Journal of Oral Rehabilitation 2006 **33**; 850–862

Review Article
A review of the shortened dental arch concept focusing on the work by the Käyser/Nijmegen group

T. KANNO*,† & G. E. CARLSSON† **Department of Fixed Prosthodontics, Graduate School of Dentistry, Tohoku University, Sendai, Japan and †Department of Prosthetic Dentistry/Dental Materials Science, Sahlgrenska Academy at Göteborg University, Göteborg, Sweden*

SUMMARY **The aims of this paper were to review the literature on shortened dental arches with special focus on publications of the Käyser/Nijmegen group, and to evaluate the discussions on the shortened dental arch concept found in the literature. A MEDLINE (PubMed) search was conducted for articles in English published in the dental literature from 1966 to November 2005. The search revealed epidemiological, cross-sectional and longitudinal clinical studies as well as opinion papers, the majority of which were published by the Dutch group. The studies found in general no clinically significant differences between subjects with shortened dental arches of three to five occlusal units and complete dental arches regarding variables such as masticatory ability, signs and symptoms of temporomandibular disorders, migration of remaining teeth, periodontal support, and oral comfort. The findings from cross-sectional studies were corroborated longitudinally. No systematic clinical study with conflicting results was found. The shortened dental arch concept was accepted by a great majority of dentists but not widely practised. The studies reviewed showed that shortened dental arches comprising anterior and premolar teeth in general fulfil the requirements of a functional dentition. It may therefore be concluded that the concept deserves serious consideration in treatment planning for partially edentulous patients. However, with ongoing changes, e.g. in dental health and economy, the concept requires continuing research, evaluation and discussion. Patients' needs and demands vary much and should be individually assessed but the shortened dental arch concept deserves to be included in all treatment planning for partially edentulous patients.**

KEYWORDS: **epidemiology, mastication, molar teeth, removable partial denture, temporomandibular disorders**

Accepted for publication 14 January 2006

Introduction

For a long time, it was stated in practically all textbooks in prosthodontics and taught in most dental schools that a full complement of teeth is a prerequisite for a healthy masticatory system and satisfactory oral function. In consequence with this opinion, by many considered a dogma, teeth that were lost should be replaced to avoid a number of negative sequelae (1). Some clinicians dared to question this dogma (2–5). For example, De Van wrote, when discussing indications for removable partial dentures (RPDs): 'Many times it is much better to preserve what is left instead of replacing what has been lost' (2). Karlsen stated that the dental profession cannot ascertain the number of teeth that each individual needs (3). If a patient manages well with a reduced dentition there is no reason to recommend prosthetic appliances. With some irony, Lewin wrote that many dentists suffered from the '28-tooth syndrome', the perceived need to restore lost teeth up to the second molars (4). As many subjects masticate quite well even with missing molars, non-replacement should also be considered as an alternative for such patients. According to Ramfjord (5), replacement of

doi: 10.1111/j.1365-2842.2006.01625.x

missing molars is a common source of iatrogenic periodontal disease and should therefore be avoided if aesthetics and functional stability can be satisfied. However, these opinions were controversial and not generally accepted, especially not in academic dentistry. They lacked scientific support at that time, which was also the case with the concept of replacing all lost teeth.

The term 'shortened dental arches' (SDA) was first used in 1981 by the Dutch prosthodontist Arnd Käyser for a dentition with loss of posterior teeth (6). After clinical studies, he concluded that there is sufficient adaptive capacity in subjects with SDA when at least four occlusal units are left (one unit corresponds to a pair of occluding premolars; a pair of occluding molars corresponds to two units). The results were received with mixed feelings, and many 'traditionalists' – those who believed in the necessity of a complete dentition – considered the SDA concept heretical.

Gradually, the findings that dental arches comprising the anterior and premolar teeth in general constitute a functional dentition has gradually met increased acceptance (7–11). However, the SDA concept is still considered controversial by many clinicians. It has for example been criticized because loss of molars is associated with reduced masticatory performance and has been reported to lead to mandibular displacement and various changes in the body, at any rate in animals (12, 13). SDA has also been suggested to be associated with an increased risk for changes in the temporomandibular joint (TMJ) (14, 15).

There were three purposes of this paper: (i) to review the literature on shortened dental arches published by the Käyser/Nijmegen group; (ii) to review clinical studies related to SDA by other groups; and (iii) to evaluate and discuss reviews and opinion papers on the SDA concept in the current literature.

Materials and methods

A MEDLINE (PubMed) search was conducted for articles published in English in the Dental Literature from 1966 to November 2005 using the terms 'Shortened Dental Arch' and/or 'Käyser A'. Furthermore, manual searches of the bibliographies of all full-text articles and related reviews were performed. The search revealed altogether 77 articles, of which 32 articles (6, 16–46) comprising epidemiological and clinical studies and opinion papers on SDA were published in English by the Käyser/Nijmegen group (hereafter 'the Dutch group'; a few papers in collaboration with other authors were included). Besides these 32 articles that constitute the basis for the review, the search revealed 45 other articles related to SDA. From these, only clinical studies, reviews and opinion papers published in English were included, reducing the number of papers from other centres to 12 (47–58). The findings of the research and opinions in the papers were first extracted and tabulated by the two authors independently. In a following joint evaluation, the results were summarized and presented under various subtitles. The first section comprises the papers of the Dutch group and the second one SDA-related articles by other authors.

Results

SDA-related papers by the Dutch group

Epidemiological surveys In the 1980s, the Dutch group conducted epidemiological surveys in the Netherlands and later on in Tanzania (16, 17, 28) (Table 1). In the Netherlands, the number of teeth and occluding tooth contacts decreased with increasing age. In the lower socio-economic group, more teeth were missing than in the higher socio-economic group. An average of 60% of all open tooth spaces was not prosthetically restored. The proportion of middle-aged subjects with SDA was thus already high. The results showed no significant correlation between missing teeth or number of contacting pairs of teeth and the functioning of the dentition.

