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Cost comparison of reusable and disposable air/water syringe tips in a large French teaching hospital

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SUMMARY

Air/water syringe (AWS) tips can be used in any type of dental care. They may be disposable (plastic) or reusable (stainless steel or plastic). We assessed the costs of using both sorts of tips in a French teaching hospital. A systematic use of one AWS tip per dental consultation was considered. Consultations performed with reusable AWS (stainless steel) tips give rise to costs linked to initial purchase of tips, their sterilisation, and replacement. Consultation costs of disposable AWS tips were calculated at their current purchase price. Replacing reusable tips was evaluated in two different situations: annual replacement or replacement in case of visual deterioration. Results showed that the number of consultations must lie beyond a certain threshold in order to make reusable tips more economical in use than disposable counterparts. If the reusable tips are replaced every year, this threshold is higher (e.g.: 1,366 consultations at the University of Bordeaux) than under a rule of tip replacement in case of visual deterioration (e.g. at the Bordeaux University: 1,267 consultations in case of an annual replacement rate of 10%, or 1,289 with a replacement rate of 30%). This is the first study regarding the costs of disposable versus reusable AWS tips. We suggest that disposable tips might be more cost-effective than reusable tips, notably because of their reduced risk of cross-contamination. The choice of the use of one or another AWS tip crucially depends on the number of consultations, as well as on their practical utilisation and on infection control issues.

1. Introduction

Air/water syringe (AWS) tips are an essential part of the dental armamentarium. The three-way syringes or AWS are used in any type of dental care enabling precise propulsion of water, or air, or a mixture of both. The AWS tips may be disposable or reusable: disposable tips are plastic devices, while reusable tips are made of either stainless steel or plastic.

A fundamental difference between disposable and reusable tips is that the latter may be affected by contamination problems. Dealing with highly contaminated aerosols, which are generated by the high-speed handpiece and the three-way syringe, is a challenging task (Lisboa et al. 2014). In fact, when actuating the AWS syringe, a reflux occurs for a fraction of a second, capable of contaminating the inside of the tip. Once contaminated, the lumen surface of the tip can act as a reservoir, facilitating cross-contamination (Russo et al. 2000).

In order to avoid cross-contamination, disinfection is required. According to international references, any type of reusable AWS tips must be disinfected following manufacturer's instructions (ADF 2013; CDC 2016).

Several authors have compared differences in the use of disposable and reusable AWS tips (namely metal tips) (Puttaiah et al. 1999; Russo et al. 2000; Shin et al. 2013). These studies generally focus on the effectiveness of both types of instruments regarding contamination issues and infection control, but they leave aside the no less important question of the respective costs associated to the use of these two types of tips. Cost comparisons of disposable and reusable medical devices can be found in other research papers, but they do not fall within the dentistry field (Lejeune et al. 2000; McCahon & Whynes 2015). To the best of our knowledge, there is no published research work dealing with cost comparison of disposable and reusable AWS tips, not to mention joint analysis of cost and effectiveness issues.

As a consequence, dental managers dispose of no scientific support, which could guide their choice between disposable and reusable AWS tips. This is unfortunate as they are faced with a trade-off between costs and medical effectiveness: on the one hand, instrument reuse could represent a substantial source of cost reduction; on the other hand, sterilisation of reusable tips may not be perfectly efficient (Puttaiah et al. 1999; Russo et al. 2000; Shin et al. 2013). In fact, reusable metal AWS tips fall into Spaulding's semi-critical category, requiring sterilisation or high-level disinfection between uses on different patients (Offner et al. 2016). The external layer of this type of tip is often a chrome-plated metal while the inside lumen is brass: both of them are corrosive, all the more as they regularly undergo the sterilisation process. Over time, the amount of corrosion increases which in turn enhances the number of niches inside the lumen, creating more surface area for a bioburden development (Hu et al. 2001; Watson 1996). Moreover, sterilisation of metal tips cannot be accomplished without pre-cleaning (Purohit et al. 2009). Because of the small openings to each lumen, the presence of contaminants on the rough internal surfaces of the metal tips cannot be visually examined or cleaned. Hence, sterilisation of metal AWS tips may not ensure perfect absence of microorganisms, possibly causing cross-contamination between patients (ADF 2013; Sonntag et al. 2016). This contrasts with disposable plastic tips: these have the advantage of presenting fewer recesses than the metal tips (Russo et al. 2000), and contamination problems are much less of a concern as disposable tips are intended for single-use only.

With regard to this trade-off, the present paper aims at providing a better understanding of the issues at stake by explicitly taking into account the cost considerations regarding the two types of AWS tips. Against this background, it should be noted that the effectiveness of disinfection of *reusable plastic* tips remains controversial, and requires further investigation (Russo et al. 2000). Consequently, this study focuses on reusable metal AWS tips. Issues related to reusable plastic tips are beyond the scope of our paper.

2. Material and Methods

In order to properly address the aforementioned issues of medical effectiveness (i.e. cross-contamination and infection control) in light of concrete numeric cost results, we proceed as follows. We start with a literature review (subsection 2.1) in order to make sure that we have not overlooked any research work dealing with cost comparison of disposable and reusable AWS tips (or other dental instruments). Subsequently, on the basis of an inventory of the different cost elements collected at the University Hospital of Bordeaux, we propose a general formula for AWS tip cost computations and comparisons (subsection 2.2).

2.1 Literature review

This investigation relied on the main electronic databases: Web of Science, Google Scholar, PubMed, EconLit, Dentistry & Oral Sciences Source–DOSS, and The Cochrane Library. Restrictions were applied on release dates (from 2000 on), but not on location. The following search terms were combined: cost OR expense OR prices OR economy AND dental, dentistry AND syringe OR syringe tip OR syringe tip air/water AND sterilization OR reusable AND disposable OR single use.

