Content

Sample Storage Tubes as Critical Quality Components in Biobanking

1. Introduction

Biobanks store biological samples and associated data to make them available for clinical studies as well as research on biomarkers, personalized medicine and public health. The paramount goal of biobanking is the preservation of sample integrity during all steps of sample collection, processing, storage and delivery; hence, factors influencing the sample quality during these steps need to be understood and controlled.

Whereas storage temperatures and environments as well as methods for secure sample tracking were always considered important factors in biobanking, the actual sample containing tubes have long been disregarded. Here we emphasize the importance of sample tubes as critical components of biobanking. In particular, Cryo.s™ Biobanking tubes are analyzed with regards to cleanliness of tube raw material, tube closure, biomolecule adsorption onto the tube surface and quality of the datamatrix barcodes used for tube identification and tracking.

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2. Polymer Quality and Leachables

2.1. Background

Multiple additives and agents can be utilized to alter the physical properties and processability of polymers used for labware production.

Such chemicals are:

- UV stabilizers (e.g. benzophenone, benzotriazole, oxalanilide),
- antioxidants (e.g. organo phosphites),
- thermo stabilizers,
- nucleation starters,
- plasticizers (e.g. phthalate esters),
- mold release agents,
- antistatic agents,
- irradiation protectors,
- clarifiers

Several studies have shown that polymer additives or their degradation products can migrate out of polymer-based microtiter plates or tubes and affect the outcome of biochemical assays performed with these products[i] [ii] [iii]. There is the potential risk of similar phenomena occurring with biological samples stored in polymer tubes over long periods of time. Thus, storage tubes used in biobanking should be made of high-quality, virgin polymers with the least possible contents of additives and leachable substances. Virtually all polymer-based cryogenic storage tubes are made of polypropylene – a polymer proven to be excellently suited for the application at ultra-low temperatures. Today, an immense variety of different polypropylene qualities are available, although these raw materials widely differ in chemical composition and physical properties, as well as purity and certification. Greiner Bio-One uses a medical-grade, USP class VI certified polypropylene type for the production of all Cryo.s™ Biobanking tubes. In this context, the attribute 'medical grade' refers to the comprehensive certification of the material (e.g. European Pharmacopeia 3.1.3, 3.1.6 and 3.2.2), special cleaning processes before production start and more than 15 years of history of the raw material with unchanged polymer composition. The USP class VI certification refers to a biocompatibility testing in accordance with the United States Pharmacopeia (USP). Primarily, passing this test is indicative of a high biocompatibility of the tested raw material; secondarily, it suggests a low content of leachables in the material. In addition, the raw material of Cryo.s™ Biobanking Tubes is certified free of the following chemical elements and agents[1]:

- heavy metals,
- phthalate esters,
- mold release agents,
- antistatic agents,
- TSE and BSE.

Table 1: 96 way cryogenic storage tubes from different suppliers were tested for leachables. This table provides an overview on leachable tests performed with selected tubes from Greiner Bio-One and other suppliers. Besides Greiner Bio-One all other tube manufacturers are anonymised and tube codes are utilized to differentiate between different tube types offered by individual manufacturers (e.g. manufacturer 'D' offers the two different tube types 'D1' and 'D2').

Manufacturer Code	Tube Code	Extraction and IR spectrum to check for amide	Extraction and complete GC/MS scan
Greiner Bio-One	G1 (300 µl Cryo.s™ biobanking tubes, non-sterile)	•	•
A	A1	•	-
B	B1	•	-
C	C1	•	-
D	D1	•	-
	D2	•	-

[1]All 'free of' statements are based on supplier information and formulated to the best of Greiner Bio-One's knowledge and understanding. Some statements depend on detection methods with individual detection limits. For further details and actual certificates please contact your Greiner Bio-One representative.

2.2. Method

In order to assess the potential contaminations of storage tubes with amides (often used as mold release agents in injection molding), six different cryogenic storage tubes (see table 1) were extracted with 50 % ethanol in water for nine days at room temperature. Subsequently, the extractable material was characterized by IR spectroscopy after complete evaporation of the solvent. Typically amides yield signals in the infrared wavenumber bands between 1630 and 1690 cm^{-1} (C=O stretch) and between 3300 and 3700 cm^{-1} (N-H stretch).

In a second leachable test, Greiner Bio-One's Cryo.s™ Biobanking tubes (300 µl version, non-sterile version) were extracted with four different solvents: 10 % ethanol/water, acetic acid-acetate-buffer (pH 4.6), Tris-EDTA-buffer (pH 8.0) and 100 % DMSO. This extraction was carried out over 72 h at 37 °C. Subsequently complete GC/MS fingerprints were recorded. This analysis was performed by UL International GmbH (Ochsenhausen, Germany).