Of the large sample in Tanzania (5532 adults), 41% had complete dental arches, 44% had interruptions, and 15% had SDA; 0·5% were edentulous. As molars had the highest risk of dental decay and were most frequently absent, SDA developed. The authors concluded that given the limited resources in Tanzania, it seemed reasonable to extract decayed molars, leading to an SDA.

Cross-sectional clinical studies During the period 1987 to 2004, the Dutch group conducted cross-sectional studies comparing a variety of clinical indices between subjects with SDA and other types of dentitions (18–23) (Table 2). Furthermore, investigations on dentists' attitudes to SDA were performed in several countries (24–27). More recently, the Dutch group also performed SDA-related studies in Tanzania (27–31), because it was pointed out that the results of previous studies were from small populations limited to industrialized countries only. Therefore, the studies were conducted in

Table 1. Epidemiological studies related to SDA conducted by the Dutch group

Ref. (year)*	Description of study	Subjects, *n* (age)	Methods	Results
16 (1987)	Investigation of tooth loss in a Dutch population	Dutch employees: 750 (25–54 years)	Questionnaire clinical exam	Tooth loss was related to age and socio-economic level
17 (1987)	Investigation of prosthetic treatment at partial edentulism in a Dutch population	Dutch employees: 750 (25–54 years)	Questionnaire clinical exam non-response rate: 15%	In the lower social levels the percentage of removable prostheses was lower than in the higher levels. An average of 60% of all open tooth spaces were not prosthetically restored
28 (2003)	Decayed/missing/filled teeth and SDA in Tanzanian adults	Tanzanian population: 5532 (adults)	Questionnaire clinical exam non-response rate: 7·5%	As molars had the highest risk of dental decay and were most frequently absent, SDA developed. The authors concluded that given the limited resources in Tanzania, it seemed reasonable to extract decayed molars, leading to SDA

*Ref. (year) = reference number (year of publication).

populations that were unable to obtain sufficient dental treatment and whose diets required more occlusal activity. The study designs included large populations in order to make possible a subdivision of subjects with SDA. The study in Tanzania comprised 725 adults and this large sample allowed a classification of SDA in eight levels (28).

1. Occlusal factors in SDA. No significant differences in overbite were found between the dentition groups. In all dentition groups, occlusal tooth wear increased with age (Table 2). When the groups were compared, subjects with CDA ≥40 years of age had the most occlusal tooth wear. Although a systemic effect of SDA on interdental spacing was found for <40-year-old subjects, it was concluded that this migration was small and clinically insignificant (18).

In Tanzania, extreme SDA (zero to two pairs of occluding premolars) had significantly more interdental spacing, occlusal contact of incisors, and vertical overlap compared with complete dental arches (30). Occlusal wear and prevalence of mobile teeth were highest in these categories. Nearly all subjects with SDA (98%) had one or more unopposed (pre)molars. Despite the observed over-eruption, almost no subjects (2%) reported hindrance of oral function. Signs of increased risk of occlusal instability seemed to occur in extreme SDA, whereas no such evidence was found for intermediate categories of SDA (30).

2. Mastication in subjects with SDA. In younger subjects with SDA in the Netherlands, some reported various chewing problems (Table 2). A fifth of the subjects with SDA often had chewing difficulty, they had to chew for a longer time than before losing their molars and some of them (7%) had to change food preparation as a consequence. However, most subjects with SDA had no or only minor problems with chewing. For some subjects with SDA, the chewing function, food preparation, food selection and actual food consumption were hindered but the majority considered their chewing ability satisfactory (19).

In Tanzania, it was concluded that SDA with intact premolar regions and at least one occluding pair of molars provided sufficient chewing ability. The chewing ability deteriorated with a decrease of occluding pairs of teeth, especially for hard foods. Subjects with extreme SDA (0 to 2 occluding premolars) complained of severely reduced chewing ability. The findings were in some contrast to those in industrialized countries

Table 2. Cross-sectional studies related to SDA conducted by the Dutch group

Ref. (year)*	Description of study	Subjects, *n* (age)	Methods	Results
6 (1981)	Changes of oral functions in SDA	SDA group: 90 CDA group: 28 (19–71 years)	Interview, radiographic and clinical examination	There is sufficient adaptive capacity to maintain adequate oral function in SDA when at least four occlusal units are left, preferably in a symmetrical position
18 (1987)	Relation between SDA and migration of teeth	SDA group: 60 CDA group: 72	Examination about occlusal contact, interdental space, etc.	Although a systemic effect of SDA has been found on interdental spacing, it was concluded that this migration is within acceptable levels
19 (1988)	Relation between SDA and mastication	SDA group: 43 CDA group: 54 (21–50 years)	Interview	In the subjects with SDA, the chewing function, food perception, food selection and actual food consumption were hindered but within an acceptable degree
20 (1988)	Relation between SDA and signs and symptoms of mandibular dysfunction	SDA group: 60 CDA group: 72	Examination about TMD (interview, registration of clicking of TMJ, etc.)	The absence of molar support did not appear to provoke signs and symptoms of mandibular dysfunction. The presence of bilateral premolar support seemed to provide sufficient mandibular stability
21 (1989)	Relation between SDA and removable partial denture on the oral function	SDA group: 55 SDA group with previous RPD: 19 SDA group + RPD: 25	Questionnaire, clinical exam	Oral function was not evidently improved by the insertion of a free-end RPD
22 (1990)	Relation between SDA and oral comfort	SDA group: 74 SDA group + RPD: 25 CDA group: 72	Oral comfort: absence of pain or distress, acceptable chewing ability and appearance of the dentition	SDA appeared to provide sufficient oral comfort and free-end RPD did not contribute to oral comfort
23 (1991)	Relation between SDA and periodontal support	SDA group: 74 SDA group + RPD: 25 CDA group: 72	Examination of periodontal support (tooth mobility, alveolar bone height)	The combination of increased occlusal loading, as in a reduced dentition, and existing periodontal involvement appeared to represent a potential risk factor for the loss of teeth
25 (1996)	Views of consultants in restorative dentistry in the United Kingdom towards SDA therapy	Consultants in restorative dentistry in the UK: 135	Questionnaire (response rate: 67%)	SDA therapy was widely accepted by consultants in restorative dentistry in the UK, but not widely practised by the members of this group
24 (1997)	Views of Dutch consultants in restorative dentistry towards SDA therapy	Members of staff in restorative dentistry in the Nijmegen school of dentistry	Questionnaire (response rate: 64%)	Most of the qualified members of staff were of the view that the SDA concept has a useful place in clinical practice

