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Determination of siloxanes, silicon, and platinum in tissues of women with silicone gel-filled implants

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Abstract Silicone [poly(dimethylsiloxane)] gel used in breast implants has been known to migrate through intact silicone elastomer shells, resulting in the clinically observable “gel bleed” on the implant surface. Although silicon concentrations in capsular tissues of women with silicone prostheses have been measured with element-specific silicon analyses, no silicone-specific investigation of these tissues has been performed as yet.

A combination of element-specific inductively coupled plasma high-resolution isotope dilution mass spectrometry (ICP–HR–IDMS) and species-specific gas chromatography coupled mass spectrometry (GC–MS) was used to analyze silicon, platinum, and siloxanes in prosthesis capsule, muscle, and fat tissues of women (n=3) who had silicone gel-filled breast implants and in breast tissue of non-augmented women (n=3) as controls.

In all tissues of augmented women, siloxanes, in particular octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5), and dodecamethylcyclohexasiloxane (D6) were identified. Depending on the siloxane species and type of tissue analyzed, siloxane levels in the range of about 10–1,400 ng g⁻¹ were detected; total silicon was found in all tissue samples in the range of about 8,900–85,000 ng g⁻¹. Higher platinum levels ranging from 25–90 ng g⁻¹ were detected in fibrin layer and fat tissue of two patients with prostheses. No siloxanes were detected in control breast tissue samples.

This investigation of human tissues by a combination of element-specific and species-specific analytical techniques clearly demonstrates for the first time that platinum and siloxanes leak from prostheses and accumulate in their surrounding tissues.

Keywords Siloxane · Silicone · Silicon · Platinum · Silicone breast implants · Capsule tissue

Introduction

The gel of silicone gel-filled breast implants contains only 1–2% GC-detectable low molecular weight (LMW) silicones identified as cyclic siloxanes like hexamethylcyclotrisiloxane (D3), octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5), dodecamethylcyclohexasiloxane (D6), and tetradecamethylcycloheptasiloxane (D7); the other 98% of the silicone gel comprises mostly high molecular weight (HMW) silicones without further identification [1]. During the production of silicone materials, platinum catalysts are commonly used and trace levels of this metal might still be present in the finished product.

In the late 1970s it was noticed that, besides implant rupture as one complication of silicone prostheses [2], silicone can migrate through intact silicone elastomer shells, resulting in the clinically observable “gel bleed” on the implant surface [3]. At that time, the silicone “bleeding” from prostheses was not characterized further. Nowadays, however, fractions of LMW and HMW silicones can be separated by means of chromatographic techniques. In the 1970s, the focus was on identifying foreign material in droplet form found in fibrous capsules around silicone devices, which was analyzed as silicone by spectrometric infrared analysis [4]. Under laboratory conditions, in addition to the release of LMW silicones, platinum was found to diffuse at 24 µg day⁻¹ from intact silicone gel-filled implants into a lipid-rich medium [1]. The regional migration of silicone gel into the axilla and the medial upper arm of patients with ruptured mammoplasty was demon-

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strated by magnetic resonance imaging (MRI) [5]. Furthermore, the migration of silicone into the liver of women with silicone prostheses was confirmed by ^1H NMR spectroscopy [6].

Silicon seems to play an important role in soft tissue development such as bone and cartilage at least in chicken and rat [7, 8]. A recent Belgian study even reported that silicon levels were higher in babies and small children compared to adults, indicating that silicon is essential for human beings [9]. Variations in the silicon concentration of tissues and body fluids were explained by aging and dietary intake [10].

In the literature, various techniques are described for silicon and silicone detection in biological samples [11]. By using element-specific analytical techniques without further species separation (e.g., by gas chromatography) the total element content, including inorganic silicon compounds, siloxanes and silicone, is analyzed. However, this does not provide information on the chemical composition of these silicon species. Element-specific analyses have been applied to determine silicon concentrations in breast and prosthesis capsular tissues. For example, Evans et al. digested breast tissues from non-augmented persons as well as breast and capsule tissues from augmented women in concentrated nitric acid and examined these digestates by element-specific inductively coupled plasma atomic emission spectroscopy (ICP-AES) [12]. With concentrations in the range of $370\text{--}1,400\ \mu\text{g g}^{-1}$, the silicon content in the capsular tissues of patients with ruptured silicone implants was notably higher than the elevated silicon baseline levels. Schnurr et al. also observed higher silicon concentrations in periprosthetic capsular tissues ($410\text{--}45,532\ \mu\text{g g}^{-1}$) and breast tissues ($5\text{--}30,333\ \mu\text{g g}^{-1}$) around ruptured silicone gel-filled implants compared to control samples [13]. Their control tissue levels were in the range of $4\text{--}446\ \mu\text{g g}^{-1}$, which is higher than the data published by Evans et al. [12].