2.3. Results

The IR spectra of ethanol extracts indicated the potential contamination of tube type 'B1' from manufacturer 'B' with amides. A mild contamination with amides was also detectable for the tubes 'D1' and 'D2' from manufacturer 'D'. All other tube extracts did not reveal amide-specific peaks in their IR spectra (figure 1).

The full GC/MS footprint of four different extracts (1. ethanol/water, 2. Acetic acid-acetate-buffer pH 4.6, 3. Tris-EDTA-buffer pH 8.0, 4. 100 % DMSO) of Greiner Bio-One's Cryo.s™ Biobanking Tubes revealed no extracted substances in any of the four extracts (figure 2) to undermine the high purity of the raw materials used for producing these tubes.

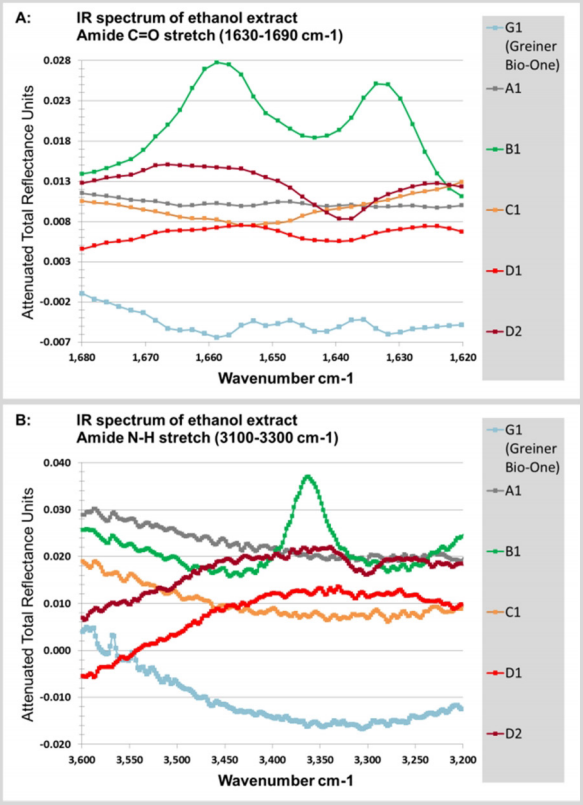

Figure 1: Extraction of cryogenic tubes with 50 % ethanol in water with subsequent IR-spectroscopical analysis revealed amide-specific signals in the extract from tube 'B1' and mild signals in the extracts from tubes 'D1' and 'D2'. **A:** IR spectrum from 1620-1690 cm^{-1}. **B:** IR spectrum from 3220-3600 cm^{-1}.

2.4. Conclusion

Greiner Bio-One utilizes a high-quality, virgin and pure polypropylene type for the production of Cryo.s™ biobanking tubes. Extraction of these tubes with four different solvents revealed no detectable substances in the corresponding GC/MS fingerprints. Exemplified based on the presence of amide-specific IR signals in ethanolic extracts from some tube types, it becomes evident that the absence of leachable additives is not a guaranteed feature of tubes intended for sample storage in biobanking. Rather, raw material types vary between individual tube manufacturers and commonly accepted standards, such as the use of materials with low additive content, are still missing.