Papers without abstracts or with full text written in a language different from English, French, Spanish, German, Italian, or Portuguese were excluded. Using a checklist, the studies were screened, selected, and data were extracted. The recorded data covered the following points: first author, the study's year of publication, context (dental or other), segment of the dental context under investigation, methods used for cost evaluation. Papers were only included if they met the following criteria:

i. Focus on dental AWS tips, whether disposable or reusable;
ii. Description of general costs, in particular sterilisation costs;
iii. Focus on a cost comparison of disposable versus reusable medical devices (similar to dental AWS tips).

More precisely, inclusion required satisfaction of criteria i and ii or of criterion iii.

We also searched for documents published in non-peer-reviewed journals and on websites of widely recognised institutions that play a major role in dental devices recommendations, such as the US Centers for Disease Control and Prevention (CDC) and the European Centre for Disease Prevention and Control (ECDC). These latter documents were only used for discussion.

The primary bibliographic search retrieved 930 references. Based on the screening of titles and abstracts, 883 documents were excluded and 47 were retained for full text reading. The exhaustive list of the selected documents is available in Annex 1.

2.2 Cost assessment

This subsection provides a cost assessment scheme for AWS tips use (subsection 2.2.3) based on the routine practice of the Dentistry Division of the University Hospital of Bordeaux, as observed in the first semester of 2016 (subsections 2.2.1 and 2.2.2).

2.2.1 Study design

The Dentistry and Oral Health Division of the University Hospital of Bordeaux is composed of three sites with a total of 54 dental chairs: Saint-André (12 chairs), Pellegrin (22 chairs), Xavier Arnozan (18 chairs + 1 geriatric chair) and one additional chair at the prison of Bordeaux-Gradignan.

Each chair has a maximum capacity of ten dental visits per day (whether children or adults); visits are by appointment only. Currently, all chairs are exclusively provided with non-sterile plastic disposable AWS tips in original packaging (containing 250 tips).

Within the Bordeaux University Dental Division, healthcare is delivered by dentistry students/residents and supervised by 78 practitioners; the former provide a wide range of treatment techniques (from general dentistry to dental specialities) to around 65,000 patients per year (see subsection 2.2.2). This figure implies a mean chair occupancy rate of approximately 50% (i.e. five patients per chair per day, see subsection 2.2.4).

Based on national regulation (ADF 2013), the hospital's Infection Control Committee recommends either: (i) disposable tips for single-use (thrown away after each patient), or (ii) reusable tips for multiple-use (compulsory sterilisation after each patient) (Marque 2015; Service d'hygiène hospitalière 2008).

Besides requirements of the Infection Control Committee, manufacturers of metal AWS tips usually recommend pre-cleaning, which breaks down into three steps to be accomplished before sterilisation: 1. thorough nuts brushing with a nylon brush, 2. ultrasonic cleaning of the tips involving immersion in a disinfectant solution, 3. purging of all cleaning agents from the tips (A-dec 2017).

The Dental Division strictly follows the abovementioned requirements: the instruments requiring sterilisation are cleaned and pre-disinfected (Anyosime DD1 0,5%) before being sent to the Central Sterilisation Services (Service de Stérilisation Central) of the hospital. This latter unit is responsible for disinfection and sterilisation (steam autoclave 134 °C, 18 min) of all reusable instruments dispatched by the entire set of medical divisions of the Bordeaux University Hospital, such as the dentistry and surgical units (Bodin 2008).

2.2.2 Cost items

The cost comparison of disposable versus reusable AWS tips relies on observations of dentistry practices and related expenditures collected at the University Hospital of Bordeaux:

i. *Disposable tips:* we drew upon the usage cost of the currently used tips (Riskontrol® Classic); this cost corresponds exactly to the money amount spent on purchasing tips.
ii. *Reusable metal tips:* usage costs of reusable tips break down into initial purchasing costs (upfront acquisition of a well-sized set of tips), replacement costs (repurchasing of tips having become unusable) and sterilisation costs. Regarding initial purchasing costs, we relied on current market prices. With respect to replacement costs, we accounted for two different replacement schemes
   a) in line with recommendations of the Infection Control Committee, we first considered entire replacement of all reusable tips after one year of use;
   b) alternatively, we supposed that reusable tips would be used until visual deterioration (Dentist SkySea 2016) occurring at a given rate.

The estimation of AWS tips sterilisation costs was based on observations of sterilisation costs of other reusable instruments requiring sterilisation (e.g. mouth mirror, handpieces, amalgam condensers, impression trays). More precisely, we established two possible scenarios to simulate AWS tip sterilisation costs accruing for one dental chair: reusable tips are sterilised and put in multi-instruments packs

a) by batches of 10 (10 corresponds to the daily maximum capacity of each dental chair), or
b) by batches of >10–50 (50 corresponds to the weekly maximum capacity of each dental chair).

Importantly, batch size has a direct incidence on the required frequency of sterilisation:

a) In the case of batches of 10 tips, sterilisation must be carried out at least every 2 days (mean number of 5 consultations per chair per day), if not more often (because of dispersion around this mean, possible giving rise to use of more than 10 tips over the course of 2 days). These elements argue in favour of a daily frequency of sterilisation.
b) In the case of batches of 50 tips, a weekly frequency of sterilisation is necessarily sufficient. In fact, as the maximum weekly consultation capacity per chair amounts to 50, it is impossible that one chair uses more than 50 tips per week.

