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What dentition assures oral function?

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Abstract

Objective: To evaluate the relationship between dentition and oral function.

Material and methods: A search of the English literature was undertaken using PubMed and appropriate keywords. Citations were identified and hand sorted to confirm their validity against our inclusion criteria. Four specific areas of oral function were addressed; (I) masticatory function, (II) aesthetics, satisfaction and psychosocial ability, (III) occlusal support and stability and (IV) other functionality including tactile perception, phonetics and taste.

Results: From an initial pool of 1460 citations, 83 articles met the inclusion criteria. These were summarized and relevant data extracted for incorporation into the review. Masticatory efficiency (assessed as comminution efficiency) and masticatory ability (self-reported) are both linked to the number of teeth. A minimum of 20 teeth with nine to 10 pairs of contacting units (including anterior teeth) is associated with adequate efficiency and ability. Tooth numbers below that level yield impaired masticatory efficiency and are likely to result in reduction in reported masticatory ability. Aesthetics and satisfaction are markedly impaired with loss of anterior teeth. Satisfaction is most likely to be achieved in people who also retain a premolar dentition. Further, there is little increase in satisfaction seen in subjects who retained molar teeth. However, there are marked variations in subjective measures of aesthetics and psychosocial comfort between age groups, social classes, cultures, regions and countries. For most people, occlusal support and stability are obtained with three to four functional posterior units with a symmetrical pattern of tooth loss or five to six units with an asymmetrical pattern. There was no relationship between occlusal factors and symptoms of temporomandibular dysfunction. Phonetics may be maintained even with large anterior restorations. Patients generally attribute a low significance to phonetics, tactile perception and taste compared with mastication and appearance.

Conclusions: The World Health Organization goal for the year 2000, namely to maintain a natural dentition of not less than 20 teeth throughout life, is substantiated by the current literature review as this proposed dentition will assure an acceptable level of oral function.

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How many teeth are necessary for adequate function or what dentition assures oral function? Such questions are not easily answered and will be answered very differently depending on who is asked, when they are asked, and which oral functions

they are referring to (Käyser 1996; Carlsson & Tangerud 2000).

The number of teeth has been chosen as a key indicator of oral health status (WHO 1992; Petersen et al. 2004). The World Health Organization (WHO) stated in 1992 that the retention, throughout life, of a functional, aesthetic, natural dentition of not <20 teeth and not requiring recourse to prostheses should be the treatment goal for oral health (WHO 1992). Therefore, a number of epidemiological studies have used 20 teeth as an operative expression for a functional natural dentition (Sheiham et al. 1999; Shimazaki et al. 2001; Petersen et al. 2004).

After an extensive review of the literature, Elias & Sheiham (1998) concluded that a complete dentition is not necessary to satisfy oral functional needs. This is in accordance with a number of publications, which suggest that middle aged and older people have sufficient oral function with 20 natural teeth, and question the need to replace missing molars (Witter et al. 1999; Armellini & von Fraunhofer 2004). The demand for tooth replacement has, however, been assessed under normative and theoretical condition rather than among patients who have experienced tooth loss. As an example, adult patients from Norway perceived that the need for replacement of extracted teeth was high and that the tooth type, the number of extracted teeth and not believing in keeping teeth for life increased the likelihood of these patients wanting their extracted teeth replaced (Trovik et al. 2002a). On the other hand, it has been demonstrated that people can function without any teeth (Wilding & Owen 1987). Their functional level is, however, low and may lead to malnutrition (Mojon et al. 1999; Sheiham et al. 2001b) and even compromised physical or psychological health (Hildebrandt 1995; Walls et al. 2000). Is this acceptable today, when treatment alternatives are possible? This is a question about the acceptable level of oral functions in different countries and societies. It is a question about the individual oral health-related quality of life (OHRQoL).

One of the great aims of modern prosthetic treatment is to assure oral function for the individual patient. However, the needs and demands are very different among patients and between patient and dentist (Smith & Sheiham 1980; Vigild 1989; Burgersdijk et al. 1991; Slagter et al. 1992; Walter et al. 2001; Trovik et al. 2002b; Narby et al. 2005). In this context it is important to distinguish between subjective, prosthetic treatment needs and objective, normative needs determined by dental assessment of oral function. Oral function has mainly been restricted to masticatory and occlusal components in the past (Armellini & von Frauenhofer 2004). Today, when decision making is based on the individual patient, the oral functionality needs to be defined in more detail, as:

I. Masticatory functions
   i. Masticatory efficiency (performance, capacity)
   ii. Masticatory ability (an individual's perception of his/her ability to chew)

II. Aesthetics, satisfaction and psychosocialability
   i. Appearance
   ii. Psychological ability and comfort
   iii. Social ability and comfort

III. Occlusal support and dental arch stability

IV. Other oral functions
   i. Tactile perception
   ii. Pronouncing during speech (phonetics)
   iii. Taste

These oral functions are overlapping, and for a patient it may be difficult to categorize an impaired function. During the last 10 years, however, great efforts have been made to categorize subjective aspects of oral function comprising social and individual factors, patient's desires, individual oral well-being in different specific OHRQoL measures, for example oral health impact profile (OHIP-49) (Slade & Spencer 1994), OHIP-14 (Slade 1997), dental impact on daily living (DIDL) (Leao & Sheiham 1995), oral impact on daily performance (OIDP) (Adulyanon & Sheiham 1997); geriatric oral health assessment index (GOHAI) (Atchison & Dolan 1990) and more generic QoL measurements as the 36-item short form health survey (SF-36) (Ware & Sherbourne 1992), sickness impact profile (SIP) (Locker 1988), schedule for the evaluation of individual quality of life-direct weighting (SEIOoL-DW) (Hickey et al. 1996), EuroQoL (Brennan & Spencer 2005).

