 (0.99–1.00)	.003	0.99 (0.98–1.00)	.009
Number of comorbidities	0.90 (0.88–0.93)	≤.001	0.95 (0.91–0.99)	.021	0.86 (0.80–0.93)	≤.001
Diagnostic and infection						
Vascular diagnosis[c]	0.80 (0.72–0.90)	≤.001	0.99 (0.83–1.18)	.935	0.66 (0.52–0.83)	≤.001
Smear test[c]	0.62 (0.50–0.76)	≤.001	0.85 (0.66–1.07)	.171	0.61 (0.40–0.93)	.022
Biopsy[c]	0.78 (0.62–0.97)	.026	0.61 (0.39–0.96)	.031	0.73 (0.44–1.20)	.216
Allergy diagnosis[c]	0.97 (0.44–2.17)	.944	0.00 (0.00–0.00)	.941	0.00 (0.00–0.00)	.941
Infection[c]	1.10 (0.98–1.25)	.114	1.09 (0.88–1.36)	.427	0.96 (0.76–1.22)	.752
Causal therapy						
Compression therapy[c]	0.89 (0.80–0.98)	.024	n.a.	n.a.	n.a.	n.a.
Pressure distribution (eg, shoe provision)[c]	0.89 (0.79–1.01)	.067	n.a.	n.a.	0.98 (0.78–1.23)	.847
Pressure relief (eg, mattress systems)[c]	n.a.	n.a.	0.61 (0.52–0.70)	≤.001	n.a.	n.a.
Vascular surgery[c]	0.66 (0.56–0.77)	≤.001	n.a.	n.a.	0.62 (0.46–0.83)	.001
Local therapy						
Negative pressure therapy[c]	0.78 (0.64–0.95)	.013	0.76 (0.55–1.05)	.099	0.92 (0.67–1.25)	.582
Skin grafts[c]	0.75 (0.64–0.87)	≤.001	0.61 (0.47–0.80)	≤.001	0.89 (0.69–1.14)	.353
Debridement[c]	0.79 (0.66–0.94)	.009	0.63 (0.46–0.88)	.007	0.84 (0.62–1.15)	.284
Further characteristics						
Medical wound specialist[c]	1.13 (1.01–1.26)	.030	1.07 (0.92–1.23)	.392	1.01 (0.81–1.28)	.903
Number of hospital stays	0.73 (0.68–0.78)	≤.001	0.76 (0.69–0.85)	≤.001	0.81 (0.73–0.90)	≤.001

Note: Likelihood-ratio test < 0.001. c-statistic: leg ulcer (0.6206), pressure ulcer (0.6059), diabetic foot ulcer (0.6025).

Abbreviation: n.a., not assessed.

[a]Referent category = male.

[b]Referent category = centred mean age (leg ulcer = 87, pressure ulcer = 81, and diabetic foot = 74).

[c]Referent category = no.

TABLE 3 Adjusted Cox regression model

	Leg ulcers		Pressure ulcers		Diabetic foot ulcers	
	HR (95% CI)	*P*	HR (95% CI)	*P*	HR (95% CI)	*P*
Sociodemographic data						
Female[a]	—	—	1.27 (1.08–1.50)	.004	—	—
Centred age[b]	0.99 (0.99–0.99)	≤.001	0.99 (0.99–0.99)	.001	—	—
Number of comorbidities	0.94 (0.91–0.97)	≤.001	—	—	0.88 (0.81–0.95)	≤.001
Diagnostic						
Smear test[c]	0.65 (0.52–0.80)	≤.001	—	—	—	—
Causal therapy						
Pressure relief (eg, mattress systems)[c]	n.a.	n.a.	0.63 (0.54–0.72)	≤.001	n.a.	n.a.
Further characteristics						
Medical wound specialist[c]	1.18 (1.05–1.31)	.004			—	—
Number of hospital stays	0.74 (0.67–0.80)	≤.001	0.77 (0.70–0.86)	≤.001	0.83 (0.74–0.92)	≤.001

Note: Likelihood-ratio test < 0.001. *c*-statistic: leg ulcer (0.6206), pressure ulcer (0.6059), diabetic foot ulcer (0.6025).

Abbreviation: n.a., not assessed.

[a]Referent category = male.

[b]Referent category = centred mean age (leg ulcer = 87, pressure ulcer = 81, diabetic foot = 74).

[c]Referent category = no.

— = excluded by backward selection (level of significance < 0.01).

can be transferred to the population. In all models, the proportional hazard assumption was not violated.

4 | DISCUSSION

The aim of the present article was to identify predictors of wound healing. Predictive factors are of great relevance for identifying potential starting points for healthcare improvements. In addition to a significant reduction in the burden of disease and thus also quality of life, economic aspects need to be taken into account.[41] For these reasons, we analysed predictors that influence the length of time to wound closure. Given that clinical information is not included in SHI data, we modelled active wound duration and the main outcome, wound closure, by means of available wound-relevant information. To our knowledge, this is the first study that attempts to model the clinical outcome wound closure from SHI data and identifies predictors of wound closure based on such a large number of incident patients with chronic wounds.

4.1 | Modelled closure rates

We compared the modelled wound closure times in the SHI data to other comparable primary studies from Germany. The average time to closure of all leg ulcers was 6.1 months in the primary study[42] and 8.9 months according to the SHI data. No comparable figures on

average wound duration for the other indications have been published to date. Data from the US Wound Registry show similarly low healing rates.[43]

To ensure that all insured persons have a comparable stage of disease, only incidence wounds were included in the study. The beginning and the end of wound duration were defined based on the first and last prescription of wound dressings. Therefore, the model specifically examined the ending of treatment and not the clinical outcome of wound closure. Using SHI data, wound dressings have already been shown to be a valid criterion for identifying florid (active) chronic wounds.[28] On the basis of available information about the wound treatment (wound dressings and package size), it is not possible to estimate the treatment period to obtain a closer approximation of the actual time to clinical closure. Thus, the modelled time to closure may have been underestimated. As health insurance is compulsory in Germany, less than 0.1% of the total population in Germany does not have health insurance and therefore has free access to the German health system.[44] Therefore, the underestimation of the wound beginning is considered to be low. Time to wound healing may also have been underestimated in patients with multiple wounds, as healing could only occur at the person level and not at the wound level.