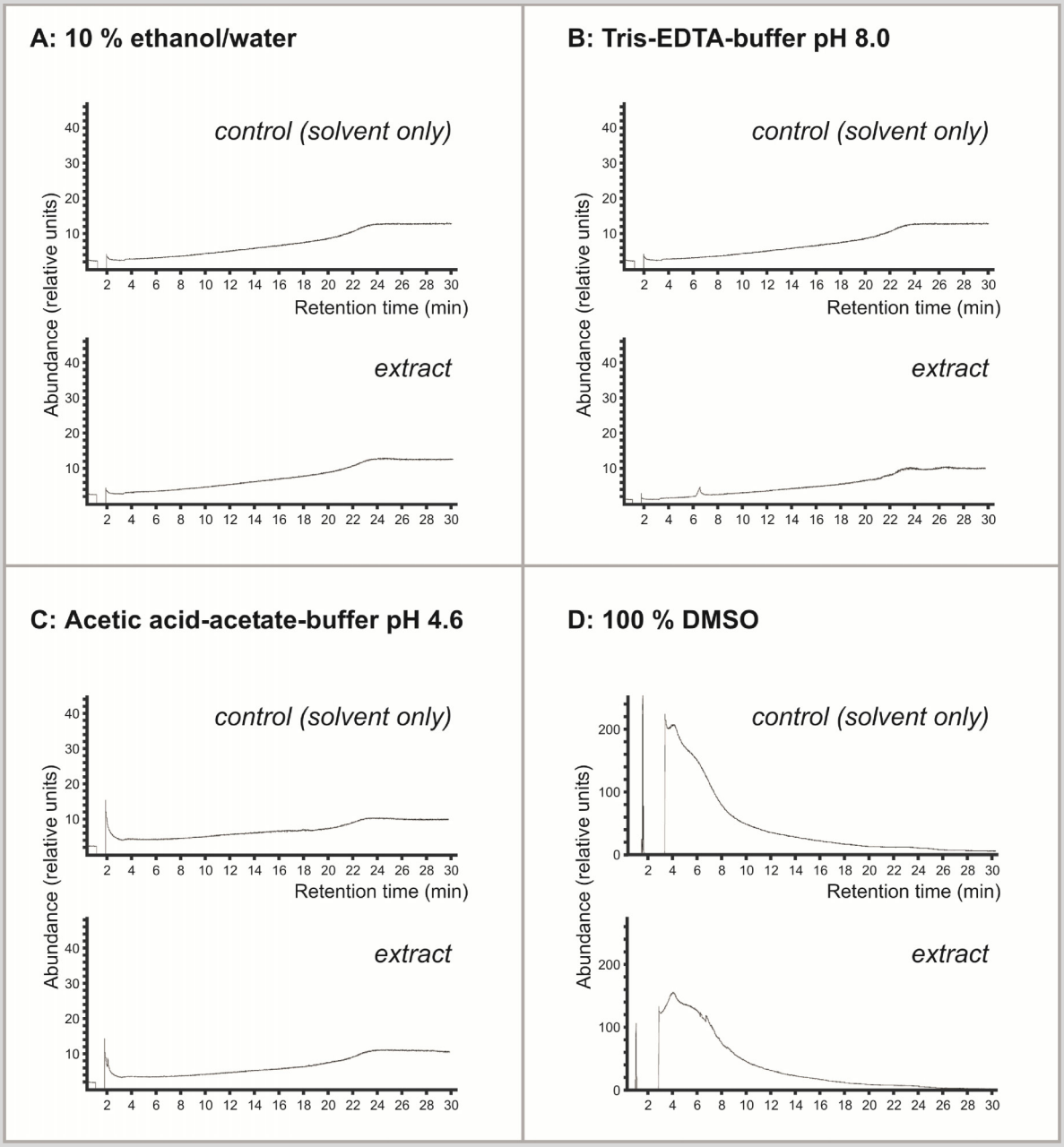

Figure 2: Extraction of Cryo.s^{TM} Biobanking Tubes with four different solvents and subsequent GC/MS footprint analysis of the extracts. Extraction with 10 % ethanol/water (**A**), basic buffer solution (Tris-EDTA-buffer pH 8.0, **B**), acidic buffer solution (Acetic-acid-acetate-buffer pH 4.6, **C**) and 100 % DMSO (**D**) revealed no significant extractable substances.

3. Biomolecule Adsorption onto Storage Tube Surfaces

3.1. Background

In biobanking, the concentration of biomarkers in liquid samples (e.g. blood serum) should remain unchanged over the entire period of sample processing and storage. However, there is a general risk of certain biomarkers binding onto the surfaces of tubes used for sample aliquotation and storage. Such unintended sample adsorption onto tube surfaces depends on the actual type of biomolecule (e.g. nucleic acid, polysaccharide, lipid, peptide, protein etc.), as well as the type of tube raw material[iv] and details of the tube manufacturing process. In order to assess the adsorption of biomolecules onto storage tube surfaces, we have chosen an Iodine^{125}-labelled derivative of the peptide Insulin-like growth factor 1 (IGF 1^{I125}) as the test substance and developed a radioactivity-based adsorption assay (figure 3).

3.2. Method

Humane IGF 1 was labelled with I^{125} on tyrosine residues applying the lactoperoxidase method, purified by HPLC (Dr. Carsten Tober, rent-a-lab, Reutlingen/Germany) and dissolved in fetal calf serum (FCS) to yield an IGF 1^{I125} concentration of 33.3 ng/ml. Disc-shaped material samples (Ø = 5.2 mm) were punched out of the side walls, (figure 3, A) of cryogenic storage tubes from different suppliers (table 2). Per supplier three tubes were analysed.

The discs were placed into the wells of 6-well plates. The internal side of each material sample (originally facing towards the tube's interior) was incubated with 30 µl test solution overnight in at -80 °C (figure 3, B). After incubation, the test solution was completely removed and the material samples were put into the wells of a 96-well plate with scintillation fluid. Emitted gamma-radiation was quantified and adsorbed IGF 1^{I125} determined based on standard curves derived from known amounts of IGF 1^{I125} (figure 3, C).