Table 2. Continued

Ref. (year)*	Description of study	Subjects, *n* (age)	Methods	Results
26 (1998)	Views of members of the European Prosthodontic Association towards SDA therapy	Members of the European Prosthodontic Association	Questionnaire (response rate: 42%)	96% of respondents agreed that the approach was acceptable in clinical practice
27 (2003)	Attitudes of dentists in Tanzania towards SDA concept	Dentists in Tanzania: 77	Questionnaire (response rate: 82%)	SDA concept was considered an acceptable strategy for dentists in Tanzania. However, many dentists did not use it in clinical practice
29 (2003)	Relation between SDA and signs and symptoms of TMD	Tanzanian employees SDA group: 725 CDA group: 125 (≥20 years)	Interview and clinical examination about TMD	No evidence that SDA provoked signs and symptoms associated with TMD. However, when all posterior support was unilaterally or bilaterally absent, the risk for pain and joint sounds seemed to increase
30 (2003)	Occlusal stability in SDA	Tanzanian employees SDA group: 725 CDA group: 125 (≥20 years)	Interview and clinical examination about occlusal stability	Signs of increased risk to occlusal stability seemed to occur in extreme SDA, whereas no such evidence was found for intermediate categories of SDA
31 (2003)	Chewing ability in SDA	Tanzanian employees SDA group: 725 CDA group: 125 (≥20 years)	Interview and clinical examination about chewing ability	Shortened dental arches with intact premolar regions and at least one occluding pair of molars provided sufficient chewing ability

*Ref (year) = reference number (year of publication).

where a premolar dentition without molar support often was sufficient (31).

3. Signs and symptoms of TMD in SDA. No significant differences were found between the groups with shortened and complete dental arches regarding signs and symptoms of temporomandibular disorders (TMD) (Table 2) (20). For the Dutch population with SDA, the absence of molar support did not appear to provoke signs and symptoms of mandibular dysfunction. In subjects with absence of molar support, morphological changes in the TMJs may occur. However, such changes in the TMJs may not be pathological, but signs of adaptation. In Tanzania, no significant differences were found between categories of dental arches with respect to pain, restricted mobility of the mandible, maximum mouth opening <40 mm, or clicking or crepitating of the joints (29). Joint sounds were reported significantly more frequently by subjects with posterior support only unilaterally and by subjects with no posterior support compared with other categories of dental arches. Pain in the joint and restricted mouth opening were reported in low percentages in subjects with SDA. No evidence was found that SDA provoked signs and symptoms associated with TMD. However, when all posterior support was unilaterally or bilaterally absent, the risk for pain and joint sounds seemed to increase.

4. The effect of RPDs in SDA. There was no indication that oral functions were improved by the insertion of a RPD in the case of an SDA with three to five occlusal units (21) (Table 2). Many patients stopped wearing their RPDs. The factor 'dentist' played a greater role in the prescription of a free-end RPD than the oral condition of the patient. Patient-related factors seemed to be the major reason to stop wearing a free-end RPD.

5. Oral comfort in SDA. On the whole, the results did not reveal any significant differences between the three groups with respect to pain or distress (22) (Table 2). The oral comfort of subjects with SDA in this study was compromised to a small extent but remained on an acceptable level. Free-end RPDs did not appear to help oral comfort in these cases.

6. SDA and periodontal support. Subjects with SDA, with or without RPD in the mandible, had more mobile teeth and lower alveolar bone scores (23) (Table 2). The combination of increased occlusal loading, as in a reduced dentition, and existing periodontal involvement appeared to represent a potential risk factor for the loss of teeth. Because of confounding variables such as a history of dental treatment and interrelated amount of crowns and fixed partial denture (FPD), longitudinal data are required in order to confirm these conclusions. It must be taken into consideration that subjects with SDA most probably belonged to a dental high-risk group leading to SDA condition but probably also explaining some of the negative periodontal findings.

7. Dentist attitudes towards the SDA concept

7.1. Survey in the Netherlands: From a survey with 64% response rate, it was found that all but one of the respondents viewed the SDA concept as having a useful place in clinical practice (Table 2) (24). Although the respondents indicated regular or occasional use of SDA in <10% of patients, outcome of SDA management was generally satisfactory or at least sufficient. The findings supported the view that the SDA concept has a role in contemporary clinical practice, particularly in the care of elderly patients with limited possibilities for complicated restorative care, e.g. poor general health and financial restrictions.

7.2. Surveys in other European countries: The results of a survey among consultants in restorative dentistry in the UK (25) indicated that 95% of the participants were of the opinion that SDA had a place in contemporary clinical practice and the great majority (88%) reported having prescribed SDA therapy during the last 5 years. Among the respondents, 63% had used it 'on occasion' and 25% 'frequently'. Around four-fifths (82%) of the participants indicated that SDA therapy was satisfactory in terms of oral function, comfort and well-being. However, 37% of the participants had experienced a need to prosthetically extend SDAs after first applying the SDA concept.