4.2 | Predictors

In the literature, the severity of the wound, the complexity of aetiology, and hospitalisation have been identified

as predictors of healing.[14,17,19-21,23,25,45] Clinical information such as disease severity is not provided in SHI data. Therefore, these factors could not be considered in the present analysis. In all of the adjusted models, an increasing number of further inpatient stays as well as number of comorbidities were found to be significant predictors of wound closure. Assuming that patients with hard-to-heal wounds are more frequently treated in hospitals and more frequently suffer from comorbidities, this may give an indication of the complexity of aetiology.

Patient age was a predictor of wound closure in the adjusted models for patients with leg ulcers and pressure ulcers. Age has also been shown to be a predictor of wound closure in other studies.[17,18,23,25,45] In the adjusted model for patients with leg ulcers, treatment by a wound specialist proved to be a predictor.

Other studies have similarly shown that early specialised treatment of chronic wounds is more economical than prolonged treatment by non-specialised therapists.[46,47]

In all crude models, the diagnostic and therapeutic measures had a significant negative influence on closure success, which means that patients receiving a diagnostic or therapeutic measure had a significantly lower chance of recovery than those who did not receive any of these measures. In the adjusted model, controlled for all variables, these parameters were largely absent and the sociodemographic parameters and those defined as further characteristics remained as significant predictors of wound closure. For example, in patients with leg ulcers, the diagnostic and therapeutic measures in the adjusted model were absent and use of a specialised wound care provider instead proved to be a significantly predictor of time to wound closure. In patients with leg ulcers smear diagnosis and in patients with pressure ulcers pressure relief were negative predictors of wound closure in the adjusted models. This is of course not in line with the evidence-based recommendations for the treatment of chronic wounds.[48] Rather, it is due to the fact that insured persons with hard-to-heal wounds tend to receive inferior treatment and receive a diagnosis or therapy only during later treatment courses without successful closure.

In addition, the c-statistics did not change significantly when diagnostic and therapeutic predictors were excluded. Therefore, in the SHI-based model, these predictors did not seem to influence model performance.

The c-statistic values (eg, 0.62 in the leg ulcer model, representing between a random (< 0.5) and a moderate (0.7–0.8) effect level of discrimination) indicate that the SHI data do not provide a sufficiently valid basis for the derivation of wound closure predictors for patients with chronic wounds due to a lack of clinical information. However, c-statistic values above 0.8 are rarely reached, as

it is a theoretical measure of discrimination.[36] These clinical wound-related parameters, such as wound size and duration, were already identified as predictors of wound closure in previous studies. The observed c-statistic values may also be attributed to the fact that the modelled wound duration, using "first" and "last" wound prescription, does not adequately reflect real wound duration or time of wound closure.

4.3 | Strengths and limitations of the work

A number of limitations must be considered. Due to insufficient or inadequate differential diagnosis, chronic wounds may have been coded incorrectly. In addition, multiple diagnoses for each insured person can exist in routine SHI data. Such multiple diagnoses may be medically justified, but they may also be assigned incorrectly due to insufficient or inadequate differential diagnosis, or they may relate to historical events (wound that has already healed). An categorisation of multiple diagnoses using additional healthcare parameters was not carried out in this article, as there is no way to gauge the proportion of incorrect assignments. Nor is it possible to assess the order of magnitude of insufficiently or inadequately differentiated coded diagnoses or special features of the coding behaviour of the practitioner (continued coding of historical events). Such an assessment would require the linking (data linkage) of routine SHI data and primary studies (eg, registers).

In addition, treatment given but not invoiced can influence the results. In our analysis, only 11% of insured persons with an incidental chronic wound had documented wound debridement. In contrast, in a primary study, a significantly higher proportion of 55% was found.[49] The low proportion in the SHI data may be attributed to the fact that clinical contraindications existed (eg, dry necrosis in the case of peripheral arterial vascular disease, which we cannot control for based on the data), or that debridement was performed but not billed or encoded by the physician.

Besides, clinical information will be missing from SHI data. Therefore, to our knowledge, this is the first study that attempts to model the clinical outcome wound closure based on information available from SHI data. A further strength of this work, and of SHI data, is the large population, comprising approximately 85% of the insured German population. The other advantages of SHI data are absence of recall or selection bias. Consequently, diagnostic, therapeutic or further specified information is not subject to this bias.

5 | CONCLUSION

In our study of a large German population, we found similar predictive factors as previously reported. Our results show, especially with regard to the *c*-statistic, that the predictor multimorbidity can give an indication of the complexity of the aetiology. Poor care due to lack of diagnostic and causal treatment leads to a poorer wound healing time or even to wounds that are difficult to heal in these patients, which may ultimately lead to hospitalisation. In further analyses, the individual comorbidities should be considered as possible predictors of time to wound healing.

The results for the *c*-statistic, which were classified as mediocre, suggest that clinical information should be included in prediction models. This requires future data linkage between SHI data and primary studies (eg, registers) to verify the feasibility of modelling missing clinical results in SHI data as undertaken in this study and to include clinical parameters in future models.

CONFLICT OF INTEREST
The authors do not have any conflicts of interest.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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