A new strategy for analyzing silicone levels in tissues was the extraction of organosilicon oxide polymers (silicones) in formalin-fixed tissues by *n*-heptane and subsequent detection by atomic absorption spectroscopy (AAS) [14]. It was assumed that silicon levels, as measured by element specific AAS, should reflect mainly silicone and should retrospectively enable organic silicon compounds (silicone) to be estimated in the organic extract. That explains why some scientists talk about silicone concentration when using extraction and AAS, even though silicone has not been determined directly. Thomsen et al. applied this method to tissues around silicone breast prostheses and breast tissues of controls [15]. They also found significant differences ($p < 0.05$, $f=2$) when comparing the median "silicone" concentrations in tissues around ruptured ($6.8\ \text{mg g}^{-1}$), possibly ruptured ($5.6\ \text{mg g}^{-1}$), and intact ($1.4\ \text{mg g}^{-1}$) implants. No silicone was detected in control samples [15]. Peters et al. also applied this method for investigating capsule tissues [16]. They found no significant differences in silicon levels associated with implant status, but the median silicon level in 58 capsules from augmented women was approximately 10,000 times higher than that of control breast tissue.

However, methods combining the extraction of silicon-containing compounds by organic solvents with subsequent element analysis for the total silicon content resulted in only incomplete information with regard to silicon specification. Organic solvents extract silicone, but also possibly some inorganic silicon species in colloidal form [11]. Consequently, separation techniques like gas chromatography (GC) have been applied after sample extraction. This separation technique was coupled with a molecular-specific detector like a mass spectrometer (MS) or an element-specific one like an atomic emission detector (AED) to qualify and quantify silicone species. Only now is the speciation of silicone contamination (differentiation between LMW and HMW silicones) and the identification of siloxanes possible.

Extractions of linear and cyclic poly(dimethylsiloxane) respectively from spiked mouse liver homogenates were analyzed with GC-MS and GC-AED [17]. We recently reported the development of a sensitive one-step sample preparation technique combined with species-specific GC-MS detection to analyze siloxanes in the blood of women exposed to silicone implants [18].

To the best of our knowledge, no silicone-specific investigation by silicone species separation prior to detection in capsular and breast tissue extracts has been performed so far. Here we report on the application of a combination of two powerful instrumental techniques, inductively coupled plasma high-resolution isotope dilution MS (ICP-HR-IDMS) and GC-MS, to the analysis of the amount of silicon, siloxanes, and platinum in tissue samples of women exposed to silicone implants.

Materials and methods

Tissue samples

Tissue samples were obtained from three women who had previously had their silicone gel-filled implants explanted. The implant of woman A was removed 16 years after implantation following histological diagnosis of silicone "bleeding". The implant of woman B was removed 8 years after implantation and was macroscopically intact. The investigated fat and muscle tissues were taken from areas in direct contact with the capsular tissue. These samples were preserved by storage in the dark in buffered formalin at $3\ ^\circ\text{C}$. The silicone breast prosthesis of woman C had been implanted for 7 years and was macroscopically intact. After explantation the capsule tissue was frozen at $-20\ ^\circ\text{C}$ and stored in the dark. After defrosting, capsule tissue and a fibrin layer from the inner part of the capsule were prepared for analysis.

To avoid possible sources for contamination of tissues under investigation during explantation of the silicone gel-filled implants and opening of the implant capsules, scalpels were not allowed to make direct contact with the implants during explantation. In addition, each tissue sample was collected with an unused scalpel. The opening of the tissue capsules was performed with great care to prevent shell destruction and contamination of the capsule tissue with gel of the implant. Also, the capsule tissue sample was selected opposite to the opening.

For control data, breast tissues of three women (D-F) with no prior history of silicone implants were frozen at $-20\ ^\circ\text{C}$. Breast tissue F was kept frozen until analysis.