It is worth mentioning that our analysis does not take into account costs associated to routine practices of the Dentistry Division as long as they occur equally and indiscriminately under use of both disposable and reusable tips. Indeed, for the purposes of a cost comparison, it is sufficient to focus on costs that differ for the two types of tips, which is precisely the case of initial purchase, replacement and sterilisation costs. As a consequence, the total number of consultations is crucial to our analysis. In fact, each consultation requires the use of one AWS tip, involving either the purchase of one disposable tip or sterilisation of one reusable tip. On the basis of data provided by the Dentistry Division and the Central Sterilisation Service, we inferred a total annual number of 65,000 consultations.

Table I summarizes key characteristics of each sort of tip and provides quantifications of the aforementioned cost items (based on observations made at the Bordeaux University Hospital).

On the basis of information contained in Table I and the total annual number of 65,000 consultations, we established cost assessments for a one-year period of AWS tips use. These assessments are listed in Table II and rely on the following considerations and calculations:

i. *Number of consultations per chair:* we first established a mean number of 5 daily consultations (see subsection 2.2.4), implying a monthly number of 106.5 consultations (considering on average of 21.3 working days per month) and an annual number of 1,278 consultations.

Tab. I Characteristics of disposable and reusable AWS tips and related cost items (2016)

	Disposable tips	Reusable tips
Description	Non-sterile, recyclable food-quality plastic *Riskontrol® Classic* (Acteon 2016)	Non-sterile, metal *Skysea®* (Dentist SkySea 2016)
Packaging	250 tips[a]	50 tips[b]
Purchase cost	48.90 € per pack 0.1956 € per unit[a] (adaptor to syringe included)	21.50 € per pack 0.43 € per unit[b]
Sterilisation[c]	–	4.80 € for one multi-instruments pack
Waste[d]	Household waste	Household waste

[a] Tender 2016, Bordeaux University Hospital: the tips are billed individually 0.163 € without taxes plus 20% VAT, which means 0.1956 € (all taxes included)
[b] Dental Supply Marketplace (all taxes included) (Dentist SkySea 2016, p. 32)
[c] Costs include logistics, sterilisation process and packaging (Cubertafond & Rongeot 2014, Marque 2015)
[d] Costs of waste are included in the household refuse fee paid by each division of the hospital for elementary services, such as electricity and water

Tab. II Cost assessment per chair for disposable and reusable tips use for a one-year period (2016)

	Disposable tips	Reusable tips
Considering 1,278 consultations per chair on a one-year basis		
Number of tips required per year	1,278	50
Initial cost of tips purchase per year	249.98 €	21.50 €
Replacement costs per year	None	Only under a rule of tip use until visual deterioration. Depends on annual drop-out rate, e.g.: – 10%-rate: 5 × 0.43 € = 2.15 € – 20%-rate: 10 × 0.43 € = 4.30 € – 30%-rate: 15 × 0.43 € = 6.45 €
Additional sterilisation cost per year	None	Depends on the frequency of sterilisations, e.g.: 1 sterilisation per week: 245.66 € 1 sterilisation per day: 1,228.32 €

ii. *Duration of dental service provision:* at the Bordeaux University Dentistry Division, the mean duration of healthcare provision is 51.18 weeks per year, corresponding to 255.9 working days per year (see subsection 2.2.4).
iii. *Number of disposable tips required per chair:* the number of disposable tips to be purchased is equal to the number of consultations (implying a purchasing cost of 1,278 × 0.1956 € = 249.98 €).
iv. *Number of reusable tips required per chair:* 50 metal tips per chair are necessarily enough to guarantee the rotation of sterilised tips. Indeed, in the case of a low frequency of sterilisation (once a week), it is sufficient to make use of batches of 50 tips per multi-instrument pack: as mentioned above, due to the limited consultation capacity, one dental chair cannot use more than 50 tips per week. Upfront acquisition of a set of 50 reusable tips implies initial purchasing cost of 50 × 0.43 € = 21.50 €.
v. *Replacement costs:* expenditures due to repurchase of tips having become unusable depend on the drop-out rate. We simulated these costs for annual rates of 10%, 20% and 30%. Note here that these costs only occur under a rule of tip use until visual deterioration; under a rule of entire replacement of all tips after one year of use, there is no conceptual difference between annual replacement costs and initial purchasing costs.
vi. *Sterilisation costs:* we accounted for a weekly and a daily frequency of sterilisation. In the case of a weekly frequency, all tips used over one week are sterilised at the end of the week and put in a multi-instrument pack (batches of 11–50 tips). This involves sterilisation of 51.18 packs per year (51.18 × 4.80 € = 245.66 €). In the case of a daily frequency, all tips used over one day are sterilised at the end of the day and put in a multi-instrument pack (batches of up to 10 tips). This involves sterilisation of 255.89 packs per year (255.9 × 4.80 € = 1,228.32 €).

Finally, it should be noted that for our purpose of cost simulation, we transposed current practice of providing disposable AWS tips to the simulation scenarios for reusable tips. Indeed, at the Bordeaux University Dental Division, each chair is provided with original packs of 250 disposable AWS tips. In the same vein, we assume that sterilised packs containing several reusable AWS tips are available to each chair. Evidently, this implies that after initial opening of a pack, the reusable tips are no longer sterile. Nevertheless, the Infection Control Committee of the hospital has no objection to this operating mode. Indeed, AWS tips use does not require sterility. Note as well that the same interruption of sterility occurs when original packs of disposable AWS tips are opened.

2.2.3 Calculation schema and cost comparisons

The annual cost of disposable tips use (for one dental chair), noted c_d, is given by

$$(1) \qquad c_d = n_d \times p_d,$$

where n_d is the number of disposable tips and p_d their unit price.