Material and methods

Search strategy

The National Library of Medicine and the National Institutes of Health publications database (Medline, PubMed) was searched for studies to be considered for inclusion in this review. The search was augmented by a manual search of relevant journals and textbooks. The search was completed on October 31, 2006. Manual search of bibliographies of full-text articles and related reviews were also performed. A broad search strategy was used to identify studies helping to answer the question: What dentition assures oral functions? The following areas related to the question were selected: tooth loss and oral function; tooth loss and OHRQoL; tooth loss and aesthetics; tooth loss, dentition and mastication; tooth loss and speech; remaining teeth and oral function; occlusal units and oral function; shortened dental arch (SDA); implants and shortened dental arch; implants and satisfaction or OHRQoL; Oral Health-Related Quality of Life and oral function; oral function, dentition and patient satisfaction; dentition and masticatory ability; dentition and masticatory efficiency; dentition and masticatory performance; dentition and chewing performance; dentition and social well-being; dentition and psychological factors; dentition and oral tactility.

Type of studies/selection of studies

The literature was searched according to the strategy described. The methodological quality was assessed by evaluating the levels of evidence proposed by the Oxford Centre for Evidence-based Medicine, ranging from the highest Level (1a: systematic reviews of randomized controlled trials) to the lowest Level (5: Expert opinion without explicit critical appraisal, or based on physiology, bench research or 'first principles'). The following exclusion criteria were used:

Excluded articles:

- Case reports.
- Expert opinion articles.

- Methodological studies.
- Animal studies.
- Technical procedure descriptions.

Exclusion criteria (topics):

- Complete dentures (without implant therapy).
- Overdentures (teeth and implant supported).
- Children.
- Orthodontics.
- Periodontics.
- Surgical, implant techniques.
- Implant-supported single tooth replacements.
- Studies published before 1975.

Longitudinal, prospective and retrospective cohort studies with more than 15 individuals, cross-sectional cohort studies/surveys with more than 72 individuals, case–control studies with more than 20 individuals and systematic reviews were included for evaluation. The studies were published in peer-reviewed dental journals after 1974. It was decided to include reports involving implant-supported fixed partial and complete dentures, but not implant supported overdentures and implant supported single crowns.

Data extraction strategy

The articles were categorized in four oral functional groups: (I) masticatory functions, (II) aesthetics, satisfaction and psychosocial ability, (III) occlusal support and dental arch stability and (IV) other oral functions. Masticatory functions were further divided into masticatory efficiency and masticatory ability.

For each of the selected papers the main conclusion within the topic of the present paper was extracted and related to the study design, the aim of the study, the number of patients, patient age, time and the methods used (Tables 1–4).

Results and discussion

The search provided 1460 titles/abstracts. (I) masticatory functions yielded 595 titles/abstracts, (II) aesthetics, satisfaction and psychosocial ability yielded 717 titles/abstracts, (III) occlusal support and dental arch stability yielded 114 titles/abstracts, and (IV) other oral functions 34 titles/abstracts. A total of 136 articles were selected for full-text analysis, and out of these 83 were included in the tables (Tables 1–4). These articles were used along with nine selected reviews to analyse the question: *What dentition assures oral function?* There was only a limited amount of evidence for other oral functions which was focussed mainly on phonetic function.

Masticatory functions

In a number of review articles, it has been demonstrated that there may be discrepancies between the objective masticatory function obtained in laboratory tests and the subjective perceptions of masticatory function obtained by interviews or questionnaires (Elias & Sheiham 1998; Witter et al. 1999; Armellini & von Frauenhofer 2004). Theoretically, as more teeth are lost, function should be increasingly impaired. However, the adaptation to tooth loss varies greatly among individuals, and many individuals do not feel any need to replace the lost teeth (Käyser 1996; Carlsson & Tangerud 2000).

Masticatory efficiency (performance)

A total of 33 articles were included (Table 1a and b). One study was a randomized, prospective study (Kapur et al. 1997), eight studies were prospective and one study retrospective, whereas 18 studies were cross-sectional and six case–control studies.

Objective masticatory function is evaluated with a variety of techniques, the ability of subjects to comminute test foods, chewing strokes/cycles, chewing time, swallowing threshold, mixing ability, bite force and nutritional status (Table 1a and b).

A number of studies have demonstrated that an important determinant for masticatory efficiency is the number of functional tooth units (Helkimo et al. 1978, 1978; Käyser 1981; Hatch et al. 2001; van der Bilt & Fontijn-Tekamp 2004; Tumrasvin et al. 2006). Helkimo et al. assessed the ability of 139 subjects to grind a given quantity of sample food within a specific time envelope. The number of occluding pairs of teeth was closely correlated with chewing efficiency, and individuals with fewer than 20 teeth had poorer chewing than those with more than 20 teeth (Helkimo et al. 1978).