To investigate the effect of the tissue conservation method applied, frozen capsule tissue from woman C and control breast tissues

(D and E) were fixed in buffered formalin and stored at 3 °C in the dark for 8 weeks. Before and after tissue fixation, formalin was analyzed by GC–MS.

Instrumentation

Analysis of siloxane extracts was performed using an HP 5890 Series II gas chromatograph equipped with an HP 7673 autosampler and coupled to an HP 5989A MS-Engine (Hewlett Packard). The GC–MS conditions were as follows: injector port temperature 200 °C, initial oven temperature 40 °C for 2 min, initial ramping rate of 10 °C min⁻¹ to 160 °C, followed by a second ramping rate of 30 °C min⁻¹ to 320 °C which was subsequently held for 5 min. Siloxanes were separated on a HP 5 MS column (Hewlett Packard, column dimensions of 0.25 mm×30 m and 0.25- μ m film thickness). Data analysis was subsequently performed using HP-UX MS Chem Station software. Standards and sample extracts were run in the SIM mode (using quantifying fragments for D3, D4, D5, D6 and internal standard *m/z* 207, 281, 267, 355, 341, 429, and 281) using EI (electron impact) for ionization. The measured concentrations were calculated by the HP-UX Chem Station software with external standard calibration. For the identification of the unknown peaks the MS was run in the SCAN mode. The temperature program was the same as in the SIM mode. The registered mass range was *m/z* 70–650.

All ICP–IDMS determinations of silicon and platinum were carried out with a high-resolution inductively coupled plasma mass spectrometer, ICP–HR–MS (Element2, ThermoFinnigan, Bremen, Germany) using a ³⁰Si- and a ¹⁹⁴Pt-enriched spike solution respectively for the isotope dilution step. For further details about ICP–MS measurements of silicon and platinum see articles by Klemens and Heumann [19] and Müller and Heumann [20].

Reagents

Volatile cyclic siloxanes (D3–D6) with purities ranging of 95–97% were obtained from Gelest Inc. (Karlsruhe, Germany), whilst hexane SupraSolv was obtained from Merck KGaA (Darmstadt, Germany).

HNO₃ p.a. (Merck, Darmstadt, Germany) and HF (Fluka, Buchs, Switzerland) were further purified by distillation under sub-boiling conditions in a special PFA apparatus (SAP-100 IR, AHF-Analyse-technik, Tübingen, Germany). Purified water was supplied by an 18 M Ω Milli-Q system (Millipore). Silicon dioxide enriched in ³⁰Si was purchased from Campro Scientific (Berlin, Germany). Platinum powder enriched in ¹⁹⁴Pt was purchased from Chemotrade (Düsseldorf, Germany). The preparation and the characterization of these two spike solutions are described elsewhere [19, 20]. A 1,000 μ g g⁻¹ platinum standard solution (Merck, Darmstadt, Germany) was used for external platinum calibration (method b).

Sample preparation for the determination of siloxanes

The tissue sample (0.3–0.4 g) was homogenized with an IKA dispersing tool S8N-5G (Staufen, Germany) and extracted with 1 mL *n*-hexane in a 10-mL vial by vortex-mixing using a Vortex Genius II (Scientific Industries) at a high speed setting for 5 min. Extracts were subsequently centrifuged at 10,000 rpm for 20 min to remove particulate matter (Sigma 302 centrifuge; Laboratory Centrifuges GmbH, Osterode, Germany). Each sample extract was analyzed three times.

Sample preparation for the determination of total silicon and platinum

A 0.2–0.5 g portion of the sample was weighed exactly into a Teflon PTFE microwave vessel together with 0.1–1 g of the two spike solutions, ³⁰Si and ¹⁹⁴Pt. Concentrated HNO₃ (2.5 mL) and, for

dissolving silicate compounds, 0.1 mL of concentrated HF were added. After microwave digestion and dilution with 10 mL water, the solution was used for the ²⁸Si/³⁰Si and ¹⁹⁴Pt/¹⁹⁵Pt isotope ratio measurement by ICP–HR–MS. Each sample extract was analyzed three times. Under these conditions silicon contamination by the introduction system of the ICP–MS has no significant effect for silicon determinations in the tissue samples as demonstrated recently in a more detailed study [19].