Similar results were obtained in a survey of the attitudes of members of the European Prosthodontic Association (26). The response rate was low (42%) but among the respondents, 96% agreed that the SDA approach was acceptable in clinical practice.

7.3. Survey in Tanzania: Most of the responding dentists thought that SDA provided satisfactory or acceptable chewing function (71%), dental appearance (79%), and oral comfort (48%) (27). Most dentists (89%) indicated that the SDA concept had a useful place in clinical practice. However, only 3% of dentists indicated regular use and 68% had never applied the SDA concept; furthermore, 89% of the dentists responded that they usually inserted free-end acrylic partial dentures in subjects with SDA.

These surveys of dentist attitudes in several countries indicated that a great majority of the responding dentists accepted the SDA concept but that it was not so widely practised. Especially in Tanzania, there was a striking discrepancy between the theoretical and clinical/practical acceptance of the SDA concept.

Follow-up studies In order to evaluate if the results of the reported cross-sectional studies were stable over time, the Dutch group conducted follow-up studies with the same populations as described previously (Table 3).

1. 6-year follow-up study. Minor changes occurred with respect to occlusal contact, overbite, interdental spacing, and alveolar bone support in both the SDA group and SDA + RPD group during the 6-year evaluation period (32, 33) (Table 3). The results indicated that changes with respect to occlusal stability in SDA could not be prevented by the insertion of a free-end RPD. However, SDA provided durable occlusal stability. The changes seemed to take place for a new occlusal equilibrium rather than collapse of the bite. From this study, it could not be substantiated that SDA was a risk factor for developing TMD. The subjects with SDA, wearing a free-end RPD in the lower jaw, did not perceive better oral comfort than those without an RPD. Improvement of oral function by inserting a free-end RPD in the SDA was just marginal and often questionable as several subjects stopped wearing the RPD.

2. 9-year follow-up study. Not even in the long term did SDA itself result in occlusal collapse (34) (Table 3). Within 5 years after the treatment that had led to SDA, minor changes were seen, but the occlusal relationship remained stable over time. The occlusal changes appeared therefore to be self-limiting and adaptive in character, leading to a new equilibrium. It was concluded that precautions to prevent occlusal collapse by extending SDA by prosthetic devices as a routine action should be discouraged.

SDA-related concept Based on the results of the above cross-sectional studies, the Dutch group published many opinion papers suggesting the usefulness of the SDA concept and dental treatment (6, 35–46) (Table 4).

Several papers dealt with the concept of problem-oriented treatment planning. Traditional treatment planning in restorative dentistry is based on the

Table 3. Clinical follow-up studies related to SDA conducted by the Dutch group

Ref. (year)*	Description of study	Subjects, *n* (age)	Methods	Results
32 (1994)	Occlusal stability in SDA	SDA group: 55 SDA group + RPD: 19 CDA group: 52 (follow-up rate: 74%)	Examination of occlusal stability at start, after 3 and 6 years	(i) SDA provided durable occlusal stability (ii) Changes in occlusal stability could not be prevented by free-end RPD (iii) The combination of existing periodontal involvement and increased occlusal loading, such as in a reduced dentition, appeared to be a potential risk factor for further loss of teeth
33 (1994)	Craniomandibular dysfunction and oral comfort of SDA	SDA group: 55 SDA group + RPD: 19 CDA group: 52 (follow-up rate: 74%)	Examination of TMD and oral comfort at start and after 3 and 6 years	SDA was not a risk factor for TMD, and SDA provided sufficient oral comfort for a long-term period
34 (2001)	Occlusal stability in SDA	SDA group: 42 CDA group: 41 (follow-up rate: 57%)	Examination of occlusal stability at 3-year intervals, from baseline up to 9 years	SDA could provide long-term occlusal stability. Occlusal changes were self-limiting, indicating a new occlusal equilibrium

*Ref. (year) = reference number (year of publication).

Table 4. Opinion papers related to SDA published by the Dutch group

Ref. (year)*	Description of paper	Results
35 (1984)	Discussion about minimum number of teeth	The minimum number of teeth varies individually and depends on local and systemic factors
36 (1985)	Discussion about SDA in older people	The concept of SDA offers some important advantages and may be considered one of the standard strategies in treating older people
37 (1987)	Discussion about overtreatment with removable partial dentures in SDA	Overtreatment with RPD is caused by traditional mechanically and morphologically oriented occlusal concept. In occlusal therapy the traditional morphologically based approaches should be replaced by problem-solving strategies
38 (1988)	Concept of problem-oriented treatment	Important advantages of problem-oriented treatment are the objectivity of treatment planning and the elimination of overtreatment
39 (1989)	Discussion about SDA in certain high-risk groups	Restorative care should aim at preserving the strategic parts of the dental arch, which are the anterior and premolar regions
41 (1990)	Relation between SDA and mastication	From a review of pertinent literature, it was concluded that impairment of masticatory ability is manifest when <10 occluding pairs of teeth are present. SDA are not associated with shifts in food selection adversely affecting general health
40 (1990)	Discussion about acceptable reduction of the dental arch for the ageing patient	As oral functional needs change with time, treatment concepts should be dynamic by nature and primarily functionally based
42 (1993)	Discussion about needs for tooth replacement	Prosthetic dentistry should focus on criteria which really meet the demands of a healthy and physiological occlusion
43 (1994)	Discussion about limited treatment goals – SDA (1994)	The patient's subjective oral functional needs and well-being should be the starting-point for restorative treatment
46 (1995)	The role of the SDA concept in the management of reduced dentitions	It was suggested that with an increasing number of patients retaining more of their teeth for longer in life, SDA will be of increasing importance as a treatment strategy in the management of reduced dentitions in middle-aged and elderly adults
44 (1996)	Tooth loss and prosthetic appliances	Tooth loss and its sequelae have been overdramatized. Treatment goals can be limited and still satisfy patients' demands by using a problem-solving approach and the SDA concept
45 (1999)	SDA concept and its complications for oral health care	SDA can meet oral functional demands for a long-term period. Emphasis should be on preserving the functionally strategic parts of the dentition, and avoiding overtreatment with the associated costs and questionable benefits