Although a comprehensive literature review by Wöstmann et al. (2005) failed to provide highly evidence-based indications for removable partial denture (RPD) treatment for patients with SDA situations, some studies have indicated that the masticatory efficiency improves after treatment with RPD (Gunne 1985; Kapur 1991). Gunne measured masticatory efficiency in 19 patients before and after treatment with RPD He used a comminution method with formalin-hardened gelatine and almonds as test foods. Masticatory efficiency increased significantly after RPD treatment (Gunne 1985). In a randomized, prospective study, Kapur et al., compared two RPD designs. The study included 105 patients and a sieving method was used to demonstrate that, for both RPD's designs, the masticatory performance was significantly increased after treatment (Kapur et al. 1997). This is partly in agreement with a study by Liedberg et al. (1995), where the number of chewing strokes to the first swallowing of an almond was improved with an RPD compared with the same patients without an RPD. However, in a more recent study by Liedberg et al. (2005), wearing of RPD's by patients was associated with a lower level of masticatory efficiency compared with those with natural teeth only. Expressed as the corresponding number of natural teeth, the function of RPD was below the level of 20, when tested with chewing, shaping and mixing. In relation to hard food intake, the functional level was close to that of 20 natural teeth. This is in accordance with another study demonstrating that the masticatory efficiency after RPD treatment was not the same as that with lost teeth (Wayler et al. 1984).

The principle of the SDA has been extensively used in the treatment of edentulous patients with cross arch fixed complete dentures supported by implants [ISFCD(ca)], (Haraldson et al. 1979; Lindquist & Carlsson 1985; Jemt & Carlsson 1986; Haraldson & Zarb 1988; Lundqvist & Haraldson 1992). Thus, in a 10-year longitudinal study of the masticatory function in edentulous patients treated with mandibular ISFCD(ca) masticatory function was assessed before and after implant treatment. An improvement in performance was seen in association with the change from complete dentures to ISFCD(ca) (Carlsson & Lindquist 1994). Haraldson & Carlsson (1979) demonstrated, in a case–control study involving

***Table 1a*. Studies with dentition and masticatory efficiency (ME)/-performance**

Study	Year	Design	Patients (*n*)	Age (years), (range/mean)	Time (months)	Methods	Main conclusion
Helkimo et al.	1977	Cross-sectional	125	15–65	–	Bite force	Bite force decreases with loss of teeth
Helkimo et al.	1978	Cross-sectional	139	14–65	–	CT, etc.	Number of OU correlated with ME
Haraldson & Carlsson	1979	Case–control	24	43–66	–	CEI, etc.	ME of ISFPD(ca) approached that of similar dentate persons
Haraldson et al.	1979	Case–control	23	42–59	–	Bite force	Bite force of ISFPD(ca) approached that of subjects with ND
Käyser	1981	Cross-sectional	118	19–71	–	CT, etc.	Significant correlation between masticatory efficiency and occlusal units
Wayler et al.	1984	Cross-sectional	1133	25–75	–	STPT	Missing dentition, even replaced with RPD, reduces ME
Gunne	1985	Prospective	19	34–75	0–4	CT, etc.	ME increased significantly after treatment with RPD
Lindquist & Carlsson	1985	Prospective	27	< 65	0–36	CT, CEI, bite force	ME increased with ISFPD(ca)
Jemt & Carlsson	1986	Prospective	16	36–65	0–2	CT, CEI, bite force	ME improved after ISFPD(ca) treatment
Haraldson & Zarb	1988	Retrospective	28	48–73	0–120	Bite force, etc.	Bite forced improved after ISFPD (ca) treatment
Lundqvist & Haraldson	1992	Prospective	17	32–66	0–60	CT, etc.	A progressive increase of chewing efficiency and chewing force
Carlsson & Lindquist	1994	Prospective	23	< 65	0–120	CEI, bite force etc.	Improved ME after ISFPD(ca) and a slight improvement over time
van der Bilt et al.	1994	Case–control	41	–	–	CT, etc.	Subject with SDA improved ME after RPD or FPD treatment
Liedberg	1995	Case–control	22	53	–	CT, etc.	Fewer chewing strokes + RPD than – RPD
Kapur et al.	1997	R, prospective	105	51	0–60	CT, etc.	ME increased significantly after treatment with both RPD designs
Miyaura et al.	1999	Case–control	60	46	–	Bite force, etc.	Number of teeth is most important to biting ability
Miura et al.	2001	Cross-sectional	373	65–74	–	Bite force	Bite force more related to gender and health than number of teeth
Hatch et al.	2001	Cross-sectional	613	37–80	–	CT, bite force	Number of functional tooth units and bite force are key determinants for ME
Gibbs et al.	2002	Case–control	44	46	–	CF	Loss of posterior teeth resulted in a loss of clenching force
Van der Bilt & Fontijn-Tekamp	2004	Cross-sectional	176	19–70	–	CT, etc.	Significant influence of number of occlusal units on the ME
Liedberg et al.	2005	Cross-sectional	483	68	–	CT, 'MAI'	RPD's do not improve ME
Tumrasvin et al.	2006	Cross-sectional	72	63	–	CT, MAI, bite force	Gender, bite force and number of functional tooth units influences ME

CD, complete denture; OU, occlusal units; ND, natural dentition; ISFPD, implant supported fixed partial denture; ca, cross arch; SDA, shortened dental arch; CT, comminuting test; CEI, chewing efficiency index; STPT, swallowing threshold performance test; RPD, removable partial denture; FPD, fixed partial denture; CF, clenching force; MAI, mixing ability index; R, randomized study.