3.3. Results

The two tested sterile tube versions 'G2' and 'D1' revealed higher IGF 1^{I125} adsorption than the tested non-sterile tube types 'A1', 'G1', 'B1' and 'C1' (figure 4). Whereas 'G2' and 'D1' adsorbed about 12 % of the IGF 1^{I125} present in the serum sample used for incubation, the non-sterile tube types 'A1', 'G1', 'B1' and 'C1' adsorbed only 3.5 – 5 % of the contained IGF 1^{I125}. One non-sterile tube type, namely tube 'D2', revealed a >4 times higher adsorption than the average of all other tested non-sterile tubes. With this tube an absorption rate of 17.5 % of the present IGF 1^{I125} was observed.

Table 2: 96 way cryogenic storage tubes from different suppliers were tested in the IGF 1^{I125} adsorption test. Besides Greiner Bio-One all other tube manufacturers are anonymised and tube codes are utilized to differentiate between different tube types offered by individual manufacturers (e.g. manufacturer 'D' offers the two different tube types 'D1' and 'D2').

Manufacturer Code	Tube Code	Sterile
Greiner Bio-One	G1 (300 µl Cryo.s^{TM} biobanking tubes, non-sterile)	-
	G2 (300 µl Cryo.s^{TM} biobanking tubes, sterile)	•
A	A1	-
B	B1	-
C	C1	-
D	D1	•
	D2	-

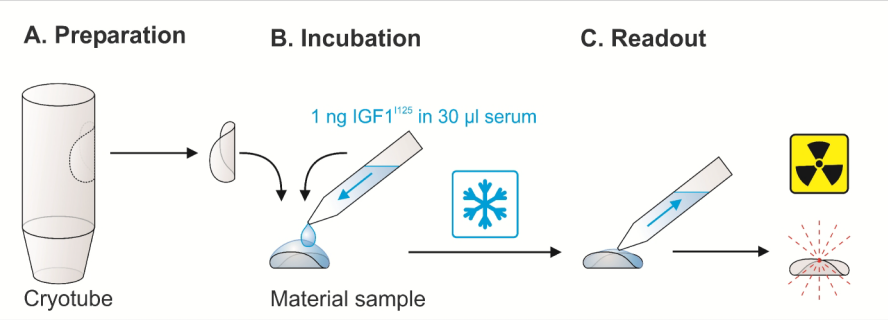

Figure 3: Experimental procedure of the adsorption assays with material sample preparation (**A**) material sample incubation with radioactively labelled test substance (IGF 1^{I125} in serum, -80 °C, **B**) and quantification of emitted radiation from adsorbed IGF 1^{I125} (**C**).

3.4. Conclusion

Irradiation-based procedures regularly used for the sterilisation of cryogenic storage tubes bear the potential risk of introducing unwanted binding sites for biomolecules which then may be adsorbed onto the product surface. The IGF 1^{I125} adsorption assay presented here indeed indicates higher IGF 1^{I125} binding onto sterile tube versions (Greiner Bio-One and manufacturer 'D') as compared to the average non-sterile tube. Although non-sterile tubes may be regarded as a gold standard for liquid sample storage, one non-sterile tube (tube 'D2') from manufacturer 'D' yielded above-average IGF 1^{I125} adsorption at -80 °C.

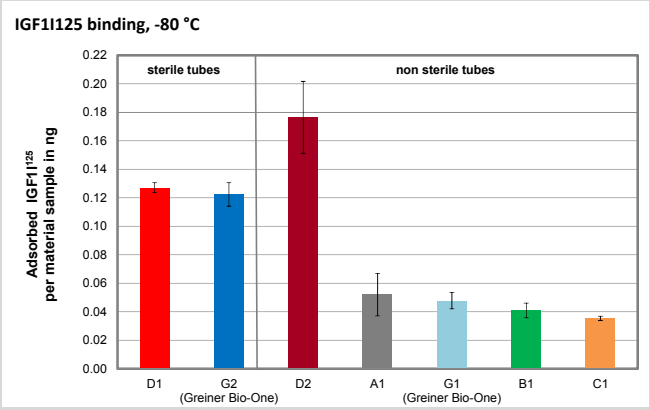

Figure 4: Amount of IGF 1^{I125} adsorbed onto material samples (5.2 mm-discs) after incubation at -80 °C with 30 µl FCS containing a total of 1 ng IGF 1^{I125}. Error bars indicate standard errors of the mean (n=3).

The data shown here indicate differences in IGF 1^{I125} adsorption onto tube surfaces depending on the tube type and sterilization. It is likely that other classes of biomolecules reveal adsorption characteristics other than those of IGF 1^{I125} – a subject remaining open for future analyses.

BOX 1

Greiner Bio-One manufactures non-sterile 96 way Cryo.s^{TM} biobanking tubes which are produced under highest hygienic standards and which (although being referred to as 'non-sterile') are guaranteed free of detectable contaminants such as DNA, DNase, RNase, endotoxins and others. These tubes are recommended for the cryogenic storage of liquid samples. Sterile Cryo.s^{TM} biobanking tubes, also part of Greiner Bio-One's product portfolio, are the first choice for the storage of viable cells for future cell culture or cell lysis with subsequent biomarker analysis.