*Ref. (year) = reference number (year of publication).

application of morphologic concepts. This means that in a broken-down dentition as many teeth as technically possible should be saved or replaced. A complete dentition, or at least 28 teeth, was considered necessary to satisfy oral functional needs. This morphological approach, sometimes called 'the 28-tooth syndrome', is being maintained in many healthcare systems, which use a fee-for-service system. Such an approach may lead to over-treatment in many cases. Recent research results tend to question the necessity for complete dental arches. Treatment planning should be problem-oriented and based primarily on the functional requirements of the subject. Treatment should only be implemented in cases where the existing condition has led to relevant problems (35, 38, 42, 44, 45) (Table 4).

An important issue discussed by the Dutch group was the minimum number of teeth needed. Dental treatment, especially restorative treatment, has many negative side-effects on the related tissues, the so-called biologic price. Many studies have shown the high failure rate of traditional dental service ('dental service is a never-ending process'; 35, 37, 43).

Käyser (44) estimated the minimum number of teeth needed to satisfy functional demands of modern man: biting: 12 front teeth + 4 premolars; mastication: 8 premolars + 4 molars; speech: 12 front teeth; aesthetics, 12 front teeth + 4 premolars in the maxilla; mandibular stability: 12 front teeth + 8 premolars + (4 molars in some cases). Therefore, the anterior and premolar regions should always get the best-quality care, as they are indispensable throughout life. The molars should get the same priority as long as there are no limiting factors. The limiting factors may emerge in high-risk groups, resulting in a situation in which adequate care for all the teeth is financially not possible. When priorities have to be set, the available and affordable dental care should focus on the anterior and premolar regions in order to maintain sub-optimal, but still satisfactory, functional level (10 occluding pairs) (36, 39, 40, 44–46) (Table 4). The adaptive capacity in SDA should be considered when assessing the need of free-end partial dentures (6).

Although the opinion papers in general emphasize the usefulness when discussing the role of the SDA concept, some contraindications are also presented, such as severe angle class II relationship, anterior open bite, marked reduction in alveolar bone support, extensive tooth wear, and pre-existing TMD (45, 46) (Table 4).

SDA-related papers by other authors

Epidemiology A few epidemiological studies have focused on SDA. In an analysis of the 1988 dental health survey in the UK on dentate adults, aged 15 to 75+ years, 54% had four good quadrants (all premolars and anterior teeth). The prevalence varied much with age, from 90% at 16–24 years to 2% at 65–74 years (47). In a random sample of 1211 dentate adults aged ≥60 years the presence of eating problems was related to a complex series of factors such as the number and distribution of teeth and dentures and some variables describing some symptoms and disease. Many of the principles of SDA were consistent with good function and satisfaction (48). Among older Canadian dentate adults aged ≥65 years, 6–8% were considered to have a functional dentition defined as 'good' upper and lower arches (containing all premolars and anterior teeth). In the mandible, the prevalence of a good arch was higher than in the maxilla (20–30% vs. 9–13%; 49). Those with a functional dentition according to the SDA concept did not need prosthodontic care but there was an urgent need in those with no 'good' arches. The conclusion of an early epidemiological study, albeit not using the SDA definition, was that 20 well-distributed teeth seemed to be sufficient to maintain a satisfactory chewing ability (50). Later on, similar studies have corroborated that 20 teeth, from premolar to premolar, are sufficient in relation to appearance and function (51).

Even if there is minor variation between the results of the Dutch group and those from other countries, the pattern of tooth loss appear to be similar resulting in many subjects with SDA according to the population studies available. No studies have presented results that significantly deviate from those of the Dutch group. It is obvious, however, that subjects with extreme SDA often exhibit functional oral problems.

Treatment of patients with SDA The traditional treatment of SDA has been a bilateral free-end RPD, often with poor long-term results (52). Clinical trials comparing such RPDs with cantilevered FPDs restoring up to the second premolar at the most have shown that the FPDs were as effective as the RPDs in terms of patient comfort and acceptance, thus supporting the SDA concept (53, 54). In these trials, patients with RPDs exhibited much more caries lesions than those with FPDs providing a further argument for not using an RPD in SDA

comprising anterior teeth and premolars. An ambitious ongoing randomized clinical trial comparing molar replacement with RPDs and restorations up to the second premolars did not find any differences between the two therapy concepts during a short-term pilot phase (55).

A recent review found neither evidence-based indications nor contraindications for prescribing RPDs. It was concluded that considering the risk of low patient acceptance and the increased risk of caries with RPDs, among other things, the application of the SDA concept tends to preclude the indication for RPDs (11).

Reviews related to SDA Studies related to the SDA concept have been reviewed in some recent articles although none of them has covered all related papers (9, 10, 51, 56–58). In general, they seem to have accepted the results of the Dutch group and the SDA concept. However, the great variation in patients' needs and demands are often emphasised and a 'patient-specific optimal dentition' should be considered including the SDA concept (57).

Discussion

The studies presented by the Käyser/Nijmegen group have shown that many of the opinions related to the need of a complete complement of teeth for a healthy masticatory system are not scientifically supported. There were in general no clinically significant differences between subjects with SDA of three to five occlusal units and complete dental arches regarding variables such as masticatory ability, signs and symptoms of TMDs, migration of remaining teeth, periodontal support and oral comfort. These findings from cross-sectional studies were also corroborated longitudinally. To our knowledge, no systematic clinical studies from other centres have refuted the main results of the Dutch group. The introduction of and research concerning the SDA may therefore be considered a significant development to have influenced prosthodontic thinking in the last few decades. It deserves serious consideration in all treatment planning for partially edentulous patients.