***Table 1b*. Studies with dentition and nutrition**

Study	Year	Design	Patients (*n*)	Age (years), (range /mean)	Time (months)	Methods	Main conclusion
Österberg & Steen	1982	Cross-sectional	368	70	–	OE; DI	Dental status and tooth contacts related to the intake of certain food items
Albiin et al.	1982	Cross-sectional	75	>75	–	NS, OE	Lack of teeth a risk factor for undernutrition
Elmståhl et al.	1988	Prospective	75	84	0–6	DR, I	Impaired masticatory function influenced food selection
Hildebrandt et al.	1995	Cross-sectional	430	71	–	I, OE	Number of teeth has a positive effect on overall health
Fontijn-Tekamp et al.	1996	Cross-sectional	1424	65–70	–	DR, OE, Q	Dentition, nutrition and MA varied greatly among towns of Europe
Garret et al.	1997	Prospective	436	51.5	0–60	DR	Prosthodontic treatment (RDP; FDP) did not alter food intake
Krall et al.	1998	Cross-sectional	638	21–75	–	OE, Q	Prosthodontic treatment of missing teeth could improve diets of older adults
Mojon et al.	1999	Cross-sectional	324	85	–	NS, OE	A compromised oral functional status seems to be associated with nutritional deficiency
Moynihan et al.	2000	Prospective	40	65	0–12	DR, OE	Prosthetic rehabilitation of SDA dentition did not improve nutrient intake
Sheiham et al.	2001	Cross-sectional	705	>65	–	DR, OE	Persons with >20 teeth consumed more nutrients than people with less or no teeth
Shinkai et al.	2001	Cross-sectional	731	37–81	–	I, OE	Masticatory function is not a predictor of overall diet quality
Liedberg et al.	2005	Cross-sectional	483	68	–	DR, OE	Food intake not affected by RPD's

OE, oral examination; DI, dietary interview; DR, dietary record; Q, questionnaire; NS, nutritional status; I, interview; >, age over; RPD, removable partial denture; SDA, shortened dental arch; FPD, fixed partial denture.

***Table 2.* Studies with dentition and (MA)**

Study	Year	Design	Patients (n)	Age (years), (range /means)	Time (months)	Methods	Main conclusion
Agerberg & Carlsson	1981	Cross-sectional	1106	15–74	–	Q	No subjects with >20 natural teeth had a poor chewing ability
Imperiali et al.	1984	Cross-sectional	300	20–60 +	–	Q	No direct relation between MA and number of teeth
Gunne	1985	Prospective	19	34–75	0–4	Interview	MA increased significantly after treatment with RPD
Lindquist & Carlsson	1985	Prospective	27	< 65	0–36	Q, VAS	MA increased with ISFPD(ca)
Jemt & Carlsson	1986	Prospective	16	36–65	0–2	Q, OE	MA improved after ISFPD(ca) treatment
Battistuzzi et al.	1987	Cross-sectional	750	25–54	–	Q	Weak correlation between MA and number of teeth
Aukes et al.	1988	Case–control	97	21–50	–	Interview	Minor differences between subjects with 28 teeth and SDA
Witter et al.	1989	Case–control	99	<25–>50	–	Q, OE	Oral function in SDA's not improved by insertion of a RPD
Witter et al.	1990	Retrospective	171	<25–>50	0–84	Q, OE	10% of persons with SDA raised complaints about masticatory ability
Kapur et al.	1991	Cross-sectional	116	–	–	Q	Patient satisfaction better for ISFPD than RPD
Lundqvist & Haraldson	1992	Prospective	17	32–66	0–60	Q, OE	Constant improvement of jaw functions
van Waas et al.	1993	Cross-sectional	320	55–75	–	Q, OE	Subject with RPD are in general less satisfied than subjects without RPD
Leake et al.	1994	Cross-sectional	338	>50	–	Q	Problems starts with 0–2 posterior functional units
van der Bilt et al.	1994	Case–control	41	–	–	Q, OE	For subject with SDA, RPD's and FPD's increased the MA
Carlsson & Lindquist	1994	Prospective	23	< 65	0–120	Q, VAS, OE	Increased MA for ISFPD(ca) and then a slightly improve during time
Liedberg	1995	Case–control	22	63	–	Interview	Most RPD-wearers were satisfied with masticatory ability
Österberg et al.	1996	Cross-sectional	10321	16–>85	–	Q	Some disability and psychosocial factors associated with MA
Yi et al.	1996	Retrospective	43	–	120	Q, OE	Oral function not significantly influenced by number of FPD-units
De Bruyn et al.	1997	Prospective	75	40–70	0–36	Q, OE	Chewing ability increased after ISFPD(ca) and ISFPD
Sarita et al.	2003c	Cross-sectional	850	>20	–	Interview	SDA's comprising 0–2 occluding premolars caused severe impairment in MA

MA, masticatory ability; ISFPD, implant-supported fixed partial denture; (ca), cross arch; RPD, removable partial denture; SDA, shortened dental arch; Q, questionnaire; OE, oral examination; ND, natural dentition; VAS, visual analogue scale.

24 subjects, that provision of ISFCD(ca) allowed subjects to approach the masticatory efficiency of individuals with a similar natural dentition. They demonstrated that a median of nine pairs of occluding teeth (including anteriors) seemed to provide sufficient masticatory efficiency for ISFCD(ca).

According to reviews by Walls et al. (2000), Walls & Steele (2004), the theoretical link between masticatory efficiency and foods choice has been established for elderly people. This has been supported in both prospective (Elmståhl et al. 1988) as well as in cross-sectional studies (Österberg & Steen 1982; Sheiham et al. 2001a, 2001b). For example, the British National Diet and Nutrition Survey of adults aged 65 years and over demonstrated that people with more than 20 teeth consumed more nutrients than those with fewer or no teeth. It was concluded that dental status could have an impact on foods choice and on the intake of key nutrients (Sheiham et al. 2001a, 2001b). It has even been suggested that impaired masticatory function, associated with tooth loss, may lead to a deficient and unbalanced diet in elderly persons (Albiin et al. 1982; Mojon et al. 1999). Shinkai et al. (2001) showed in a cross-sectional study, with a sample of 731 individuals, that masticatory function was not a predictor of overall dietary quality. This was associated more strongly with socio-economic variables. It has also been shown that prosthodontic treatment, either with removable or fixed prostheses, does not influence dietary intake significantly for the partially dentate patient (Kapur et al. 1997; Moynihan et al. 2000) and for those restored with implant-supported restorations (Garrett et al. 1997). It has been shown that change in dietary intake requires an appropriate intervention to encourage people to change their dietary habits over and above the simple provision of a prosthesis (Bradbury et al. 2006). In a cross-sectional study, including 1424 elderly subjects, substantial differences existed between towns in Europe and in the United States concerning the influence of dentition on dietary intake (Fontijn-Tekamp et al. 1996).