The annual cost of reusable tips use, noted c_r, is the sum of the acquisition cost of a well-sized set of reusable tips and the annual sterilisation cost:

$$(2) \qquad c_r = n_r \times p_r + n_{st} \times p_{st},$$

where n_r is the number of purchased reusable tips, p_r the unit price of disposable tips, n_{st} the annual number of sterilisations and p_{st} the unit price of sterilising the entire set of reusable tips. The use of reusable tips is more economical than that of disposable tips if

$$(3) \qquad n_r \times p_r + n_{st} \times p_{st} < n_d \times p_d.$$

As disposable tips cannot be reused, their number n_d is equal to the number of consultations n, and we can rewrite inequality (3) in the following way:

$$(4) \qquad \frac{n_r \times p_r + n_{st} \times p_{st}}{p_d} < n.$$

Accordingly, the use of reusable tips is cheaper when the number of consultation exceeds a threshold value determined by the values of variables n_r, n_{st}, p_r, p_{st} and p_d.

The threshold inequality (4) is based on the hypothesis that for hygienic reasons, the entire set of n_r tips has to be fully replaced each year (see recommendations of the Bordeaux University Hospital Infection Control Committee discussed in subsection 2.2.2). Under a less restrictive rule, one may assume that tips are used as long as possible, i.e. until visual deterioration (Dentist SkySea 2016). With a supposed yearly drop-out rate of δ%, only $\delta \times n_r$ reusable tips have to be replaced each year. In this scenario, the annual cost of reusable tips use writes

$$(5) \qquad c_r = \frac{n_r \times p_r}{t} + \delta \times n_r \times p_r + n_{st} \times p_{st},$$

where t corresponds to the number of years for which the hospital has planned to rely on a system based on reusable tips (if the hospital decides to permanently adopt a reusable tips-system, we get $t \to \infty$, and the cost of constituting an initial stock of tips becomes negligible, because $\frac{n_r \times p_r}{t} \to 0$). With inequality (5), the use of reusable tips is more economical than that of disposal tips if

$$(6) \qquad \frac{\frac{n_r \times p_r}{t} + \delta \times n_r \times p_r + n_{st} \times p_{st}}{p_d} < n.$$

2.2.4 Statistical and graphical analysis

Our cost calculations and comparisons involved mean values, which have been established as follows:

i. The mean duration (in number of weeks) of healthcare provision was computed by dividing the mean length of a year (365.25 days when adjusting for the leap year effect) by seven and by subtracting one week in order to take into account for the fact that the Bordeaux University Dentistry Division is closed between Christmas and New Year's Day: $365.25 \div 7 - 1 = 51.18$.
ii. As the Dentistry Division provides healthcare five days per week, this implies a mean duration (in number of working days) of $51.18 \times 5 = 255.9$.
iii. The mean value of five consultations per chair per day was obtained by dividing the number of annual consultations (65,000) by the product of the number of dental chairs (54) and the mean duration in number of working days (255.9).

For illustrative purposes, we also produced a cost/time graph (Excel® 2011), showing the respective evolutions of costs associated to use of disposable versus reusable AWS tips (see Fig.1 in section 3). Importantly, this graph is based on the assumption that all tips to be used over the coming year (disposable and reusable) are purchased at the beginning of the year.

3. Results

Since our literature review highlights that cost considerations regarding disposable and reusable AWS tips remain a blank field of the related literature (subsection 3.1), we present in the remainder of this section numeric outcomes obtained by application of the cost comparison formulas developed above. We start with general outcomes (subsection 3.2), before moving on to the numerical results implied by the specific context at the Bordeaux University Hospital (subsection 3.3).

3.1 Literature review results

After full-text reading, all the papers assessed for eligibility (n=47) on the basis of the primary bibliographic search (see subsection 2.1) were excluded because they did not meet the inclusion criteria. Several documents were excluded (n=28) because they concerned comparisons of effectiveness, contamination risks or patient security among various sorts of AWS tips and associated instruments, but not cost considerations. The remaining documents (n=19) were not retained because they did not concern dentistry; they indeed dealt with sterilisation costs or compared reusable and disposable medical devices that are used in medical branches different from dentistry (Annex).

The total absence of research contributions meeting our inclusion criteria underscores the potential stake in our investigation. Consequently, the next two subsections provide numeric outcomes, which could serve as useful guideposts for cost comparisons between metal reusable and disposable AWS tips.

3.2 Multidimensional cost comparison

As seen in subsection 2.2.3, reusable tips are cost-effective for high-levelled numbers of consultations, i.e. when the number of consultations per dental chair exceeds a certain threshold. Under a rule of total replacement of all reusable metal tips after one year of use, this threshold depends on the variables n_r, n_{st}, p_r, p_{st} and p_d (equation [4]). Therefore, it would be interesting to show different thresholds associated to different combinations of values taken for these variables. Against this context, we propose to focus on variations of n_{st}- and p_{st}-values. These variables are indeed most subject to variation. According to organisational choices regarding AWS tip sterilisation, the order of magnitude of n_{st} may vary from 1 to 5, as shown by the example of the Bordeaux University Hospital (with n_{st}-values varying from 51.18 to 255.9, see subsection 2.2.2). p_{st} may also vary significantly, because it is not a market price, but corresponds to internal costs (those occurring in the different hospital services in charge of tip sterilisation); as a consequence, it is likely to

Tab. III Minimum number of annual consultations per dental chair required for making reusable tips more economical than disposable tips[a] (for various values of n_{st} and p_{st}[b], and with replacement of all reusable tips after 1 year of use).