The WHO guidelines published in 1992 (8) provided a strong support by suggesting that the SDA concept was a possible clinical alternative in certain conditions. An unintentional application of the SDA concept but providing further support was the Brånemark system for osseointegrated implant treatment of edentulous patients (59). Originally, the placement of implants was restricted to the anterior parts of the jaws, and even using cantilevered fixed prostheses, the posterior parts of the jaws were left without dental support. This treatment has been extremely successful with excellent long-term results regarding patient-assessed oral comfort and masticatory function (60, 61). Recently, experimental findings (62) provided no evidence that SDA causes overloading of joints and teeth, a previously common belief that still is a subject of debate (63).

However, the SDA concept has also been criticized (11–15). Based on the results of a recent study assessing how patients value the potential outcomes of treatments for SDA, the authors concluded that the appropriateness of SDA as an oral health goal can be questioned (64). As the results were based on theoretical assumptions and not on clinical reality, these results may as well be called in question.

It has also been stated that the studies of the Dutch group have mainly been based on the situation in the Netherlands, the samples were too small and there was no randomization in some of the clinical studies. The Dutch group has acknowledged the first comment and conducted studies in Tanzania. The results were similar but some deviations suggest that more research would be desirable also in other countries.

In Japan, there seems to be a remaining scepticism towards SDA. The Japanese Prosthodontic Society has twice arranged symposia on the SDA concept revealing critical opinions among many of the participants (65, 66). More research seems to be indicated to solve remaining controversies.

The SDA approach offers an alternative of less treatment that is also less complicated, less time-consuming and less expensive (10). It would therefore fit well in a global perspective with widespread lack of dental and economic resources as indicated by the WHO (8). The great majority of the world's partially edentulous subjects must dispense with most of current prosthodontic modalities. To improve this situation, efforts to develop cheaper but still acceptable treatment options have been proposed, e.g. the so-called 'appropriatech' (67). The SDA concept fits in well also in such an approach and deserves to be included in the modern arsenal of prosthodontic treatments.

There was an obvious discrepancy between the theoretical and practical acceptance of SDA among dentists in many countries (24–27). The concept was

widely accepted but not widely practised, especially not in Tanzania. This demonstrates the difficulty in changing concepts that has once been learnt, which may obstruct a more general acceptance of the SDA approach. It indicates that the SDA concept needs to be presented and discussed already in the undergraduate training and be subjected to more discussion both among prosthodontists and general practitioners. The rapid global changes in dental health and economy will require a continuing discussion to adapt the SDA concept to new situations. Besides the difficulty to abandon opinions learnt in undergraduate and early postgraduate training, there are other obstacles. An important one is probably the economical incentive for the dentist to treat SDA with prosthodontic options, be they fixed, removable or implant-supported restorations. For example, in the Japanese insurance system, reimbursement for treatment is a basic principle. If a missing tooth is untreated, dentists do not gain economically (68). The situation has been similar in other countries, for example in Germany, where, attributable to the health insurance system, few people with loss of many teeth including SDA remain untreated (55, 69).

Many patients wish to have lost teeth replaced, and some of them can also afford a prosthetic treatment. However, the great variation among individuals regarding functional and aesthetic needs and demands as well as adaptive capacity necessitates a careful assessment in treatment planning including patient preferences. The SDA alternative should be presented in a neutral way to the patients in this process, together with other options.

With the great variation in dental health between as well as within countries it can be recommended that more research focusing on SDA be conducted both in industrialized and developing parts of the world using accepted designs for epidemiological and clinical studies.

Conclusions

The studies performed by the Käyser/Nijmegen group have demonstrated that shortened dental arches comprising anterior and premolar teeth in general fulfil the requirements of a functional dentition. The SDA concept may be considered a significant development to have influenced prosthodontic thinking in the last few decades. The SDA concept is accepted by a great majority of dentists but is not widely practised. Patients' needs and demands vary much and should be individually assessed but the SDA concept deserves to be included in the treatment planning process. With ongoing global changes, e.g. in dental health and economy, the SDA concept requires continuing research and discussion.

References

1. Hirschfeld I. The individual missing tooth: a factor in dental and periodontal disease. J Am Dent Assoc. 1937;24:67–82.
2. De Van MM. Physical, biological and psychological factors to be considered in the construction of dentures. J Am Dent Assoc. 1951;42:290–293.
3. Karlsen K. Factors that influence the provision of partial prosthetic appliances. J Dent. 1971;1:52–57.
4. Levin B. The 28-tooth syndrome – or should all teeth be replaced. Dent Survey. 1974;50:47.
5. Ramfjord SP. Periodontal aspects of restorative dentistry. J Oral Rehabil. 1974;1:107–126.
6. Käyser AF. Shortened dental arches and oral function. J Oral Rehabil. 1981;8:457–462.
7. Mohl ND, Zarb GA, Carlsson GE, Rugh JD, eds. A Textbook of Occlusion. Chicago, IL: Quintessence; 1988.
8. World Health Organization Expert Committee. Recent Advances in Oral Health. WHO Technical Report Series. 826:16–17. Geneva: WHO; 1992.
9. Armellini D, von Fraunhofer JA. The shortened dental arch: a review of the literature. J Prosthet Dent. 2004;92:531–535.
10. Omar R. Reappraising prosthodontic treatment goals for older, partially dentate people: Part II. Case for a sustainable dentition? SADJ. 2004;59:228–234.
11. Wöstmann B, Budtz-Jorgensen E, Jepson N, Mushimoto E, Palmqvist S, Sofou A, Őwall B. Indications for removable partial dentures: aliterature review. Int J Prosthodont. 2005;18:139–145.
12. Chiba A. Effects of molar tooth loss on central nervous system with a behavioral and histological study in mice. J Jpn Prosthodont Soc. 1999;43:299–311.
13. Kobayashi Y. The interface of occlusion as a reflection of conflicts within prosthodontics. Int J Prosthodont. 2005;18:302–304.
14. Luder HU. Factors affecting degeneration in human temporomandibular joints as assessed histologically. Eur J Oral Sci. 2002;110:106–113.
15. Tallents RH, Macher DJ, Kyrkanides S, Katzberg RW, Moss ME. Prevalence of missing posterior teeth and intraarticular temporomandibular disorders. J Prosthet Dent. 2002;87:45–50.
16. Battistuzzi P, Käyser A, Peer P. Tooth loss and remaining occlusion in a Dutch population. J Oral Rehabil. 1987;14:541–547.
17. Battistuzzi P, Käyser A, Kanters N. Partial edentulism, prosthetic treatment and oral function in a Dutch population. J Oral Rehabil. 1987;14:549–555.
18. Witter DJ, Van Elteren PH, Käyser AF. Migration of teeth in shortened dental arches. J Oral Rehabil. 1987;14:321–329.