It has been suggested that the maintenance of a dentition assures that efficient mastication is important, not only for nutrition but also for the systemic, mental and physical functions of the body (Walls

Table 3. **Studies with dentition and psychosocial factors including satisfaction and OHRQoL**

Study	Year	Design	Patients (n)	Age (years), (range/mean)	Time (months)	Method	Main conclusion
Albrektsson et al.	1987	Cross-sectional	189	20–60 +	–	Q, OE	ISFPD(ca) satisfied patients from a masticatory and psychological point of view
Rosenoer & Sheiham	1995	Cross-sectional	195	35–64	–	Q	Patients with more molar and premolar pair were most satisfied with teeth
Meeuwissen et al.	1995	Cross-sectional	320	55–74	–	Q	Satisfaction decreased when OU was reduced or RPD was present
De Bruyn et al.	1997	Prospective	75	40–70	0–36	Q, OE	ISFPD(ca) and ISFPD improved aesthetics, eating comfort, phonetics and satisfaction
Steele et al.	1997	Cross-sectional	1121	>60	–	OE, Q	Anterior aesthetics would be best restored using fixed restoration instead of RPD's
Frank et al.	1998	Cross-sectional	410	<60–75 +	–	Q, SF–36	Satisfaction with RPD mainly related to age, health and prior experiences with RPD's
Elias & Sheiham	1999	Prospective	227	45–54	0–36	Interview	Anterior teeth were the most significant predictors of satisfaction
Elias & Sheiham	1999	Cross-sectional	657	35–54	–	Interview	Direct relationship between number of teeth and satisfaction
Kuboki et al.	1999	Retrospective	63	59	21–37	Q, OE	Almost no effect of RPD treatment but increased OHRQoL for ISFPD
Zitzmann & Marinello	2000	Prospective	20	45–79	0–6	VAS	No difference in satisfaction between ISFPD(ca) and ISOD
Yi et al.	2001	Retrospective	40	25–65	13–35	Q, VAS, OE	ISFPD(ca) and ISFPD improved mastication, phonetics, aesthetics and chewing comfort
Sheiham et al.	2001	Cross-sectional	955	>65	–	OIDP	Dental status affect QoL and the masticatory ability
Shimazaki et al.	2001	Retrospective	719	59–107	0–72	OE, Q	Poor dental status related to deterioration in physical and mental ability
Miura et al.	2003	Case–control	88	>65	–	Q, VAS, HDS-R	Masticatory function associated wtih cognitive impairment
Tada et al.	2003	Cross-sectional	101	>60	–	OE, Q	Number of teeth associated with physical activity in elderly persons
Jepson et al.	2003	R, Prospective	60	67	0–12	Q, OE	Improved masticatory ability for both groups
John et al.	2004	Prospective	107	24–82	0–12	OHIP-49; RDC	Post-treatment: removable dentures 1.9 times higher problem rate than fixed dentures
Steele et al.	2004	Cross-sectional	7068	16–70 +	–	OHIP-14	Age, number of teeth and cultural background important variables influencing OHRQoL
Akifuse et al.	2005	Cross-sectional	207	85	–	SF-36	Subjects with $\geq$ 20 teeth had better subjective physical health than those with <20 teeth
Wolfart et al.	2005	R, Prospective	34	62	0–12	OHIP-49; RDC	No difference between RPD and SDA
Nassani et al.	2005	Cross-sectional	110	64	–	Interview, VAS	Cantilevered bridges and implant treatment assigned significantly higher than SDA
Pjetursson et al.	2005	Retrospective	104	23–88	60–180	Q, VAS, OE	>90% of patients were completely satisfied with implant therapy after 5–15 years
Abu-Hantash et al.	2006	Prospective	50	43	0–3	DIDL, NEO–FFI	Neuroticism was the main predictor of patients OHRQoL after implant treatment
Åstrøm et al.	2006	Cross-sectional	109	16–79	–	OIDP	Age, number of teeth and area influencing OHRQoL

ISFPD, implant-supported fixed partial dentures; (ca), cross arch; OU, occlusal units; PD, removable partial dentures, OHRQoL, oral health related quality of life; SDA, shortened dental arch questionnaire; OE, oral examination; VAS, visual analogue scale; R, randomized; RDC, research diagnostic criteria for temporomandibular disorders; DIDL, dental impact on daily living ;OIDP, oral impact on daily performance; OHIP, oral health impact profile; SF-36, short form 36 health survey; HDS-R, hasegawa dementia scale rating; NEO-FFI, neuroticism extraversion openness five-factor inventory.

et al. 2000). Studies from Japan have reported that dentition and masticatory function may influence multiple mental and physical behaviours and general health (Nakata 1998; Miura et al. 2003; Tada & Matsukubo 2003; Miyamoto et al. 2005). Miura et al. (2003) suggested that masticatory function in the elderly person was associated with cognitive status, and Miyamoto et al. (2005) claimed that clenching was effective for increasing the cerebral blood volume. The evidence for these relations between dentition, oral function and general health is, however, weak.