The spike addition was varied with respect to an optimized analyte ratio sample/spike in the range of 0.2–5 for the isotope diluted sample. This is an important precondition for precise IDMS analyses. More detailed information on the principles of IDMS are given elsewhere [21]. For accurate determinations of silicon, a mass resolution of 4,500 was adequate to avoid all possible interferences (e.g., ¹²C¹⁶O⁺ and ¹⁴N²⁺ on ²⁸Si⁺, and ¹⁴N¹⁶O⁺ on ³⁰Si⁺). This mass resolution was also used for the platinum (method a) to measure all its isotopes in one run. The limit of detection is calculated as three times the standard deviation of the blank for both elements and is in the range of 0.15–0.5 μ g g⁻¹ for silicon and 2–6 ng g⁻¹ for platinum using sample weights of 0.2–0.5 g.

An external calibration in combination with a low mass resolution mode of 300 was used to analyze platinum at concentration levels below 2 ng g⁻¹ (method b). In this case, five standard solutions were prepared (0.1–1 ng g⁻¹) by diluting a 1,000 μ g g⁻¹ platinum standard solution with 5% nitric acid and 0.1% hydrofluoric acid, respectively. The use of a lower mass resolution in connection with a more efficient quartz glass spray chamber and a concentric nebulizer resulted in better sensitivity. Under these conditions, the detection limit was found to be 50 pg g⁻¹.

Results and discussion

Siloxanes

Most microscopic studies of silicone deposits were based on formalin-fixed alcohol-xylene processed, paraffin-embedded tissue sections, a technique commonly used in diagnostic pathology. Dissolution in a xylene bath or displacement of large deposits during the actual sectioning can occur [22, 23]. To the best of our knowledge, however, there are no reports in the literature of sample loss due to the fixation of tissue in buffered formalin.

This was also supported by our experiments. Buffered formalin was investigated with the same analytical method (GC–MS) used for the tissue samples of augmented and control women. The solution used for tissue fixing was not contaminated by siloxanes, because no signals were detected in the selected ion-monitoring (SIM) mode. In addition, frozen capsule tissue from woman C was stored for 8 weeks in the buffered formalin at 3 °C in the dark and the formalin was then analyzed again. No siloxanes were found, indicating that siloxanes are not soluble in formalin under the usual storage conditions (Fig. 1). Four of the six breast tissue samples were stored in buffered formalin. Contamination due to formalin fixation can therefore be virtually ruled out; no siloxanes were extracted into formalin during storage either. Furthermore, the negative siloxane results in the control breast samples of non-augmented women (samples D and E listed in Table 1) confirm that no siloxane contamination took place during formalin fixation. Siloxanes are commonly used in cosmetic products like deodorants and shower gels, and it was assumed that this might lead to accumulations in tis-

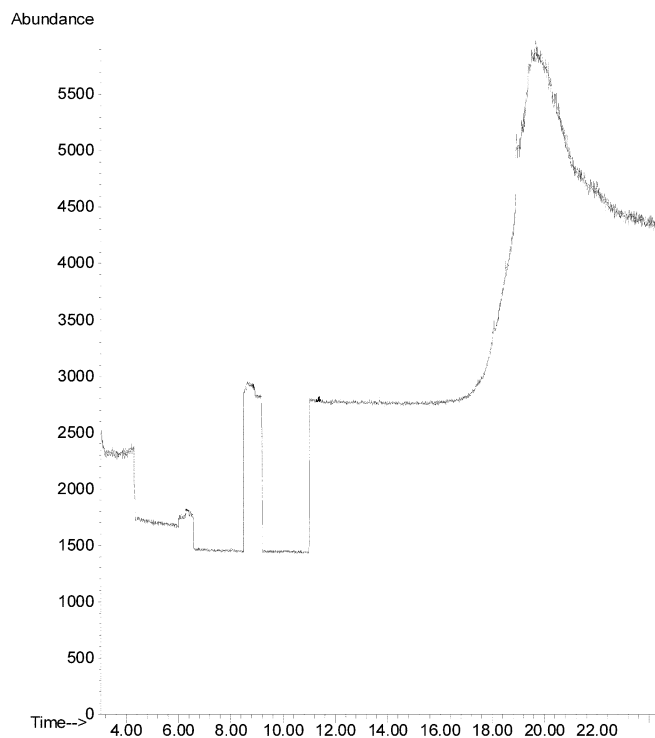


Fig. 1 Gas chromatogram (x min, y abundance) of formalin in which frozen capsule tissue from woman C was stored for 8 weeks. No cyclic siloxanes were detected. Only the background noise of the evaluated ions (in the SIM mode) differed in the field of the siloxanes retention time of the D3–D6 (<12 min) called “operating stages” and some humps were perhaps observable. At higher retention times only a big “peak” caused by silicone bleeding of the stationary phase of the column was registered

sues. However, our findings revealed that there was no contamination by investigated siloxanes in breast tissues from these sources.