19. Aukes JN, Käyser AF, Felling AJ. The subjective experience of mastication in subjects with shortened dental arches. J Oral Rehabil. 1988;15:321–324.
20. Witter DJ, Van Elteren P, Käyser AF. Signs and symptoms of mandibular dysfunction in shortened dental arches. J Oral Rehabil. 1988;15:413–420.
21. Witter DJ, Van Elteren P, Käyser AF, Van Rossum MJ. The effect of removable partial dentures on the oral function in shortened dental arches. J Oral Rehabil. 1989;16:27–33.
22. Witter DJ, Van Elteren P, Käyser AF, Van Rossum GM. Oral comfort in shortened dental arches. J Oral Rehabil. 1990;17:137–143.
23. Witter DJ, De Haan AF, Käyser AF, Van Rossum GM. Shortened dental arches and periodontal support. J Oral Rehabil. 1991;18:203–212.
24. Witter DJ, Allen PF, Wilson NH, Käyser AF. Dentists' attitudes to the shortened dental arch concept. J Oral Rehabil. 1997;24:143–147.
25. Allen PF, Witter DF, Wilson NH, Käyser AF. Shortened dental arch therapy: views of consultants in restorative dentistry in the United Kingdom. J Oral Rehabil. 1996;23:481–485.
26. Allen PF, Witter DJ, Wilson NH. A survey of the attitudes of members of the European Prosthodontic Association towards the shortened dental arch concept. Eur J Prosthodont Restor Dent. 1998;6:165–169.
27. Sarita PT, Witter DJ, Kreulen CM, Creugers NH. The shortened dental arch concept – attitudes of dentists in Tanzania. Community Dent Oral Epidemiol. 2003;31:111–115.
28. Sarita PT, Witter DJ, Kreulen CM, Matee MI, van't Hof MA, Creugers NH. Decayed/missing/filled teeth and shortened dental arches in Tanzanian adults. Int J Prosthodont. 2004;17:224–230.
29. Sarita PT, Kreulen CM, Witter DJ, Creugers NH. Signs and symptoms associated with TMD in adults with shortened dental arches. Int J Prosthodont. 2003;16:265–270.
30. Sarita PT, Kreulen CM, Witter DJ, van't Hof M, Creugers NH. A study on occlusal stability in shortened dental arches. Int J Prosthodont. 2003;16:375–380.
31. Sarita PT, Witter DJ, Kreulen CM, Van't Hof MA, Creugers NH. Chewing ability of subjects with shortened dental arches. Community Dent Oral Epidemiol. 2003;31:328–334.
32. Witter DJ, de Haan AF, Käyser AF, van Rossum GM. A 6-year follow-up study of oral function in shortened dental arches. Part: 1. Occlusal stability. J Oral Rehabil. 1994;21:113–125.
33. Witter DJ, De Haan AF, Käyser AF, Van Rossum GM. A 6-year follow-up study of oral function in shortened dental arches. Part 2. Craniomandibular dysfunction and oral comfort. J Oral Rehabil. 1994;21:353–366.
34. Witter DJ, Creugers NHJ, Kreulen CM et al. Occlusal stability in shortened dental arches. J Dent Res. 2001;80:432–436.
35. Käyser AF. Minimum number of teeth needed to satisfy functional and social demands. In: Frandsen A, ed. Public Health Aspects of Periodontal Disease. Chicago, IL: Quintessence; 1984:135–147.
36. Käyser AF, Witter DJ. Oral functional needs and its consequences for dentulous older people. Community Dental Health. 1985;2:285–291.
37. Käyser AF, Witter DJ, Spanauf AJ. Overtreatment with removable partial dentures in shortened dental arches. Aust Dent J. 1987;32:178–182.
38. Käyser AF, Battistuzzi PG, Snoek PA, Plasmans PJ, Spanauf AJ. The implementation of a problem-oriented treatment plan. Aust Dent J. 1988;33:18–22.
39. Käyser AF. The shortened dental arch: a therapeutic concept in reduced dentitions and certain high-risk groups. Int J Perio Rest Dent. 1989;9:427–449.
40. Käyser AF. How much reduction of the dental arch is functionally acceptable for the ageing patient? Int Dent J. 1990;40:183–188.
41. Witter DJ, Cramwinckel AB, van Rossum GM, Käyser AF. Shortened dental arches and masticatory ability. J Dent. 1990;18:185–189.
42. Kalk W, Käyser AF, Witter DJ. Needs for tooth replacement. Int Dent J. 1993;43:41–49.
43. Käyser AF. Limited treatment goals – shortened dental arches. Periodontology 2000. 1994;4:7–14.
44. Käyser AF. Teeth, tooth loss and prosthetic appliances. In: Öwall B, Käyser AF, Carlsson GE, eds. Proshodontics. Principles and Management Strategies. London: Mosby-Wolfe; 1996:35–48.
45. Witter DJ, van Palenstein Helderman WH, Creugers NH, Käyser AF. The shortened dental arch concept and its implications for oral health care. Community Dent Oral Epidemiol. 1999;27:249–258.
46. Allen PF, Witter DJ, Wilson NH. The role of shortened dental arch concept in the management of reduced dentitions. Br Dent J. 1995;179:355–357.
47. Gordon PH, Murray JJ, Todd JE. The shortened dental arch: supplementary analyses from the 1988 adult dental health survey. Community Dent Health. 1994;11:87–90.
48. Steele JG, Ayatollahi SM, Walla AW, Murray JJ. Clinical factors related to reported satisfaction with oral function amongst dentate older adults in England. Community Dent Oral Epidemiol. 1997;25:143–149.
49. Hawkins RJ. The shortened dental arch: prevalence and normative treatment needs in a sample of older Canadian adults. Spec Care Dentist. 1998;18:247–251.
50. Agerberg G, Carlsson GE. Chewing ability in relation to dental and general health. Acta Odontol Scand. 1981;39:147–153.
51. Elias AC, Sheiham A. The relationship between satisfaction with mouth and number and position of teeth. J Oral Rehabil. 1998;25:649–661.
52. Vermeulen AH, Keltjens HM, van't Hof MA, Kayser AF. Ten-year evaluation of removable partial dentures: survival rates based on retreatment, not wearing and replacement. J Prosthet Dent. 1996;76:267–272.
53. Budtz-Jorgensen E, Isidor F. A 5-year longitudinal study of cantilevered fixed partial dentures compared with removable partial dentures in a geriatric population. J Prosthet Dent. 1990;64:42–47.
54. Jepson N, Allen F, Moynihan P, Kelly P, Thomason M. Patient satisfaction following restoration of shortened mandibular dental arches in a randomized controlled trial. Int J Prosthodont. 2003;16:409–414.