Masticatory ability

A total of 20 studies were included (Table 2). Six of the studies were prospective and two retrospective, with eight cross-sectional studies and four case–control studies.

Subjective masticatory function is usually evaluated through interviews or questionnaires (Table 2). Agerberg & Carlsson (1975) studied oral conditions and mandibular dysfunction in a randomly selected population sample of 1106 people by questionnaires. The results indicated that 20 well-distributed teeth are needed for satisfactory chewing ability and that functional disturbances of the masticatory system are often related to impaired general health and not so much to the number of teeth. In the group of individuals with eight to 20 teeth, only 1% rated their chewing ability as poor (Agerberg & Carlsson 1981). Käyser (1981) suggested that chewing discomfort begins with fewer than four occlusal units with a symmetrically SDA, and six occlusal units with asymmetric shortening. (An occlusal unit is an antagonistic pair of premolar teeth, with opposing molars counting as two occlusal units). This was confirmed by Witter et al. (1990a, 1990b) who showed that only 8% of the subjects with SDA raised complaints about masticatory ability from a sample of 99 subjects. This is also in accordance with a study by Leake et al. (1994) on 338 people, in whom problems started to be reported with zero to two posterior functional units. Further support is available from a large recent study in Tanzania, including a sample of 725 adults with SDA and 125 with complete dental arches as controls (Sarita et al. 2003a). This study concluded that SDA, with intact premolar regions and at least one occluding pair of molars, provide

***Table 4.* Studies with occlusal support, dental arch stability**

Study	Year	Design	Patients (*n*)	Age (years), (range/mean)	Time (months)	Methods	Main conclusion
Agerberg & Carlsson	1975	Cross-sectional	1188	15–74	–	Q	TMD's frequently related to impaired general health
Käyser	1981	Cross-sectional	118	19–71	–	OE	The adaptive migration in SDA's is not nessarily deleterious for the dentition
Witter et al.	1987	Cross-sectional	132	40	–	OE	For subjects <40 years more interdental spacing were found in the SDA group
Haraldson & Zarb	1988	Retrospective	28	48–73	0–120	Q, VAS, DI	No increase in symptoms for TMD's
Budtz-Jörgensen & Isidor	1990	Prospective, R	53	61–83	0–60	OE, HDI	FPD's more favourable than RPD's
van Waas et al.	1993	Cross-sectional	329	55–75	–	OE, I	10% of the subjects had more than 1 sign of TMD
Pullinger et al.	1993	Retrospective	560	–	–	OE, casts	Increased risk for TMD: Anterior open bite, crossbite, overjets >6–7 mm, ≥ 5 missing posterior teeth, RCP-ICP slide >2 mm
Witter et al.	1994	Retrospective	126	–	0–72	OE	SDA of 3–5 OU not a risk factor for TMD; RPD do not prevent TMD
Ciancaglini et al.	1999	Cross-sectional	483	18–75	–	OE	Loss of occlusal support is not a direct reason for TMD's
Pullinger & Seligman	2000	Retrospective	381	21–78	–	OE, casts	≥ 5 missing posterior teeth increase relative risk for TMD fo a 2:1 odds ratio
Witter et al.	2001	Retrospective	74	41	0–108	OE	SDA provide long-term occlusal stability
Sarita et al.	2003	Cross-sectional	850	>20	–	OE	Increased risk to occlusal instability in ESDA but not for SDA's
Sarita et al.	2003	Cross-sectional	850	>20	–	I	SDA do not provoke signs and symptoms associated with TMD

HDI, Helkimo's dysfunction index; DI, dysfunction index; VAS, visual analogue scale; OE, oral examination; I, interview; TMD, temporomandibular disorders; SDA, shortened dental arch; ND, natural dentition; CDA, complete dental arch; FPD, fixed partial denture; RPD, removable partial denture.

sufficient masticatory ability. SDA with three to four pairs of occluding premolars, and asymmetric arches with a 'long side' resulted in some impairment of masticatory ability, and the extreme SDA comprising only zero to two occluding premolars resulted in severely impaired chewing ability (Sarita et al. 2003a).

Some studies do not find any direct (Imperiali et al. 1984) or only a weak correlation between the number of teeth and the subjective masticatory ability (Battistuzzi et al. 1987).

In contrast to the Tanzanian study, most European investigations have been performed with older people, and it is important that the subjective assessment of chewing seems to be influenced more by age than by dental and prosthodontic status (Lappalainen & Nyyssonen 1987). Furthermore, in a study by van Waas et al. (1993), it was demonstrated that older persons with an RPD in general are less satisfied and report more problems than persons without an RPD. This is in accordance with a review study suggesting that indications for RPD should be limited in elderly people with an SDA dentition (Wörstmann et al. 2005). In a large cross-sectional study, some disability and psychosocial factors were associated with the masticatory ability, but no direct correlation between inadequate mastication and general health was found (Österberg et al. 1996).

During the last decade a shift from evaluation of masticatory ability alone to a great variety of oral functions in interviews and enquiries has taken place (Slade & Spencer 1994; Adulyanon & Sheiham 1997). A great number of these publications include aesthetics, patient satisfaction and OHRQoL measurements alongside an evaluation of the masticatory ability (Sheiham et al. 2001a; Jepson et al. 2003).

Aesthetics, satisfaction and psychosocial ability

A systematic review by Strassburger et al. (2004) examined the influence of prosthodontic and dental implant treatment on patient satisfaction and OHRQoL. It was concluded that only a few studies with high levels of evidence were present and that the research field is still in the developmental stage.