4. Long-term Storage in Vapor Phase above Liquid Nitrogen

4.1. Background

More and more biobanks store their samples in screw top tubes below -130 °C in the vapor phase of liquid nitrogen. Such ultra-low temperature storage is regarded as an optimum for best sample conservation[v] [vi] [vii], but also a technical challenge for the actual sample tube and its screw cap. Today, several tube types with different types of screw caps are offered (figure 5), each promising a tight tube closure at ultra-low temperatures with only minimum amounts of water evaporating over time. However, water loss is a phenomenon observed at ultra-low temperatures and as such may cause

changes in sample volume and biomarker concentration over time.

Here 96 way tubes from different suppliers with different screw cap types were stored in the vapor phase above liquid nitrogen and tested for their ability to retain the original sample volume over time.

4.2. Method

96 way cryogenic tubes from different suppliers (see table 3) were filled with water or serum (~80 % of working volume suggested by supplier) and closed with a Hamilton LabElite Decapper at 6-7 Ncm (n=59) or manually at ~5-6 Ncm (n=8). The tubes were subsequently weighed with a precision scale and stored in 96 way racks in the vapor phase of liquid nitrogen. Tubes were thawed overnight, thus avoiding any condensation of air moisture onto the tube's exterior, and subsequently weighed with a precision scale. Weighing was carried out at several time points.

4.3. Results and Conclusion

Cryo.s™ Biobanking Tubes (300 µl and 1000 µl, abbreviated as 'G1' and 'G3') closed with a Hamilton LabElite Decapper at 6-7 Ncm revealed excellent tightness with less than 0.2 % loss of water after 550 days of storage in the vapor phase above liquid nitrogen (figure 6A). In a second set of long-term storage tests, tubes from several tube suppliers were compared: The sample retention observed in this test after 152 days of storage ranged from 90.44 % to 99.94 % (figure 6B). Whereas well sealing tubes were found within each category of tube closing systems (internal, silicone; internal, TPE and external, sealing lip), the gap between worst and best performers of each group was most narrow for silicone sealed tubes, followed by TPE sealed tubes, followed by external thread tubes with sealing lip and no additional flexible sealing material[2] (figure 7).

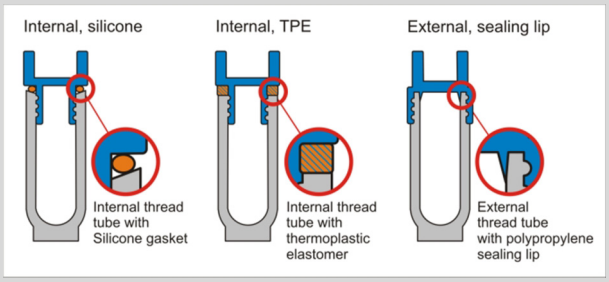

Figure 5: Types of cryogenic tubes classified based on their type of screw cap and sealing material. Shown are cross sections through tubes (grey) with their screw cap on (blue) and the flexible sealing material, if present (orange or orange/blue). TPE = thermoplastic elastomer.

Table 3: 96 way screw top cryogenic storage tubes from different suppliers were tested in a long-term storage test in the vapor phase of liquid nitrogen. Besides Greiner Bio-One all other tube manufacturers are anonymised and tube codes are utilized to differentiate between different tube types offered by some manufacturers (e.g. manufacturer 'A' offers two different tube types with different types of screw cap; 'A1' and 'A2').

Manufacturer Code	Tube Code	Type of tube closure (according to figure 5)
Greiner Bio-One	G1 (300 µl Cryo.s™ biobanking tubes, non-sterile)	Internal, silicone
	G3 (1000 µl Cryo.s™ biobanking tubes, non-sterile)	Internal, silicone
A	A1	Internal, TPE
	A2	External, sealing lip, no separate sealing material
B	B1	External, sealing lip, no separate sealing material
	B2	Internal, silicone
C	C1	Internal, silicone
	C2	Internal, silicone
D	D1	Internal, TPE
	D2	Internal, silicone

[2] Note that at the time these studies were finalized, externally threaded tubes with additional TPE sealing material were launched by some competitors which, because of their late availability, could not be included in this comparative study.