The MS was run in the SIM mode for quantitative analysis of the siloxanes. Therefore, the typical mass fragments of each siloxane were registered in a time window at the same time as the compound was eluted. As a result of this mode the background of the selected ion differed as reflected in a different baseline at retention times up to 12 min (Fig. 1). This instability of the baseline is called “operating stages”. At higher retention times the baseline started to increase due to silicone bleeding of the station-

ary phase of the column. But no real edged peaks were registered.

Some study groups prefer a drying step of frozen or formalin-fixed tissues prior to extraction of silicone [14, 15, 16]. However, when analyzing volatile compounds like siloxanes, our decision was not to dry the samples because of the risk of possible analyte losses or siloxane decompositions.

In the six investigated tissues of the augmented women, cyclic siloxanes D4–D6 were determined in a broad concentration range (Table 1). These siloxanes were detected in the fat tissue from woman A with a “bleeding” implant, as well as in the tissue from woman B with a histologically intact prosthesis. The fat tissue data of both women presented distinct differences in the siloxane concentration, with much higher siloxane values for the fat tissue of woman A with a “bleeding” silicone gel-filled breast implant.

Even though there was no indication of an implant defect, siloxanes were found in all analyzed tissues from woman B. The implant capsule surrounding the prosthesis, which is always formed by the body in response to the implantation of foreign material, revealed slightly higher total siloxane concentrations than those detected in fatty tissue. It is very likely that the mobile siloxane species were first absorbed in the capsule and subsequently migrated from there to the fat and muscle tissue. Lower levels of siloxanes were also noted in muscle tissue from woman B (Table 1), indicating siloxane accumulation. The reduced siloxane levels in muscle tissue compared to fat tissue may be due to the lipophilic nature of siloxanes, which are more likely to accumulate in a lipid-rich medium [1].

Siloxanes were also detected in a fibrin layer on the inner part of the capsule tissue and in capsular tissues from woman C, who had an intact prosthesis. This layer localized in the inner part of the capsule and close to the implant shell presented the highest siloxane content compared to the adjacent capsule tissue, indicating that siloxanes had migrated and accumulated there at first.

The siloxane concentrations in capsular tissues from women B and C were comparable. The breast prostheses of both women were intact but the tissue sample from woman B was formalin-fixed and that from woman C was frozen at -20°C ; this is another indication that the fixation of tissues in formalin has no direct influence on the siloxane content.

Table 1 Determination of siloxanes in human tissues of women with silicone gel-filled implants (A–C) and controls (D–F) and their corresponding calculated silicon levels based on the determined siloxane concentrations. The given standard deviations were obtained by three independent parallel analyses of tissue samples from the same origin

n.d. not detectable (below detection limit)

Woman	Sample	D4 (ng g ⁻¹)	D5 (ng g ⁻¹)	D6 (ng g ⁻¹)	Silicon calculated (ng g ⁻¹)
A	Fat tissue	1,333.8±0.6	637±100	780±37	1,048
B	Fat tissue	83.5±0.5	31±25	146±4	60
B	Capsule tissue	28.6±4.1	132.8±0.2	101.6±0.5	100
B	Muscle tissue	18.4±1.6	8.57±0.03	25.08±0.03	20
C	Capsule tissue	11.9±1.9	140.8±0.6	251.1±8.1	153
C	Fibrin layer	36.3±4.3	204±18	385±21	236
D (control)	Breast tissue	n.d.	n.d.	n.d.	
E (control)	Breast tissue	n.d.	n.d.	n.d.	
F (control)	Breast tissue	n.d.	n.d.	n.d.	