Tip replacement rule: after 1 year of use		Annual number of sterilisations (n_{st})	
		255.9 (1 sterile pack per day)	51.18 (1 sterile pack per week)
Unit price of sterilisation (p_{st})	**3.50 €**	4,689[c]	1,026
	4.00 €	5,344[c]	1,157
	4.50 €	5,998[c]	1,288
	5.00 €	6,652[c]	1,419
	5.50 €	7,306[c]	1,550
	6.00 €	7,960[c]	1,680
	6.50 €	8,614[c]	1,811

[a] With fixed values of other variables: p_d = 0.1956 €, p_d = 0.43 € and n_r = 50.
[b] n_{st}-values are roughly centred around the level observed at the Bordeaux University Hospital (4.80 €)
[c] Impossible in practice, because the required annual number of consultations exceeds the chair's maximum annual capacity of 2,559 consultations.

differ materially between different hospitals, or between different organisational schemes of tip sterilisation. On the contrary, p_r and p_d are market prices, hence much less subject to variation. Moreover, preliminary manipulation of the cost comparison formula (4) highlighted that p_r and n_r have low impact on the threshold values, because replacement costs have relatively little weight compared to sterilisation costs. Finally, focussing on n_{st} and p_{st} allows for a synthetic and user-friendly presentation in a single double-entry table: accordingly, Table III records threshold values implied by 14 combinations of n_{st} and p_{st} (with n_r, p_r and p_d fixed at the levels observed at the Bordeaux University Hospital).

Table III highlights the potentially beneficial effect of reusable metal tips: under realistic combinations of n_{st} and p_{st} (e.g. n_{st} = 51.18 and p_{st} = 4.50 €), reusable tips are cheaper to use than disposable tips for realistic annual consultation numbers (e.g. 1,288, which is only slightly higher than the mean number of 1,278 observed at the Bordeaux University Hospital). More precisely, the minimum consultation number associated to the aforementioned values of n_{st} and p_{st} interprets as follows: if health service managers expect the annual number of consultations to equal or exceed 1288, they should opt for the use of reusable tips.

Under a rule of reusable tip use until visual deterioration, we have to take into account two additional variables: t and δ (equation [6]). In this context, one may choose $t \to \infty$, reflecting a permanent adoption of a system relying on reusable tips. Indeed, once established that reusable tips are cheaper than disposable tips, there is no obvious reason to turn back to a system relying on disposable tips. Accordingly, we get the triple-entry Table IV.

Table IV shows that adoption of the rule of reusable tips use until visual deterioration results in a reduction of the minimum threshold of annual consultations required to make reusable tips less expensive than disposable tips. For a drop-out rate of 10% (δ = 0.1), this reduction amounts to 99 consultations, for a rate of 30% to 77.

3.3 Cost comparison for the Bordeaux University Hospital

With the variable values observed or estimated at the Bordeaux University Hospital (n_{st} = {51.18; 255.9}, δ = {0.1; 0.2; 0.3}, n_r = 50, p_r = 0.43 €, p_{st} = 4.80 €, p_d = 0.1956 €, see subsection 2.2.2), we get the threshold numbers reported in Table V.

Tab. IV Minimum number of annual consultations per dental chair required for making reusable tips more economical than disposable tips[a,b] (for various values of δ, n_{st} and p_{st}, and with use of metal reusable tips until visual deterioration).

Tip replacement rule: use until visual deterioration		Drop-out rate (δ)					
		δ = 0.1		δ = 0.2		δ = 0.3	
		Annual number of sterilisations (n_{st})					
		255.9 (daily)	51.18 (weekly)	255.9 (daily)	51.18 (weekly)	255.9 (daily)	51.18 (weekly)
Unit price of sterilisation (p_{st})	**3.50 €**	4590[c]	927	4601[c]	938	4612[c]	949
	4.00 €	5245[c]	1058	5255[c]	1069	5267[c]	1080
	4.50 €	5899[c]	1189	5910[c]	1200	5921[c]	1211
	5.00 €	6553[c]	1320	6564[c]	1331	6575[c]	1342
	5.50 €	7207[c]	1451	7218[c]	1462	7228[c]	1473
	6.00 €	7861[c]	1581	7872[c]	1592	7883[c]	1603
	6.50 €	8515[c]	1712	8526[c]	1722	8537[c]	1734

[a] With fixed values of other variables: p_d = 0.1956 €, p_d = 0.43 € and n_r = 50.
[b] Permanent adoption of a system relying on reusable metal tips, implying $t \to \infty$.
[c] Impossible in practice, because the required annual number of consultations exceeds the chair's maximum annual capacity of 2,559 consultations.

Tab. V Minimum number of annual consultations per dental chair required for making reusable tips more economical than disposable tips at the Bordeaux University Hospital[a] (for various values of δ and n_{st}, and for both tip replacement rules).

Annual number of sterilisations (n_{st})	Tip replacement rule			
	After 1 year of use	Use until visual deterioration		
		Drop-out rate		
		$\delta = 0.1$	$\delta = 0.2$	$\delta = 0.3$
$n_{st} = 51.18$ (weekly)	1,366	1,267	1,278	1,289
$n_{st} = 255.9$ (daily)	6,390[b]	6,291[b]	6,302[b]	6,313[b]

[a] With fixed values of other variables: $p_d = 0.1956$ €, $p_d = 0.43$ €, $n_r = 50$ and $t \to \infty$.
[b] Impossible in practice, because the required annual number of consultations exceeds the chair's maximum annual capacity of 2,559 consultations.