In the present review, a total of 24 articles (25 studies) were included in the review (Table 3). Two studies were randomized prospective studies, six were prospective studies and three were retrospective, whereas 13 were cross-sectional and one case–control study. In 72% of the studies, nonstandardized questionnaires or interviews were used. The most frequently used questions concerned masticatory/chewing function, aesthetics and general satisfaction. Standardized questionnaires, for example OHIP and OIDP, were included in some recent papers.

Aesthetics, or appearance during oral communication, seems to be the main reason why patients seek prosthetic treatment. Thus, in a Brazilian population the relationship between satisfaction with the mouth and the number, position and condition of teeth was analysed (Elias & Sheiham 1999). The study was divided into a longitudinal 3-year study including 227 dentate people, aged 45–54 years of two social classes, and a cross-sectional survey including 657 dentate males aged between 35 and 54 years. A direct relationship between the number of teeth and probability of satisfaction was found until the number of teeth reached 23. The most important finding was a positive correlation between satisfaction and position of teeth. Thus, the presence of anterior teeth was the most significant predictor of satisfaction, and premolars were more important for satisfaction than molar teeth. More people were concerned about having missing anterior or premolar teeth replaced than molar teeth because of concern about social interactions rather than just for self-perceived cosmetic reasons. Thus, only small differences in probability of satisfaction were found for persons with 10 compared with 20 posterior teeth (Elias & Sheiham 1999).

Patient satisfaction has been defined as a measure of perceived oral health status or psychological well being in relation to oral health status (Meeuwissen et al. 1995; Rosenoer & Sheiham 1995). Satisfaction decreased when the number of occluding units was reduced (Meeuwissen et al. 1995; Rosenoer & Sheiham 1995), and correspondingly the number of teeth also influences OHRQoL (Sheiham et al. 2001a;Åstrøm et al. 2006). Studies from Japan have even indicated that the number of teeth is related to the physical activity and physical health in elderly persons (Tada & Matsukubo 2003; Akifusa et al. 2005). A multi-centre randomized clinical trial was performed at 14 German University Dental Schools with the aim of measuring the effect of two treatment options of the SDA with OHRQoL measurements (Wolfart et al. 2005). Thirty-four patients completed the OHIP-49 and the research diagnostic criteria (RDC) for TMD before and after treatment. For RPD and FDP treatment, an improvement of OHRQoL was achieved.

In a national survey in Great Britain, 753 free living and 202 institutionalized subjects aged 65 years and over were evaluated with a modified OIDP indicator (Sheiham et al. 2001a, 2001b). The impact of oral status on 10 aspects of daily life was considerable for these older people, in particular the ability to eat several common types of foods. The prevalence of dental impacts varied significantly by social class and geographical region among the dentate (Sheiham et al. 2001a, 2001b). This emphasizes that there are likely to be marked variations in subjective measures of aesthetics and psychosocial comfort between social classes and regions, let alone between countries. This is in accordance with another paper comparing the 1998 UK Adult Dental Health Survey and the 1999 Australian National Dental Telephone Interview Survey (Steele et al. 1997). They showed that age, number of teeth and cultural background were important variables influencing OHRQoL.

In a randomized controlled study, patient satisfaction following restoration of partially dentate mandibles to an SDA, with distal cantilevered resin-bonded fixed partial dentures (CRBFPD), was compared with bilateral free-end saddle RPD (Jepson et al. 2003). The 60-patient responses to the questionnaire suggested that CRBFPD are an effective means of restoring mandibular SDA. This is in accordance with a cross-sectional study by Nassani et al. (2005), who interviewed 110 partially dentate patients (SDA) and asked the patients to indicate on a standardized visual analogue scale, how they would value the health of their mouth, if they had received each of the following treatment options: no treatment, RPD, acrylic RPD, implant treatment, CRBFPD, CFPD. The statistical analysis demonstrated perceived benefit for fixed treatment options, including implant treatment, compared with no treatment (Nassani et al. 2005). This is an interesting development based on a more patient-centred approach than earlier approaches, and it emphasizes that, if fixed restorations on teeth or implants are possible, some patients may experience an increased OHRQoL by such a treatment instead of an untreated SDA or provision of an RPD.

A number of studies have analyzed patient reactions to ISFCD(ca) and agreed that OHRQoL, including masticatory functions, aesthetics, phonetics and general social and psychological satisfaction, improves after implant treatment (Albrektsson et al. 1987; Cibirka et al. 1997; de Bruyn et al. 1997; Kuboki et al. 1999; Yi et al. 2001; Pjetursson et al. 2005). This outcome is mainly derived from patients who were edentuous and have then received ISFCDs (Albrektsson et al. 1987; de Bruyn et al. 1997; Yi et al. 2001). Additionally, in a study by Pjetursson et al. 2005 including 104 patients restored with 'smaller' implant-supported constructions, 90% of the patients were completely satisfied with implant therapy, both from a functional and aesthetic point of view.

Occlusal support and dental arch stability

A total of 13 studies were included. One study was a randomized prospective study (Budtz-Jørgensen & Isidor 1990) and five were retrospective studies, whereas seven were cross-sectional studies (Table 4).

After loss of one or more teeth there is great individual variation in the pattern of change to the remaining dentition, such as migration in the form of tipping, rotation and overeruption of unopposed teeth, opening of proximal contacts, occlusal interferences, loss of occlusal vertical dimension, overloading on the anterior region, tooth mobility, increased occlusal tooth wear, parafunctional activities and/or temporomandibular dysfunction (TMD) (Käyser 1996).