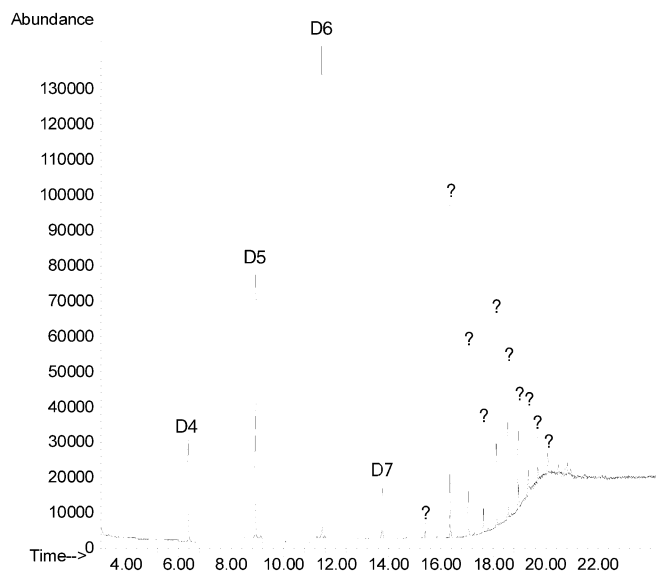


Fig. 2 Chromatogram (x min, y abundance) of fibrous tissue extract from woman C as measured by GC–MS in SIM mode. Unidentified species (?), most likely due to higher molecular weight polysiloxanes found in silicone breast implant gels

It was possible to detect both known siloxanes (D4–D6) and unidentified siloxane species with a higher molecular weight in the investigated tissues. The peaks at retention times higher than 12 min (Fig. 2) were detected by registering the n -hexane extracts of the fatty tissue sample from woman A and the fibrin layer from woman C in the SIM mode with the mass spectrometer. For this purpose, the m/z values of 341 and 429, previously used for the detection of D6, were registered till the temperature program of the GC run had ended. The peak assignments are based on these m/z ratios. However, it was possible to identify only the peak at a retention time of 13.7 min as D7 by its mass spectrum (Fig. 3). In the SCAN mode m/z 70–650 was registered. The peak at m/z 503 belonging to the typical mass fragment of D7 generated by methyl group elimination of the molecule (M–15) was also recorded. The other unknown peaks were not identified for various reasons: first, no standards of siloxane species with higher molecular weights than D6 are commercially available; second, analyzing a poly(dimethylsiloxane) standard with GC–MS in the SCAN mode revealed that compounds also eluted at higher retention times (>12 min), comparable with the retention time of the unidentified peaks in the fatty tissue extract. The mass fragmentogram of one of these compounds consisting of mass fragments at m/z 221, 281, 355, 429, and 503 is shown in Fig. 4. The typical M–15 mass fragment of siloxanes generated by methyl group elimination could not be registered, because the applied mass spectrometer could not operate so well at m/z values higher than 650. In contrast to the gas chromatogram of formalin (Fig. 1), real, edged peaks were registered at retention times greater than 12 min while the baseline recovered. Even when comparing both chromatograms (Fig. 1 and Fig. 2) it can be clearly seen that these unknown peaks

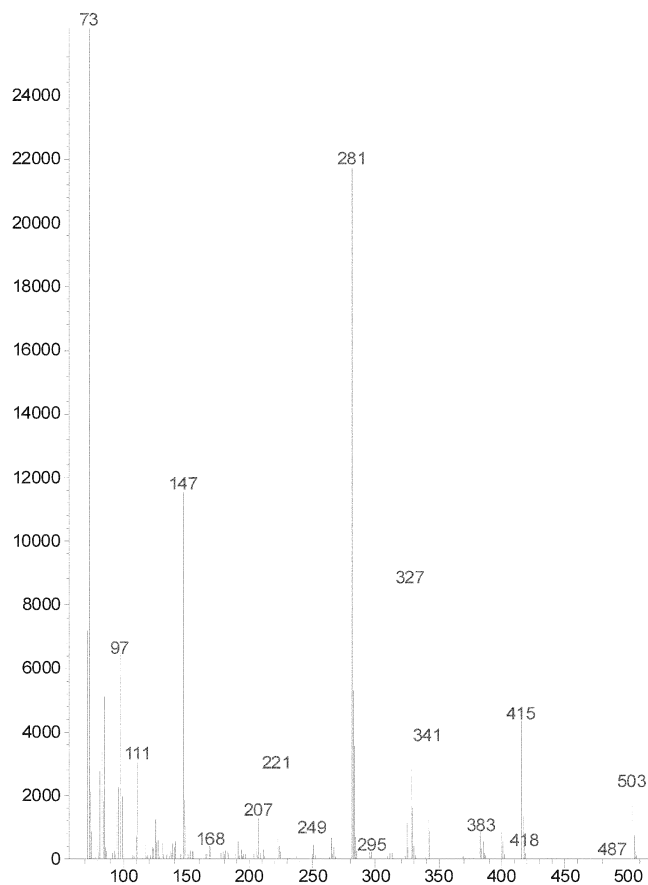


Fig. 3 Mass spectrum (x m/z , y abundance) of the unknown peak at 13.7 min. The fragmentation pattern is most likely due to the siloxane D7