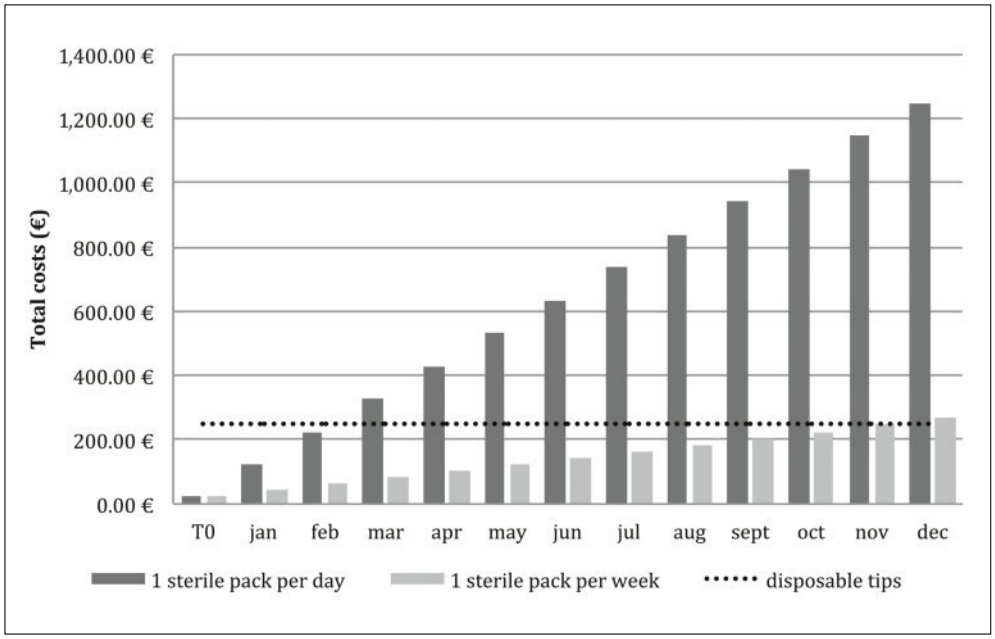

Fig. 1 Estimation of the annual expenses per dental chair with disposable versus reusable tips according to the frequency of sterilisation (no replacement costs considered)

Interestingly, the threshold values provided by the rule of tip use until visual deterioration (with drop-out rates of 10% or 20%, and with weekly tip sterilisation) are below or equal to the observed number of 1,278 annual consultations per chair.

Regarding the rule of total tip replacement after one year of use, Figure 1 provides an alternative interpretation of the numerical outcomes associated to the specific context of the Bordeaux University Hospital. It indeed shows how costs for using disposable versus reusable AWS tips evolve throughout a year, based on the underlying assumption that all disposable and reusable AWS tips to be used are purchased at the year's starting point (noted T0 in the figure). As sterilisation costs will be progressively added, one has to compare the final cost positions (on 31 December) in order to detect which type of tip gives rise to lower annual costs.

Perfectly logically, expenditures associated to disposable AWS tips do not vary during the year, as they do not need to be sterilised; indeed, expenditures associated to disposable tips correspond exclusively to the initial purchase of a sufficient set of tips (1,278 × 0.1956 € = 249.98 €). On the contrary, annual expenditures of reusable tips grow over the year. This growth is much faster in the case of daily sterilisation (cumulating to 1,228.32 € at the end of December) than under a weekly frequency of sterilisation (245.66 €). In other words, higher frequencies of sterilisation increase the total annual costs of using reusable tips. When comparing the end-of-year costs of using both types of types, we observe that disposable tips are less expensive, even if the sterilisation process is conducted on a weekly basis (with batches of 50 tips in a multi-instrument pack).

4. Discussion

To the best of our knowledge, this is the first study regarding costs of disposable versus reusable AWS tips. In this perspective, it allows for a better taking into account of the cost dimension, which had been largely absent from the conceptual framework. Indeed, according to the Bordeaux University Hospital, disposable tips haven been chosen for practical reasons (e.g. size, manipulation), and specially for their ability to reduce cross-contamination among patients (Puttaiah et al. 1999). Importantly, our paper provides a literature review as well as formulas for comparing costs of using both sorts of AWS tips. It thus sets the stage for a discussion of issues of medical effectiveness (cross-contamination, infection control, etc.) in light of the numeric outcomes obtained by application of these formulas, in particular by their application on the specific case of the Bordeaux Uni-

versity Dental Division during the first semester of 2016. Our paper allows for adding the cost dimension, which was largely lacking in the conceptual framework

4.1 The impact of pack size and frequency of sterilisation

The numeric results presented in the previous section clearly show the key role played by the frequency of sterilisation: for realistic values of the number of consultations per chair, the use of reusable metal tips is systematically and significantly more expensive under high-frequency (e.g. daily) sterilisation; with lower frequencies (e.g. weekly), reusable tip costs are nearing those of disposable tips (see Tables IV and V). Against this background, it has to be stressed that choices in terms of sterilisation frequency and of sterile pack size are inseparably linked. Low frequency sterilisation requires larger pack sizes (e.g. batches of 50 tips for a weekly frequency) than high frequency sterilisation (e.g. batches of 10 tips for a daily frequency). The important point is that a reduction of the frequency of sterilisation, with a concomitant increase in the number of reusable tips per sterile pack, could make reusable tips more economical than disposable tips. In this regard, the rule of tips use until visual deterioration deserves particular consideration. As seen in subsection 3.3 (Tab. V), for drop-out rates ranging from 10% or 20%, this rule implies threshold values inferior or equal to the number of consultations observed at the Dental Division of the Bordeaux University Hospital. In other words, reusable tips may be reliable, at least if there are no objections to the associated tip replacement rule, and if the supposed drop-out rates of 10% to 20% are considered to be close to actual rates.