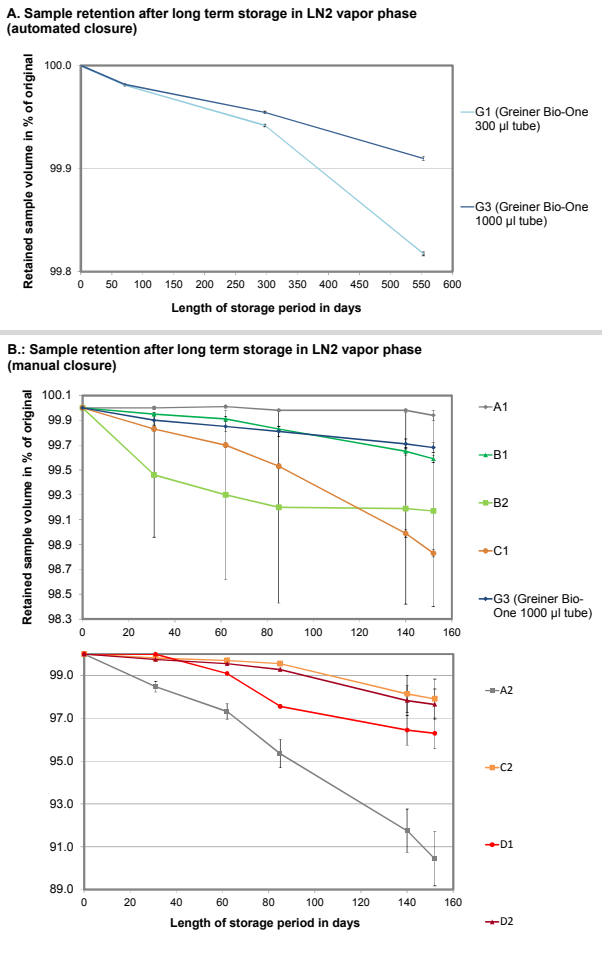

Figure 6: Sample retention after long-term storage in the vapor phase above liquid nitrogen. Tubes were closed with the Hamilton Labelite Decapper at 6-7 Ncm (**A**) or manually (**B**). Error bars indicate standard errors of the mean.

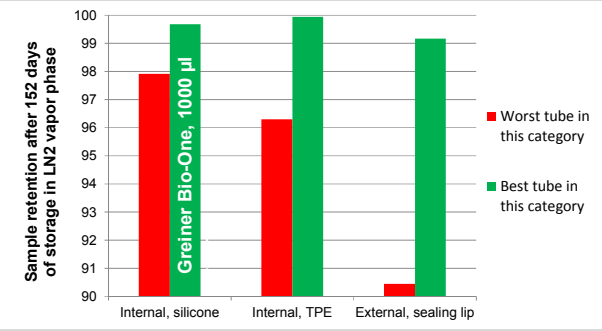

Figure 7: Performance range of different screw cap types in long-term vapor phase storage test.

In conclusion, the long-term storage test presented here revealed differences in the ability of different tubes to retain sample volume over time. These differences may not only be explained by differences in the type of tube closure; rather, other product features seem to exert influence on tube tightness. It is likely that parameters such as tube material, tube wall thickness and over-all tube design play an important role in long-term sample retention. The data shown within, however, indicate that the combination of internally threaded tubes with silicone gasket provides a reliable and robust solution for long-term storage in the vapor phase above liquid nitrogen.

BOX 2

Greiner Bio-One's Cryo.s™ Biobanking Tubes are excellently suited for the long-term storage of aqueous samples in the vapor phase above liquid nitrogen. It is recommended to utilize semi-automated (e.g. Greiner Bio-One's eight-channel handheld decapper, part no. 852070) or fully automated devices (e.g. Hamilton's LabElite Decapper) for tube closure with a recommended torque value of 6-7 Ncm.

5. Datamatrix Quality

5.1. Background

Machine-readable codes, in particular datamatrix codes, are state of the art solutions for an error-free, unambiguous and efficient identification and tracking of samples in biobanking. Most manufacturers of cryogenic sample storage tubes utilize laser technologies for applying datamatrix codes onto storage tubes. The major advantage of such direct tube labelling over adhesive barcode labels is better temperature, mechanical and chemical resistance. Whereas adhesive labels bear the risk of detachment during long storage periods, with increased risk at cryogenic storage temperatures; laser etched labels persist both harsh storage conditions and long periods of time.

Table 4: 96 way cryogenic storage tubes from different suppliers were tested for datamatrix quality. Besides Greiner Bio-One all other tube manufacturers are anonymised and tube codes are utilized to differentiate between different tube types offered by some manufacturers (e.g. manufacturer 'D' offers the two different tube types 'D1' and 'D2'). 14 x 14 datamatrix codes can encode tube IDs composed of 16 digits or 10 alphanumeric characters. Their intrinsic error correction tolerates 5-7 errors/erasures. 12 x 12 datamatrix codes can encode tube IDs composed of 10 digits or 6 alphanumeric characters. Their intrinsic error correction tolerates 3 errors/erasures