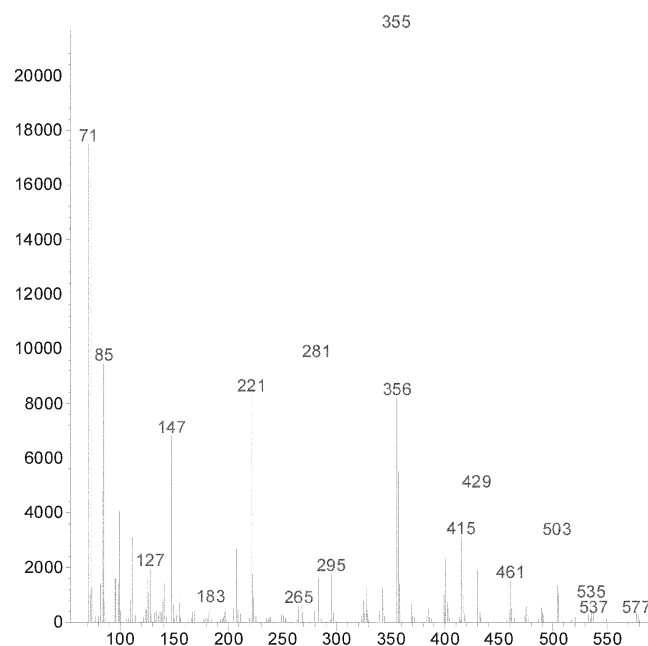


Fig. 4 Mass spectrum (x m/z , y abundance) of an unidentified siloxane species registered at higher retention times (19.5 min) by GC–MS in the SCAN mode. The values of m/z 207, 281, 355, 429, and 503 are typical mass fragments of these higher molecular siloxanes

were not caused by silicone bleeding out of the column but in fact were siloxane species of the extract of both tissues. In summary, it can be concluded that the peaks in the chromatogram of fatty tissue from woman A and of the fibrin layer from woman C at higher retention times most likely reflect siloxane species with a higher molecular weight than D6.

Silicon and platinum

Silicon levels of 8909–72788 ng g⁻¹ were determined by ICP–HR–IDMS in tissues of the three women (A–C) with silicone breast implants (Table 2): The high standard deviation of the tissues samples analyzed in parallel may be due to inhomogeneities in the sample. The highest measured silicon concentration was found in the capsule tissues from women B and C. There was no apparent correlation between the implant status “bleeding” and “intact” and the measured silicon content, because the fat tissue values of women A and B were at the same level. The lowest silicon concentration was found in the muscle tissue samples. Comparison of silicon levels in both tissues from woman C revealed that the silicon content was higher in the capsular tissue than in the fibrin layer located on the inner side of the capsule.

In all breast tissue samples of controls as well as from patient C, platinum was registered using method b, whereas the samples from patients A and B were measured by method a. The lower detection limit of method b allowed platinum traces to be determined in the controls, because analyte losses during sample preparation and interferences in the ICP–MS analysis were negligible here.

Platinum was also determined in the tissue samples of women A and C. The highest concentration was found in the fat tissue from woman A who had a “bleeding” implant. In the fibrin layer of woman C, a higher platinum

concentration was registered than in her capsule tissue. The tenfold higher platinum concentration in the fibrin layer may also indicate the migration of this element through an intact implant envelope.