At this stage of reflection, increasing pack sizes combined with decreasing frequencies of sterilisation could appear as a promising strategy to yield cost savings. However, decisions regarding the choice of using one or another tip should also consider important factors, such as the context of the dental practice and contamination issues. For example, providing each chair with sterile packs containing more than 25 reusable tips might not represent the gold standard of dental practice. According to the University Hospital of Bordeaux, this could represent a source of hygiene concerns and misuse of the sterile pack (Martin 1998).

4.2 Limitations

The relatively strong result of our literature review – no current publication dedicated to cost comparisons of AWS tips (even when taking into account of non-peer-reviewed magazines) – should be assessed in the light of the underlying choices in terms of keywords, keyword combinations and queried databases. To some extent, these choices are necessarily arbitrary.

A further limitation of our analysis might arise from potential biases in data related to operational routines. Indeed, there may exist intra- and/or inter-variations in the number of consultations per chair and per hospital site, but these details are not reflected in our data. In addition, the time spent by the hospital's dental staff on pre-cleaning and decontamination of reusable tips was neglected (Edwards et al. 2015; Shin et al. 2013; Watson 1996). These are important and interesting topics for future research, which may build on real observations and health insurance data in order to tackle these points.

Another candidate issue for future research is uncertainty regarding the influx of patients, involving adequate statistical treatment by means of statistical and econometric tests. In fact, as the cost comparison between disposable and reusable AWS tips can be satisfactorily carried out in a deterministic framework, the present study does not deal with this uncertainty.

4.3 Suggestions for pragmatic solutions

AWS tips are not the only dental instruments requiring sterilisation: this is also the case of mouth mirrors, explorers, periodontal probes, cotton pliers, etc. When it comes to cleaning of these instruments, it thus might be possible to add AWS tips, which should result in very low extra-costs. Operating this way could mean an important reduction in AWS tip sterilisation costs, possibly making reusable tips less expensive than disposable ones.

Another simple way of reducing sterilisation costs is pooling of AWS tips used by all chairs of a given hospital site. This could allow for a sharp reduction in the number of sterilisations. One could even imagine that all tips of all chairs are pooled together each evening and put in a single sterile pack; the next morning, they are again dispatched to all chairs. This type of internal organisation of the sterilisation procedure should be accompanied by a simple rule: all AWS tips should be sterilised each evening, whether or not they have been used throughout the day. This rule should minimize cross-contamination by preventing situations where some tips remain unused and unsterilised over several weeks or even months.

5. Conclusion

This study provides a methodology of assessment and comparison of use costs of disposable and reusable metal AWS tips. The latter costs were established by means of estimations based on use costs of similar reusable instruments that had been observed in the first semester 2016 at the Bordeaux University Hospital. On the basis of our assessment methodology and the related literature (Martin 1998; Puttaiah et al. 1999; Russo et al. 2000; Shin et al. 2013), we suggest that disposable tips might be more cost-effective than reusable tips, notably because of their reduced risk of cross-contamination. However, the respective use costs crucially depend on the overall number of dental consultations and the frequency of sterilisation of reusable tips.

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7. Résumé

7.1 Introduction

Les embouts des seringues air/eau utilisés fréquemment par les praticiens dentaires peuvent être constitués de matériel jetable (plastique) ou réutilisable (plastique ou métallique). La principale différence entre les deux types d'embout est la possibilité de contamination: l'intérieur de l'embout réutilisable peut être contaminé par un reflux d'eau venant de la seringue. Le lumen

de l'embout pourrait donc agir comme un réservoir de micro-organismes, pouvant provoquer la contamination croisée entre patients.

La contamination croisée peut être évitée avec la stérilisation des embouts métalliques. Plusieurs auteurs ont comparé les différences entre les deux types d'embouts en termes d'efficacité et de contrôle d'infection. Toutefois, les différences budgétaires entre les embouts est très peu prise en compte. Nous ne connaissons pas de publication scientifique évaluant les coûts d'utilisation des embouts jetables versus les embouts métalliques réutilisables.

Par conséquent, les décideurs en soins dentaires sont contraints de faire un choix entre la balance coût-efficacité des embouts en absence d'information économique.

Nous avons mené une revue de la littérature sur les études de coût concernant une comparaison entre les embouts air/eau jetables et réutilisables en odontologie. Ensuite, nous avons mis en place une investigation empirique pour évaluer les coûts de l'usage des deux sortes d'embouts, utilisant comme contexte un centre hospitalier universitaire en France.

7.2 Matériels et méthodes

Nous avons recueilli des informations auprès du Pôle odontologie et santé buccale de l'Université de Bordeaux pendant le premier semestre de 2016. Nous avons considéré l'utilisation systématique d'un embout air/eau par chaque consultation dentaire. Des consultations effectuées avec des embouts air/eau réutilisables (métalliques) engendrent des coûts d'achat initial des embouts, de stérilisation et de remplacement des embouts. Les coûts associés aux consultations avec des embouts air/eau jetables ont été calculés avec le coût d'achat de ces embouts. Le remplacement des embouts métalliques a été évalué dans deux situations distinctes: annuel ou jusqu'à dégradation visuelle.

7.3 Résultats

La revue de la littérature a retrouvé 930 documents, mais aucun n'a été retenu, car ils ne correspondaient pas à des études évaluant les coûts d'utilisation des embouts dentaires air/eau.