In a cross-sectional study carried out among 118 subjects, where 90 had a SDA, it was concluded that 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 (Käyser 1981). This view has been supported by a number of Dutch studies (Witter et al. 1994, 1999, 2001). In a prospective 9-year study by Witter et al. (2001), 74 subjects with SDA were compared with 72 subjects with complete dental arches. No differences between the two groups were observed concerning overbite and occlusal tooth wear, but the SDA group had more interdental spacing in the premolar regions, more anterior teeth in occlusal contact and lower marginal bone levels. As the differences remained constant over time, it was concluded that an SDA is associated with long-term occlusal stability (Witter et al. 2001).

A cluster sample, including 725 subjects with SDA from Tanzania, was examined for occlusal stability by assessing: interdental spacing, occlusal tooth wear, occlusal contact and vertical and horizontal overlap (Sarita et al. 2003a). A matched control group of 125 subjects with complete dental arches (CDA) was used. Changes in occlusal stability were associated with extreme types of SDAs, while there was no evidence that occlusal instability was associated with moderate types of SDAs e.g., intact anterior and premolar regions (Sarita et al. 2003b).

Studies analysing skull and autopsy material, as well as radiographic investigations have suggested that loss of molar support may result in changes in the temporomandibular joint (TMJ) and signs of osteoarthrosis (OA) (De Boever 1979; Hylander 1979; Hansson et al. 1983). Thus, Hylander (1979) emphasized that biting and chewing in the anterior part of the mouth may lead to more loads on the TMJ. He also stressed, however, that the magnitude and direction of the forces acting on the TMJ was adjusted by the muscles and may have prevented joint instability.

Loss of molar support does not seem to be significant in the aetiology of TMD (Witter et al. 1994; Ciancaglini et al. 1999; Tallents et al. 2002). Three review articles have pointed out that no single occlusal factor, including posterior molar support, could differentiate TMD patients from healthy subjects (Seligman & Pullinger 1991, 1996; Pullinger et al. 1993). On the other hand, patients who had lost more than five teeth may have an increased risk of having TMD problems, especially in relation to a history of OA (Pullinger & Seligman 2000).

In both cross-sectional and longitudinal clinical studies of patients with and without lost molar support, no evidence of increased signs and symptoms of TMD over the years, in individuals with a SDA, were found (de Boever & Adriaens 1983; Mejersjö & Carlsson 1984). Furthermore, a removable partial denture did not influence the prevalence of signs of TMD (Witter et al. 1994). Even for edentulous patients not wearing dentures, the prevalence of TMD problems did not differ from more general population studies (Wilding & Owen 1987). Many patients seem to adapt to the situation with no molar support without any dysfunction (Käyser 1981, 1996). A good indicator of this is also the implant-supported prostheses for edentulous patients, where the SDA principles are used. Both cross-sectional (Haraldson et al. 1979) and longitudinal (Jemt & Carlsson 1986; Lindquist 1987) studies showed prevalence's of TMD symptoms not exceeding those found in epidemiological samples with natural teeth.

In conclusion, there is no linear relationship between occlusal support and TMD. The occlusal support from an SDA dentition seems to assure oral function, without pain and dysfunction, for the majority of patients.

Other oral functions

In the present literature search, only a few articles reported on oral functions other than the above. However, in a number of articles evaluating the perceived function of ISFCD(ca) phonetic function was included (Haraldson & Zarb 1988; de Bruyn et al. 1997; Yi et al. 2001; Pjetursson et al. 2005). Also for teeth supported FDP (Yi et al. 1996) and for RPD (Frank et al. 1998), a subjective evaluation of phonetics has been undertaken. In most of the studies, patients adapted to and were subsequently satisfied with the phonetics, and in the studies including ISFCD(ca), most patients felt improved phonetics after treatment (de Bruyn et al. 1997; Zitzmann & Marinello 2000; Yi et al. 2001).

In contrast to oral tactile perception, the oral functions, phonetics and taste, are included in some commonly used methods for OHRQoL e.g., OHIP (Slade & Spencer 1994; Slade 1997). However, when these functions are weighted by patients in comparison with other oral functions (as done in a modified oral version of the individual quality of life-direct weighting, SEIQoL-DW method), phonetics, taste and tactile perception are not so frequently mentioned by partial edentulous patients compared with appearance and chewing ability (Özhayat et al. 2007).

Although there are many publications in dentistry as well as in implant dentistry concerning taste, phonetics, tactile perception and osseoperception, no meta analysis or single articles addressed the question of the present review: 'What dentition assures oral function'. Therefore, it was decided not to make any further analyses of these oral functions.

Conclusions

Few studies with high levels of evidence were found to analyse the question: What dentition assures oral function?

Masticatory efficiency decreases with the loss of teeth. There is some evidence that a SDA involving nine to 10 pairs of occluding teeth (including the anterior dentition) assures masticatory function, occlusal support and dental arch stability for most elderly people. Dietary intake for people with this level of oral function is unchanged. Reduction in the number of occlusal units below this level is likely to result in impaired mastication, altered foods choice and reduced OHRQoL.

The loss of anterior teeth is an aesthetic and psychosocial problem for most people, whereas the loss of posterior teeth may be a psychosocial problem for some individuals. There are marked variations in subjective measures of aesthetics and psychosocial comfort between social classes and regions, let alone between countries.

It is established that there is no linear relationship between tooth loss and dysfunction of the masticatory system.

Consequently, the WHO goal for the year 2000, namely, to maintain a natural dentition of not less than 20 teeth to assure individual optimal function maintain throughout life, is substantiated by the current literature.

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