The high platinum level recorded in the tissue of woman A suggests that a correlation may also exist between the detection of platinum and the “bleeding” of the silicone gel-filled implants. Obviously, siloxanes and platinum migrate through an intact implant envelope and accumulate in the fat tissue. In a simulated laboratory study, Lykissa et al. reported the detection of approximately 20–25 µg platinum per day leaking from an intact 250-g silicone gel-filled implant into a lipid-rich medium [1]. Our data demonstrate, for the first time in humans, that platinum leaks from intact prostheses and accumulates in a lipid-rich medium analogous to fat tissue or fibrous tissue. Although the chemical form of platinum in the tissues could not be characterized, these results indicated that a fraction of platinum may exist as organoplatinum or silicone–platinum complex as postulated by Lykissa et al. [1]. The *in vivo* and *in vitro* toxicity of silicone–platinum complexes has not yet been described in the literature.

Siloxane and silicon

Our results from the control group clearly revealed that the detection of silicon is not directly linked to siloxane or silicone contamination in tissues or even in other human material. Nor did Thomsen et al. find silicone in their controls by means of heptane extraction and AAS determination [15]. In contrast, extractable silicon was analyzed by others in control tissues using element-specific detection [16, 24]. These contradictory results on control tissues with comparable sample treatment steps may be due to extraction of some inorganic silicon species in colloidal form as postulated by Vavic–Vlasak et al. [11]. The use of chromatographic methods prior to silicon or siloxane determination is indispensable if conclusions are to be drawn about silicone contamination in tissues through silicone breast implants.

Table 2 Determination of silicon and platinum by ICP–HR–IDMS in human tissue of women with silicone gel-filled implants (A–C) and in controls (D–F). The given standard deviations were obtained by three independent parallel analyses of tissue samples from the same origin. They therefore represent mainly the inhomogeneity of silicon in the different types of tissues rather than the precision of the analytical method

Woman	Sample	Silicon (ng g ⁻¹)	Platinum (ng g ⁻¹)
A	Fat tissue	28,612±1,019	90±16 ^a
B	Capsule tissue	72,788±1,748	n.d. ^a
B	Fat tissue	23,856±5,289	n.d. ^a
B	Muscle tissue	8,909±745	n.d. ^a
C	Capsule tissue	84,998±28,977	2.1±0.7 ^b
C	Fibrin layer	46,486±6,963	25±9 ^b
D (control)	Breast tissue	33,412±7,629	0.3±0.2 ^b
E (control)	Breast tissue	11,800±1,966	1±0.6 ^b
F (control)	Breast tissue	23,777±6,896	n.d. ^b

n.d. not detectable

^aMethod a (detection limit=2–6 ng g⁻¹)

^bMethod b (detection limit=50 pg g⁻¹)

Conclusions

These investigations clearly demonstrated elevated levels of the siloxanes D4–D6 in fatty tissue of a woman with a “bleeding” implant. Siloxane D4 was the most abundant species, being present at levels of 1,300 ng g⁻¹ (Table 1). Calculation of elemental silicon in fatty tissue of woman A, based on the detected amounts of siloxanes D4–D6, revealed up to 1,048 ng g⁻¹ of the element. Comparison of these data with the total element content demonstrates that siloxanes D4–D6 comprise only a small portion of the total amount of silicon present in fat tissue of woman A, where a total concentration of 29,000 ng g⁻¹ silicon was found (Table 2). This means that less than 4% of the total elemental silicon present in the fatty tissue comprises low molecular weight cyclic siloxanes. It was also found that

the concentration of siloxanes was approximately twofold higher in capsular tissue compared to fat or muscle tissues. This suggests that siloxane species first migrate from the breast implant into the capsular tissue, and subsequently from there to fatty and muscle tissues.

The determination of elemental silicon is commonly used today as a marker of siloxane contamination of blood and tissues. This work has demonstrated that variations in the total silicon concentration is at least at a similar level to or significantly higher than the calculated silicon present as cyclic siloxanes D4–D6. It has recently been suggested that only cyclic siloxanes and not the elemental silicon content are reliable indicators of implant bleeding [1, 18]. Thus, the data of this work clearly show that the use of elemental silicon as an indicator of migration of siloxane species from breast implants to the surrounding tissue is not appropriate. The combination of an element-specific and a species-specific analytical technique is the method of choice to determine siloxanes and silicon in tissues of women with silicone mammary prostheses.

Today, health effects and risks are still discussed in connection with silicone breast implants. But this is a controversial issue and the issue of health problems in women with silicone breast implants is still not resolved as yet. In addition, little is known about the toxicological effects of siloxanes. Also, even though siloxanes and platinum are good indicators for defect implants, this work does not prove that they are the cause of health problems in women with implants.

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