Les résultats de l'investigation empirique sur les coûts d'utilisation des embouts dentaires ont montré que les embouts jetables peuvent être moins chers que les embouts réutilisables selon la situation de la pratique, notamment le nombre de consultations et la fréquence des stérilisations. En effet, pour avoir un avantage en termes de coûts en faveur des embouts réutilisables, il faut que le nombre de consultations se situe au-dessus d'un certain seuil. Si les embouts sont échangés tous les ans, ce seuil est plus haut (1366 consultations à l'Université de Bordeaux) qu'avec une règle de remplacement en cas de dégradation visuelle (à l'Université de Bordeaux: 1267 consultations en présence d'un taux de remplacement annuel de 10%, ou 1289 avec un taux de remplacement de 30%).

7.4 Discussion

Il s'agit de la première étude sur le coût des embouts dentaires air/eau jetables et réutilisables. Nous suggérons que les embouts jetables pourraient être plus coût-efficace que les embouts réutilisables, notamment en raison de leur risque réduit de contamination croisée. Le choix de l'utilisation de l'un ou l'autre embout dépend crucialement du nombre de consultations, mais aussi de leur utilisation pratique et les questions de contrôle de l'infection.

8. Zusammenfassung

8.1 Einleitung

Die häufig von Zahnärzten verwendeten Dreiwegaufsätze von Luft-Wasser-Spritzen werden entweder aus Einwegmaterial (Plastik) oder aus Mehrwegmaterial (Plastik oder Metall) hergestellt. Der Hauptunterschied zwischen diesen beiden Arten von Aufsätzen besteht in der Möglichkeit einer Kreuzkontamination: der Innenraum der wiederverwendbaren Teile kann durch einen Wasserrückfluss aus der Spritze kontaminiert werden. Das Lumen des Aufsatzes kann so zu einem Reservoir für Mikroorganismen werden; ein Umstand der zu Kreuzkontamination zwischen Patienten führen kann.

Eine Kreuzkontamination kann durch Sterilisation der Metallaufsätze verhindert werden. Mehrere Autoren haben die beiden Arten von Aufsätzen in Bezug auf Effizienz und Infektionsschutz verglichen. Die Kostendifferenz zwischen beiden Aufsatzarten ist dabei allerdings wenig berücksichtigt worden. Nach unserem Wissensstand gibt es derzeit keine wissenschaftliche Veröffentlichung, die die Anwendungskosten von Einwegaufsätzen und wiederverwendbaren Metallaufsätzen evaluiert. Daher müssen Entscheidungsträger der zahnärztlichen Abteilungen eine Wahl bezüglich des Kosten-Effizienz-Verhältnisses beider Arten von Aufsätzen treffen, ohne jedoch über relevante Kosteninformationen zu verfügen.

Wir haben im vorliegenden Artikel einen Literaturüberblick bezüglich der Studien, die sich im Bereich der Zahnheilkunde mit dem Vergleich von Einweg- und wiederverwendbaren Luft-Wasser-Dreiwegaufsätzen befassten, durchgeführt. Danach haben wir in einer empirischen Untersuchung die Anwendungskosten beider Arten von Aufsätzen im Kontext eines französischen Universitätskrankenhauses evaluiert.

8.2 Materialien und Methoden

Die Information des Mundgesundheitsdienstes der Universität Bordeaux aus dem ersten Semester 2016 wurde erfasst. Für jede Konsultation wurde die Anwendung eines Luft-Wasser-Aufsatzes veranschlagt. Konsultationen mit Anwendung von wiederverwendbaren Metallaufsätzen verursachen Kosten für deren Kauf, Sterilisation und Ersatz. Die Kosten für Konsultationen mit Einwegaufsätzen bestehen lediglich in den Einkaufskosten. Für den Ersatz der Metallaufsätze wurden zwei verschiedene Situationen berücksichtigt: jährlicher Ersatz und Ersatz im Falle visueller Abnützung.

8.3 Resultate

Der Literaturüberblick förderte 930 Dokumente zu Tage, wobei letztendlich keines berücksichtigt wurde, da es sich nicht um Untersuchungen zu den Anwendungskosten von zahnärztlichen Luft-Wasser-Aufsätzen handelte.

Die Befunde unserer empirischen Untersuchung zu den Anwendungskosten der Dreiwegaufsätze von Luft-Wasser-Spritzen haben ergeben, dass je nach Anwendungspraxis (Anzahl der Konsultationen, Sterilisationsfrequenz) Einwegaufsätze kostengünstiger sein könnten. Die Zahl der Konsultationen muss in der Tat oberhalb eines bestimmten Schwellenwertes liegen, damit man mit wiederverwendbaren Aufsätzen einen Kostenvorteil erzielen kann. Bei jährlichem Ersatz der Aufsätze liegt dieser Schwellenwert höher (z.B. 1366 Konsultationen an der Universität Bordeaux) als bei Ersatz im Falle einer visuellen Abnützung (z.B. an der Universität Bordeaux: 1267 Konsultationen für eine jährliche Ersatzrate von 10%, oder 1289 für eine Rate von 30%).

8.4 Diskussion

Bei der vorliegenden Studie handelt es sich um die erste Untersuchung bezüglich der Anwendungskosten von Einweg- und wiederverwendbaren Dreiwegaufsätzen von Luft-Wasser-Spritzen. Diese Untersuchung legt nahe, dass Einwegaufsätze vor allem aufgrund eines geringeren Kreuzkontaminationsrisikos kosteneffizienter sein könnten als wiederverwendbare. Die Auswahl zwischen den beiden Sorten von Aufsätzen hängt entscheidend von der Anzahl der Konsultationen und ebenfalls von der jeweiligen Anwendungspraxis und von Fragen des Infektionsschutzes ab.

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