Manufacturer Code	Tube Code	Technology for datamatrix application	Size of datamatrix on tested tube type (dots)	Human readable text next to datamatrix code
Greiner Bio-One	G1 (Cryo.s™ Biobanking Tubes)	Laser	14 x 14	•
A	A1	Laser	14 x 14	-
B	B1	Laser	12 x 12	-
C	C1	Laser	12 x 12	•
D	D1	Laser	14 x 14	-
	D2	Laser	12 x 12	-

In principle two laser-labelling technologies are utilized for applying datamatrix codes onto storage tubes: (1) *material foaming* and (2) *material removal*. During *material foaming*, the laser beam melts the material. As a result, gas bubbles are produced in the material, which reflect the light diffusely. Thus, the laser mark is rendered lighter than all non-etched areas. This type of laser marking requires a dark (black) portion of the storage tube. Code application by *material removal* requires a part of the tube irreversibly coated with two contrasting thin layers of material. The outer material layer is dark (thus laser light absorbing) and completely vaporized after absorption of the laser light. The second layer (usually white) reflects the laser, thus avoiding further material removal. This layer becomes visible as a white mark surrounded by the non-etched dark material. Both technologies produce datamatrix labels which have proven resistant against chemicals used in the context of laboratory and biobanking work, such as ethanol and isopropanol used for disinfection and DMSO used as a cryoprotectant in cell banking and as a solvent in compound storage.

Besides the chemical, thermal and mechanical stability of datamatrix codes on cryogenic storage tubes, the code print quality is an important quality criterion. A widely accepted methodology for characterizing the print quality of datamatrix symbols is described in ISO/IEC 15415. In this standard several symbol properties, such as symbol contrast, axial nonuniformity and unused error correction, are delineated and their assessment under standard conditions (defined light source and aperture) [3] is described.

The datamatrix symbol quality is important, as it directly influences the readability of the code, hence the identifiability of the datamatrix-carrying sample storage tube – the lower the quality of a datamatrix code, the higher the vulnerability of the code to mechanical damage and subsequent loss of readability.

5.2. Method

Here we validated the quality of the datamatrix codes on cryogenic storage tubes from six different suppliers (table 4) using an Integra 9505 Bar Code Quality Station from Label Vision Systems, Inc. Eight randomly selected tubes were analysed per supplier. In particular, the following code parameters were assessed:

- **Symbol contrast** – detecting the differences between the dark and light areas as seen by the scanner,
- **Modulation** – measuring differences in contrast between adjacent areas of the datamatrix code,

[3] For details please refer to the standard 'ISO/ IEC 15415:2011 Information technology -- Automatic identification and data capture techniques -- Bar code symbol print quality test specification -- Two-dimensional symbols'

- **Axial nonuniformity** – assessing uneven scaling of the datamatrix symbol along its X or Y axis,
- **Unused Error Correction** – measuring the reading safety margin that error correction provides[4],
- **Fixed Pattern Damage** – analysing any damage to the finder pattern, quiet zone and clocking pattern in the symbol (for explanation see figure 10, I).

All parameters were graded on a scale of 0 to 4 with 4 as the best possible result.

5.3. Results and Conclusion

In the datamatrix validation test Greiner Bio-One's Cryo.s™ Biobanking Tubes revealed outstanding results with excellent scores for symbol modulation, axial nonuniformity, non-used error correction and defects in finder pattern. The symbol contrast category yielded very good results, with remarkable extremely low variation between individual tubes. All other tube brands yielded inferior results (figure 8). Some defects or problems identified with these tubes are illustrated in figure 9 (II, III, IV).

BOX 3

The datamatrix code on Greiner Bio-One's Cryo.s™ Biobanking Tubes is 'best in class' and provides a robust and reliable means for the machine readable identification of sample tubes in biobanking. A clear human readable text surrounding each datamatrix symbol helps to identify the datamatrix code content with the bare eye without requirement of a datamatrix reader.

[4] Unused error correction indicates the amount of available error correction in a symbol. Error correction is a method of reconstructing data that is lost via damage, erasure of the symbol, or poor printing. 100% unused error correction is the ideal case.