55. Wolfart S, Heydecke G, Luthardt RG et al. Effects of prosthetic treatment for shortened dental arches on oral health-related quality of life, self-reports of pain and jaw disability: results from the pilot-phase of a randomized multicentre trial. J Oral Rehabil. 2005;32:815–822.
56. Walther W. Determinations oh a healthy aging dentition: maximum number of bilateral centric stops and optimum vertical dimension of occlusion. Int J Prosthodont. 2003;16(Suppl):77–79.
57. de Sa e Frias V, Toothaker R, Wright RF. Shortened dental arch: a review of current treatment concepts. J Prosthodont. 2004;13:104–110.
58. Omar R. The evidence for prosthodontic treatment planning for older, partially dentate patients. Med Princ Pract. 2003;12(Suppl. 1):33–42.
59. Brånemark PI, Hansson BO, Adell R, Breine U, Lindstrom J, Hallen O, Őhman A. Osteointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. Scand J Plast Reconstr Surg. 1977;16(Suppl.):1–132.
60. Karlsson S, Carlsson GE. Oral motor function and phonetics in patients with implant-supported prostheses. In: Naert I, van Steenberghe D, Worthington P, eds. Osseointegration in Oral Rehabilitation. An Introductory Textbook. London: Quintessence; 1993:123–132.
61. Ekelund J-A, Lindquist LW, Carlsson GE, Jemt T. Implant treatment in the edentulous mandible: a prospective study on Brånemark system implants over more than 20 years. Int J Prosthodont. 2003;16:602–608.
62. Hattori Y, Satoh C, Seki S, Watanabe Y, Ogino Y, Watanabe M. Occlusal and TMJ loads in subjects with experimentally shortened dental arches. J Dent Res. 2003;82:532–536.
63. Sanz M. Occlusion in a periodontal context. Int J Prosthodont. 2005;18:309–310.
64. Nassani MZ, Devlin H, McCord JF, Kay EJ. The shortened dental arch – an assessment of patients' dental health state utility values. Int Dent J. 2005;55:307–312.
65. Igarashi Y, Ono J, Komiyama Y, Yamashita S. Evaluation to the concept of shortened dental arch; indication and limitation for clinical application. J J Jpn Prosthodont Soc. 2003;47:41–42.
66. Igarashi Y, Arai Y, Hattori Y, Fueki K, Yamashita S. Evaluation to the concept of shortened dental arch 2; assessment by the multi-sectional scientific research. J Jpn Prosthodont Soc. 2003;47:38–40.
67. Owen P. Appropriatech: Prosthodontics for the many, not just for the few. Int J Prosthodont. 2004;17:261–262.
68. Kanno T, Hirooka H, Kimura K. Is it necessary to replace the molar regions for dentition maintenance? – A review of literature: Käyser's shortened dental arch concept (in Japanese with English summary). J Jpn Prosthodont Soc. 2004;48:441–456.
69. Mack F, Schwann C, Feine J, Mundt T, Bernhardt O, John U, Kocher T, Biffar K. The impact of tooth loss on general health related to quality of life among elderly Pomerians: results from the study of health in Pomerania (SHIP-O). Int J Prosthodont. 2005;18:414–419.

Correspondence: Taro Kanno, Division of Fixed Prosthodontics, Graduate School of Dentistry, Tohoku University, 4-1, Seiryo-machi, Aoba-ku, Sendai, Miyagi, 980-8575 Japan.
E-mail: tarou@mail.tains.tohoku.ac.jp