Tube type	Test tube no.	Symbol contrast	Modulation	Axial nonuniformity of datamatrix	Non-used error correction	Defects in finder pattern
G1 (Greiner Bio-One)	1	3	4	4	4	4
	2	3	4	4	4	4
	3	3	4	4	4	4
	4	3	4	4	4	4
	5	3	4	4	4	4
	6	3	4	4	4	4
	7	3	4	4	4	4
	8	3	4	4	4	4
A2	1	1	2	4	4	3
	2	1	2	4	4	2
	3	1	3	4	4	3
	4	1	1	4	4	3
	5	1	2	4	4	3
	6	1	2	4	4	2
	7	1	2	4	4	2
	8	1	2	4	4	3
B1	1	1	1	4	4	0
	2	1	1	4	4	0
	3	1	1	4	4	1
	4	1	1	4	4	0
	5	1	0	4	1	0
	6	1	1	4	4	0
	7	1	1	4	4	0
	8	1	0	4	4	0
C1	1	1	2	4	4	2
	2	1	4	4	4	3
	3	1	4	4	4	2
	4	1	2	4	4	2
	5	0	1	4	4	1
	6	1	2	4	4	4
	7	1	4	4	4	4
	8	1	2	4	4	3
D1	1	1	3	4	4	1
	2	2	3	4	4	1
	3	2	3	4	4	0
	4	2	0	4	4	0
	5	2	2	4	4	1
	6	1	2	4	4	1
	7	1	2	4	4	0
	8	1	2	4	4	1
D2	1	2	2	4	4	3
	2	2	4	4	4	1
	3	3	4	4	4	0
	4	2	4	4	4	3
	5	3	4	4	4	1
	6	2	4	4	4	3
	7	3	0	4	1	0
	8	2	4	4	4	1

Figure 8: Datamatrix quality of different sample tubes. Symbol contrast, modulation, axial nonuniformity, non-used error correction and defects in the finder pattern are scored from 0 (bad performance) to 4 (best performance, no defects).

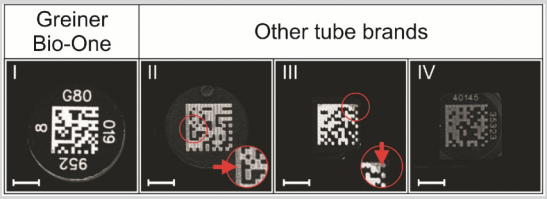

Figure 9: Examples of datamatrix codes on cryogenic storage tubes. **I:** Greiner Bio-One's Cryo.s™ Biobanking Tubes feature a 14 x 14 datamatrix code with surrounding human readable text. The L-shaped border (left/top) is the finder pattern. Together with the dashed line at the opposite margins of the symbol – the so called clocking pattern – it helps to locate the symbol and determine its orientation. Each datamatrix code must be surrounded by a non-patterned area (quiet zone). **II, III:** Datamatrix code examples with high modulation and defects in finder patterns (arrows). **IV:** Datamatrix code with low contrast.
All code images were taken under identical conditions; scale bars indicate a length of 2 mm.

6. Summary

Here we analysed several quality aspects of cryogenic sample tubes and point out differences between tubes from different tube manufacturers. In particular the aspects of raw material purity, biomolecule adsorption onto tube surfaces, long-term tube tightness and datamatrix quality were analysed in detail. The data presented here shall sharpen the awareness for the sample storage tube as an important and potentially quality-determining component of biobanking.

Greiner Bio-One's Cryo.s™ Biobanking Tubes yielded outstanding results in the individual tests and thus represent an optimum solution for cryogenic sample storage within the context of biobanking.

In conclusion, table 5 summarizes several suggested good practices for maintaining sample integrity in biobanking.

7. Literature

[i] J Biomol Screen. 2014 Dec;19(10):1409-14.

[ii] Can J Physiol Pharmacol. 2012 Jun;90(6):697-703.

[iii] Clin Chem. 2009 Oct;55(10):1883-4.

[iv] J Alzheimers Dis. 2012;31(1):13-20.

[v] Biopreserv Biobank. 2011 Sep;9(3):237-44.

[vi] Clin Chem. 2005 Jan;51(1):189-95.

[vii] Proteomics Clin Appl. 2007 Jul;1(7):699-711.

Table 5: Good practice in biobanking: Challenges and solutions.

Aim	Solution
Maintaining high cell viability, keeping cells mostly unaltered	Store in the vapor phase of liquid nitrogen
	Avoid or reduce periods of exposure to higher temperatures
	Minimize time from sample acquisition until freezing
	Use appropriate freezing medium (10-20 % DMSO, serum)
	Freeze at -1 K/min cooling rate
	Avoid contamination of storage tube with cytotoxic substances
	Avoid contamination of storage tube with endotoxins
	Strictly avoid repeated freeze-thaw cycles
Avoiding biomarker disintegration in liquid sample (e.g. serum)	Store at -80 °C or below
	Avoid or reduce periods of exposure to higher temperatures
	Minimize time from sample acquisition until freezing
	Strictly avoid repeated freeze-thaw cycles
Avoiding changes of biomarker concentration in liquid sample	Use storage tube which closes tightly at storage temperature
	Avoid non-specific biomarker adsorption onto storage tube surface
	Avoid contamination of storage tube with degrading enzymes (e.g. DNases, RNases)
Avoiding sample contamination	Use storage tube made of pure material, low in additives and leachables

All tests described in this document were performed applying good practice and maximum care. Competitor tubes analysed within represent the design status as commercially available in December 2015 or prior. Note since that time tube materials and designs of competitor products included in these tests may have been subject to change.